Proof of Evidence – Electromagnetic Compatibility (Mr Rasheed R. Hameed) Appendices

(Inquiries Procedure (England & Wales) Rules 2004

January 2022

List of Appendices

Appendix 01	**List of EMC standards**
Appendix 02	**EMC Strategy [158454-JMS-ZZ-ZZZ-STR-EDS-000002]; and, DRN [158454-NRS-ZZ-ZZZ-DRN-EDS-000001]**
Appendix 03	**EMC Control Plan [158454-JMS-ZZ-ZZZ-PLN-EDS-000003]; and, DRN [158454-NRS-ZZ-ZZZ-DRN-EDS-000002]**
Appendix 04	**Load Demand Assessment [158454-JMS-ZZ-ZZZ-ASS-EDS-000001]**
Appendix 05	**EMC Technical Methodology [158454-ARC-ZZ-ZZZ-REP-EDS-000001]**

[This page is left intentionally blank]

Proof of Evidence – Electromagnetic Compatibility (Mr Rasheed R. Hameed) Appendix 01 List of EMC Standards

(Inquiries Procedure (England & Wales) Rules 2004

January 2022

[This page is left intentionally blank]

Cambridge South Infrastructure Enhancements

List of EMC Standards

JANUARY 2022

Prepared By:
Rasheed R. Hameed
80 Fenchurch Street
London EC3M 4BY
United Kingdom

Arcadis (UK) Limited is a private limited company registered in England registration number: 01093549. Registered office, 80 Fenchurch Street, London EC3M 4BY. Part of the Arcadis Group of Companies along with other entities in the UK. Regulated by RICS.

This report dated 20 December 202120 December 2021 has been prepared for Network Rail Network Rail (the “Client”) in accordance with the terms and conditions of appointment dated 21 December 202121 December 2021(the “Appointment”) between the Client and **Arcadis (UK) Limited** (“Arcadis”) for the purposes specified in the Appointment. For avoidance of doubt, no other person(s) may use or rely upon this report or its contents, and Arcadis accepts no responsibility for any such use or reliance thereon by any other third party.

Contents

Acronyms and Abbreviations **6**

1 List of EMC Standards **7**

Tables

Table 1. Acronyms and Abbreviations.....6

Figures

Not used in this document.

Acronyms and Abbreviations

Abbreviation	Description
AC	Alternating Current
BS	British Standard
DC	Direct Current
EMC	Electro- Magnetic Compatibility
EMI	Electro Magnetic Interference
EN	European norm
ETSI	European Telecommunications Standards Institute
FDM	Frequency Division Multiplexing
HV	High Voltage
LV	Low Voltage
NR	Network Rail

Table 1. Acronyms and Abbreviations

1 List of EMC Standards

1.1.1 For the Earthing & Bonding and the EMC assessment, there are a number of standards are recommended to be used as a guidance. As a competent designer, I have recommended the following British and International standards.

1.1.2 I have included a list of the European, British and Network Rail standards that I consider to be relevant this section to this Proof of Evidence. Given the number of such documents and their technical nature, I have not provided copies, but the same could be made available to the Inspector and/or other parties to the Inquiry upon request.

1.1.3 The following British standards are of relevance to the EMC assessment:

a) BS 7430:2011, Code of practice for earthing
b) BS 7671, 18th Edition, 18th Edition IET Wiring Regulations; and,
c) BS 6701:2016, Telecommunication equipment and telecommunications cabling – specification for installation, operation and maintenance.

1.1.4 The following European/British standards are of relevance to the EMC assessment:

a) BS EN 50121-1, Railway applications- Electromagnetic Compatibility- Part 1: General.
b) BS EN 50121-2, Railway applications- Electromagnetic Compatibility- Part 2: Emissions of the whole railway system to the outside world.
c) BS EN 50121-3-1, Railway applications- Electromagnetic Compatibility- Part 3-1: Rolling stock train and complete vehicle.
d) BS EN 50121-3-2, Railway applications- Electromagnetic Compatibility- Part 3-2: Rolling stock apparatus.
e) BS EN 50121-4, Railway applications- Electromagnetic Compatibility- Part 4: Emissions and immunity of the signalling and telecommunications apparatus.
f) BS EN 50121-5, Railway applications- Electromagnetic Compatibility- Part 5: Emissions and immunity of fixed power supply installations and apparatus
g) BS EN 50122-1, Railway applications- Fixed installations- part 1: Protective provisions relating to electrical safety and earthing; and,
h) BS EN 50238: Railway applications- Compatibility between rolling stock and train detection systems.

1.1.5 The following European/British standards are of relevance to specific products, i.e. for specific types of items of equipment that can be installed as part of the project. Those standards focus on the equipment only without considering the wider EMC environment; however, using compliant equipment facilitates the EMC demonstration of the wider project.

a) BS EN 12015, Electromagnetic compatibility - Product family standard for lifts, escalators and moving walks – Emission.
b) BS EN 12016, Electromagnetic compatibility - Product family standard for lifts, escalators and moving walks – Immunity.
c) BS EN 50130-4, Alarm systems - Part 4: Electromagnetic compatibility — Product family standard: Immunity requirements for components of fire, intruder and social alarm systems.
d) BS EN 50174-2, Information technology Cabling installation Part 2: Installation planning and practices inside buildings.
e) BS EN 50310, Application of equipotential bonding and earthing in buildings with information technology equipment.

f) BS EN 55015, Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment.
g) BS EN 61547, Equipment for general lighting purposes — EMC immunity requirements
h) BS EN 55022, Information technology equipment – Radio disturbance characteristics -Limits and methods of measurement.
i) BS EN 55024, Information technology equipment – Immunity characteristics – Limits and methods of measurement.
j) BS EN 55103-1, Electromagnetic compatibility - Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use - Part 1: Emission.
k) BS EN 55103-2, Electromagnetic compatibility - Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use - Part 2: Immunity.
l) BS EN 60439-1, Low-voltage switchgear and control gear assemblies - Part 1: Type tested and partially type-tested assemblies.
m) BS EN 60947-1, Low-voltage switchgear and control gear - Part 1: General rules.
n) BS EN 60947-2, Low-voltage switchgear and control gear - Part 2: Circuit-breakers.
o) BS EN 62040-2, Uninterruptible power systems (UPS) - Part 2: Electromagnetic compatibility (EMC) requirements.
p) GT/TD INT100, Earthing and equipotential bonding of Telecommunications equipment; and,
q) BS EN 300683, Radio Equipment and Systems (RES); Electromagnetic Compatibility (EMC) standard for Short Range Devices (SRD) operating on frequencies between 9 kHz and 25 GHz.

1.1.6 The following European/British standards are of relevance to the EMC fundamentals assessment. Those standards are used as a guidance to inform the EMC assessment of a system, i.e. one item of equipment (or a set of items) that are used in a wider EMC environment.

a) BS EN 61000-3-2, Electromagnetic compatibility (EMC) — Part 3-2: Limits — Limits for harmonic current emissions (equipment input current ≤16 A per phase);
b) BS EN 61000-3-3, Electromagnetic compatibility (EMC) — Part 3: Limits — Section 3: Limitation of voltage changes, voltage fluctuations and flicker in public low voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection.
c) BS EN 61000-4-2, Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrostatic discharge immunity test.
d) BS EN 61000-4-3, Electromagnetic Compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radiofrequency, electromagnetic field immunity test.
e) BS EN 61000-4-4:1995, Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrical fast transient/burst immunity test. Basic EMC publication.
f) BS EN 61000-4-5:1995, Electromagnetic compatibility (EMC). Testing and measurement techniques. Surge immunity test.
g) BS EN 61000-4-6:1996, Electromagnetic compatibility (EMC). Testing and measurement techniques. Immunity to conducted disturbances, induced by radiofrequency fields.
h) BS EN 61000-4-8, Electromagnetic Compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test.
i) BS EN 61000-4-9:1994, Electromagnetic compatibility (EMC). Testing and measurement techniques. Pulse magnetic field immunity test. Basic EMC publication.
j) BS EN 61000-4-11, Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques — Voltage dips, short interruptions and voltage variations immunity tests.
k) BS EN 61000-4-12, Electromagnetic Compatibility (EMC) – Part 4-12: Testing and measurement techniques – Oscillatory waves immunity test.
l) BS EN 61000-4-16, Electromagnetic compatibility (EMC) - Part 4-16: Testing and measurement techniques — Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz; and,

m) BS IEC 61000-5-2, Electromagnetic Compatibility (EMC) – Part 5: Installation and mitigation guidelines Section 2: Earthing and Cabling.

1.1.7 The following British/European standards are of relevance to the EMC assessment for different environments. The standards listed below are used as a guidance to assess any railway or non-railway EMC environment.

a) BS EN 61000-6-1, Electromagnetic compatibility (EMC) - Part 6-1: Generic standards –Immunity for residential, commercial and light-industrial environments.
b) BS EN 61000-6-2, Electromagnetic compatibility (EMC) - Part 6-2: Generic standards -Immunity for industrial environments.
c) BS EN 61000-6-3, Electromagnetic compatibility (EMC) - Part 6-3: Generic standards -Emission standard for residential, commercial and light-industrial environments, and.
d) BS EN 61000-6-4, Electromagnetic compatibility (EMC) - Part 6-4: Generic standards -Emission standard for industrial environments.

1.1.8 The following standards are of relevance to the EMC assessment for Radio Spectrum Matters. In EMC, radio interferences are always addressed separately using specific standards due to their physical nature and due to the fact they can be used for safety and/or military purposes.

a) ETSI EN 300 279, Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for Private land Mobile Radio (PMR) and ancillary equipment (speech and/or non-speech);
b) ETSI EN 300 339, Electromagnetic compatibility and Radio spectrum Matters (ERM); General Electromagnetic Compatibility (EMC) for radio communications equipment.
c) ETSI EN 300 386-2, Electromagnetic compatibility and Radio spectrum Matters (ERM); Telecommunication network equipment; and,
d) ETSI EN 301 489, Series of EMC standards applicable to Article 3.1 of the EU (EUROPEAN UNION) Radio Equipment Directive

1.1.9 The following railway group standards are of relevance to the EMC assessment:

a) GE/RT8015, Electromagnetic Compatibility between Railway Infrastructure and Trains.
b) GE/RT8217, Introduction and Use of Axle Counters. Managing the Risk 1;
c) GE/RT8270, Route Acceptance of Rail Vehicles including changes in Operation or Infrastructure; and,
d) GK/RT0217, Technical Requirements for Axle Counters.

1.1.10 The following Network Rail standards are of relevance to the EMC assessment:

a) NR/L1/RSE/30040, Issue 69, EMC Strategy for Network Rail.
b) NR/L2/RSE/30041, Issue 2, June 12, Electromagnetic Compatibility (EMC) Assurance Process.
c) RT/E/PS/00009, Issue 1, May 01, Message Handling & Data Transmission Requirements between Processor Based Systems.
d) NR/L2/ELP/23003, Issue 1 Mar 20, Technical Requirements for Transformers, Rectifiers, and
e) NR/SP/SIG/50002, Issue 2, Feb 07, Methodology for the Demonstration of Compatibility with Single Rail Reed Track Circuits on the AC Railway.
f) RT/E/C/50005, Issue 1, Feb 03, Methodology for the Demonstration of Compatibility with 50 Hertz Single Rail Track Circuits.
g) NR/SP/SIG/50006, Issue 1, Apr 06, Methodology for the Demonstration of Compatibility with 50 Hz Double Rail Track Circuits.
h) NR/RT/E/C/50007, Issue 1, Feb 03, Methodology for the Demonstration of Compatibility with HVI Track Circuits.

i) NR/RT/E/C/50008, Issue 1, Feb 03, Methodology for the Demonstration of Interaction with Neighbouring Railways.

j) NR/GN/SIG/50011, Issue 2, Mar 20, Methodology for the Demonstration of Compatibility with Axle Counters.

k) NR/SP/SIG/50012, Issue 2, Apr 06, Methodology for the Demonstration of Compatibility with TPWS (Train Protection Warning System) Trackside Equipment.

l) NR/GN/SIG/50013, Issue 2, Sep 19, Methodology for the Demonstration of Compatibility with Route Relay and Solid State Interlockings.

m) NR/GN/SIG/50014, Issue 2, Aug 08, Methodology for the Demonstration of Compatibility with Lineside Equipment.

n) NR/GN/SIG/50015, Issue 3, Sep 20, Methodology for the Demonstration of Compatibility with Reed FDM Systems on the AC and DC Railways.

o) NR/SP/TEL/50016, Issue 3, Apr 06, Methodology for the demonstration of compatibility with Telecoms Systems.

p) RT/E/C/50018, Issue 1, Feb 03, Methodology for the Demonstration of Interaction with Neighbouring Railways.

q) NR/GN/TEL/31106, Issue 1, Jun 09, Overview of Electromagnetic Coupling Between Traction Systems and Telecommunications Cables.

r) NR/L2/TEL/31107, Issue 2, Mar 10, Limits and test method of induced voltages on telecommunications cables due to electrification systems.

s) NR/L2/TEL/30028, Issue 3, Mar 10, Installation of Operational Telecommunications Equipment.

t) NR/L2/ELP/21085, Issue 4, Jun 20, Earthing and Bonding on AC electrified railways.

u) NR/L2/RSE/02009, Issue 7, Mar 21, Engineering Management for Projects; and,

v) NR/SP/ELP/27224, Issue 7, Mar 21, Specification for installation of cable routes forming part of the traction distribution system.

Arcadis (UK) Limited

80 Fenchurch Street
London EC3M 4BY
United Kingdom

T: +44 (0)20 7812 2000

arcadis.com

Proof of Evidence – Electromagnetic Compatibility (Mr Rasheed R. Hameed) Appendix 02
EMC Strategy [158454-JMS-ZZ-ZZZ-STR-EDS-000002]
DRN [158454-NRS-ZZ-ZZZ-DRN-EDS-000001]

(Inquiries Procedure (England & Wales) Rules 2004

January 2022

[This page is left intentionally blank]

Client	Murphy
Project Title	Cambridge South Infrastructure Enhancements – Electromagnetic Compatibility (EMC) Control Strategy (GRIP 4)
Project Number	158454
Operating Unit	M2 - CP6

REPORT

CAMBRIDGE SOUTH INFRASTRUCTURE ENHANCEMENT

EMC STRATEGY

(GRIP 4)



Ayad Al-Khoury

E&P (HV) Senior Engineer

22/10/2021

MAIN AUTHOR



Abubakar Tariq

E&P (HV) Principal Design Engineer

22/10/2021

REVIEWER



Pierre Fayet

E&P (HV) Associate Technical Director

22/10/2021

APPROVER

ISSUE CONTROL

DOCUMENT No.	158454-JMS-ZZ-ZZZ-STR-EDS-000002

CURRENT REVISION	CURRENT STATUS CODE	SECURITY CLASSIFICATION
A02	S3 – Suitable for Review and Comments	Public

REVISION HISTORY

REVISION	STATUS CODE	DATE	REVISION DESCRIPTION
P01	Draft Issue	24/09/2021	Draft Document
A01	First Issue	22/10/2021	First Issue
A02	Second Issue	07/12/2021	Reissued to incorporate DRN comments

Reviewers

NAME	Position	Date Reviewed	Outcome
James Drury	CEM		

Document History

Revision	Date	Summary of Change
P01	24/09/2021	Draft document
A01	22/10/2021	First Issue
A02	07/12/2021	Reissued to incorporate DRN comments

Distribution List

NAME	JOB TITLE / COMPANY
James Drury	CEM, Murphy

Contents

1 Abbreviations and Definitions 9
1.1 Abbreviations 9
1.2 Definitions 11
2 Introduction 12
2.1 Project Background 12
2.2 Purpose 12
2.3 Scope 14
2.4 Geographical Scope 14
3 Reference Documents 16
4 EMC Standards 17
4.1 Legislative Documents 17
4.2 British Standards 17
4.3 Railway EMC Standards 17
4.4 EMC Product Standards 18
4.5 Basic EMC Standards 19
4.6 Generic Environmental Standards 20
4.7 Radio Standards 21
4.8 Railway Group Standards 21
4.9 Network Rail Standards 21
5 Detailed Scope of Works 23
5.1 Electrification 23
5.2 Signalling 24
5.3 Telecoms 25
5.4 Station Information and Surveillance Systems (SISS) 26
5.5 LV Systems 27
5.6 Interfacing Projects 27
5.7 Staging Requirements 27
5.8 Rolling Stock 27
6 Systems and EMC Assessment on Cambridge South Infrastructure Enhancement Project 28
6.1 EMC Assessment 28
6.2 EMC HAZID Process 28

6.3 HAZID Workshop 29
6.4 Railway Systems Interface 30
6.5 Potential EMC Hazards 30
6.6 Generic Hazards 30
6.7 Specific Hazards – Interfaces with Third Parties along the route 30
7 General EMC Requirements 31
7.1 UK EMC Regulations 31
7.2 Common Safety Method on Risk Evaluation and Assessment 31
7.3 Overview of applicable EMC standards 32
7.4 EMC and Safety Recommendations 34
8 Project EMC Deliverables 40
8.1 EMC Control Plan 42
8.2 Immunisation Study 42
8.3 EMC Hazard Log 43
8.4 EMC Test Plan 44
8.5 EMC Project File 44
9 EMC Roles & Responsibilities 45
9.1 Responsibilities for EMC Deliverables 46
9.2 EMC RACI Matrix 47
10 Conclusion 49

Tables

Table 1. List of Abbreviations 10
Table 2. List of Definitions 11
Table 3. Reference Documents 16
Table 4. List of Legislative Documents 17
Table 5. List of British Standards 17
Table 6. List of Railway EMC Standards 18
Table 7. List of EMC Product Standards 19
Table 8. List Fundamental EMC Standards 20
Table 9. List of Generic EMC Standards 20
Table 10. Table of Radio Standards 21
Table 11. Table of Railway Group Standards 21
Table 12. Network Rail Standards 23
Table 13. EMC Current Levels for (0Hz - 150kHz) 39
Table 14. EMC Voltage Levels for (0Hz - 150kHz) 40
Table 16. EMC Roles and Responsibilities 45
Table 17. EMC Deliverables responsibilities 47
Table 18. Table of EMC RACI Matrix 48

Figures

Figure 1. Geographic View of site plan..... 15
Figure 2. Close Aerial View of the Site 15
Figure 3. Control scheme of Project EMC activities and deliverables requested by Network Rail. 40
Figure 4. Proposed EMC documentation 41
Figure 5. Arcadis EMC Verification & Validation model for project Lifecycle 42

1 Abbreviations and Definitions

1.1 Abbreviations

Table 1 below outlines a list of Abbreviations applicable to this document.

Abbreviations	Description
AC	Alternating Current
AFIL	Audio Frequency Induction Loop
ALARP	As Low As Reasonably Practicable
APC	Automatic Power Control
ATM	Automated Teller Machine
AWS	Automatic Warning System
BS	British Standard
CCTV	Closed Circuit Television
CIP	Competent Independent Person
CEM	Contractors Engineering Manager
CRE	Communications Equipment Room
CIS	Customer Information Service
CSIE	Cambridge South Infrastructure Enhancement
DANS	Dynamic Ambient Noise Sensors
DC	Direct Current
DeBo	Designated Body
DLIT	Data Link Isolating Transformers
DOO	Driver Only Operation
DoC	Declaration of Conformity
DPE	Designated Project Engineer
EMC	Electro Magnetic Compatibility
EMF	Electro Magnetic Field
EMI	Electro Magnetic Interference
ETSI	European Telecommunications Standards Institute
EN	European norm
EVC	Emergency Voice Communications
FDM	Frequency Division Multiplexing

Abbreviations	Description
FED	Fixed Earthing Device
FTN	Fixed Telecom Network
GRIP	Governance for Railway Investment Projects
HAZID	Hazard Identification
HV	High Voltage
ISPU	Isolating Surge Protection Unit
iTSS	Indicative Train Service Specification
kV	kiloVolt
LV	Low Voltage
M&E	Mechanical & Electrical
Murphy	J. Murphy and Sons Limited
NR	Network Rail
OLE	Overhead Line Equipment
PA	Public Address
PAVA	Public Address and Voice Alarm
PCB	Printed Circuit Board
PHP	Passenger Help Point
REB	Relocatable Equipment Building
RACI	Responsible - Accountable - Consulted - Informed
R&TTE	Radio and Telecommunication Terminal Equipment
RF	Radio Frequency
S&T	Signalling and Telecom
SCADA	Supervisory Control and Data Acquisition
SHESQ	Safety; Health; Environment; Sustainability; Quality
SSI	Solid State Interlocking
TSC	Track Sectioning Cabin
TSI	Technical Specifications for Interoperability
TSS	Train Stop Sensor
VOIP	Voice Over Internet Protocol

Table 1. List of Abbreviations

1.2 Definitions

The Table below outlines the list of definitions applicable to this document.

Definitions	Meaning
Critical Systems	Systems or products that, when installed, would be safety-critical or performance-affecting.
Deviation / Variation	A departure or alternative approach from the originally specified requirement.
GRIP 3 – Option Selection & Approval in Principle	Sufficiently developed options which may be supported by survey and analysis showing ability to achieve specification, integration across disciplines, constructability and highlighting land purchases and other long lead items. This would be the stage when Approval of Single Option Selection is achieved for each affected discipline
GRIP 4 – Single Option Development	Development of the chosen single option. This is the stage when the assurance activities of the suppliers should enable Network Rail to use a risk-based assurance process.
GRIP 5 – Detailed Design	Drawings and documentation that enable the infrastructure to be constructed, tested and commissioned.
GRIP 6 – Construction, Testing and Commissioning	To enable the works to be brought into service with evidence showing correct construction, testing and commissioning records and results including details of any changes to design and outstanding works/defects
Engineering Compliance Certificate (ECC)	A compliance certificate to be produced to comply with the NR/L2/INI/02009 in the production of a Design or Construction package
Engineering Deliverables	Designs, specifications, reports, certificates, data and other information that fulfil the requirements of the Project Engineering Requirements (CRD/RRD/DRRD).
Hazard	Situation with potential to cause harm or loss
Project Engineering Requirements (CRD/RRD/DRRD)	The Project Engineering Requirements are included as part of the Sponsors Instructions (SI) and shall be updated by the sponsor whenever the Sponsors Instruction is issued (Previously known as Project Requirements Specification PRS)
Risk	Something that may happen in the future with an adverse effect on the Project
Sponsor	A Network Rail person who acts as the single point of contact between the Client and the Project or Development Manager.
Supplier	Any provider (internal or external to Network Rail) of engineering deliverables or functions.

Table 2. List of Definitions

2 Introduction

The Cambridge South Infrastructure Enhancements (CSIE) Project is a multi-disciplinary project being undertaken by Arcadis for the client, J. Murphy & Sons Limited (JMS). The aim of the CSIE Project is to develop infrastructure options to improve connectivity in the Cambridgeshire region. As outlined by Network Rail, the objective of GRIP 4 is to complete deliverables and surveys to an Approval in Principle (AiP) Design for all disciplines (including provision of agreed surveys) that will enable the project to proceed to GRIP 5 and achieve a successful decision to deliver following Full Business Case (FBC) submission. Alongside this the project needs to secure the necessary consents to proceed, namely Network Change Approval and a Transport and Works Act Order (TWAO).

2.1 Project Background

Cambridge is a successful and fast-growing city and by 2020, the Cambridge Biomedical Campus is expected to house the largest concentration of biomedical expertise in Europe. Over the next four years many new jobs are expected to be created and the Cambridge Southern Fringe will be further developed. This is expected to place significant pressures on an already close to capacity transport system. There are local and national stakeholder aspirations for a new station to the south of Cambridge in the vicinity of Addenbrooke's Hospital.

The aim of the Cambridge South Infrastructure Enhancements Project is to develop infrastructure options to improve connectivity and capacity in the Cambridgeshire region meeting rail demand forecast up to 2043. The baseline infrastructure for this work will be based on 2020.

Cambridge is served by both the East Coast Main Line (via the Shepreth Branch) and the West Anglia Main Line. Both routes offer services to and from London. In addition, the city is served by Cross Country services which provide connectivity between Stansted Airport and Birmingham as well as several intermediate locations. Thameslink services on the East Coast Main Line provide direct trains across central London to Maidstone East and Brighton via Gatwick Airport.

Early-stage operational feasibility work and timetable analysis undertaken by Network Rail and train operating companies in 2017, identified the need for several interventions to accommodate long term capacity needs:

- Four-tracking of the West Anglia Main Line between Shepreth Branch Junction and the existing Cambridge Station.
- Reconstruction of the A1134 Long Road overbridge (Structure BGK/1544a) to facilitate Four-tracking.
- A new station at Cambridge South.
- Grade separation at Shepreth Branch Junction to provide for future East West Rail requirements.

2.2 Purpose

The existing services and new electrical systems will require assessment to ensure they meet the requirements of current Electromagnetic Compatibility standards and the Electromagnetic Compatibility Strategy.

This document is the Electromagnetic Compatibility (EMC) Strategy for the GRIP4 Design of the Cambridge South Infrastructure Enhancements project. It clarifies the fundamental requirements that will apply to the next GRIP stages to ensure that the forecasted changes on the area:

- Will not affect the safe and efficient operation of the existing railway electronic equipment that could encounter possible interference from a new or existing electronic component or system on the rail section or system to be installed or enhanced.
- Will not create any unwanted electromagnetic disturbances on third-party sensitive equipment located in the vicinity of the Railway. In particular, it has been noted that the Cambridge South area is intended to become a pole of excellence for the pharmaceutical industry, with new laboratories and sensitive equipment involved.

As required by Network Rail in its general EMC Strategy (NR/L1/RSE/30040) and its EMC Assurance Process (NR/L2/RSE/30041), this EMC Strategy is the key document that governs all the other EMC deliverables of the Project:

- By describing how EMC activities should be managed through the Project's Lifecycle; and,
- By defining the EMC roles and responsibilities for the project team.

The purpose of this Electro-Magnetic Compatibility (EMC) strategy document is to specify the methods which will be used on Cambridge South project to ensure that all the equipment used on the project meets the Network Rail EMC standards (Including, but not limited to, the EMC Assurance Process reference NR/L2/RSE/30041) and UK Statutory EMC 2016/1091 specification, which define Designers' and Contractors' obligations to manage the EMC within their scope of works.

This document sets out a series of high-level requirements for Designated Project Engineers (DPEs), designers and contractors in terms of managing EMC activities to deliver a safe and reliable railway and to provide the appropriate level of assurance to the following interested parties:

- J Murphy and Sons Limited;
- West Anglia Mainline (WAML);
- Network Rail System Review Panel (NRSRP);
- Network Rail Approvals Panel (NRAP);
- Competent Independent Persons (CIPs), and;
- Statutory Bodies (including, but not limited to: Notified Bodies (NoBos), Designated Bodies (DeBos) etc.).

Therefore, this EMC Strategy defines the approach, process and procedure that designers and constructors will use to achieve this process through the various deliverables of the Project. It stipulates the EMC Requirements and the EMC Responsibilities for each party involved. The aim of all EMC documents which will be produced for the CSIE Project is to enable the Designer and Contractors:

- To demonstrate compliance to Network Rail's EMC requirements.
- To demonstrate compliance with UK statutory EMC obligations.
- To demonstrate that the level of Emission/Immunity of the stations plant and systems is compliant to BS EN 50121-2 requirements.
- To demonstrate that the level of Emission/Immunity of the new electrified railway system to the Outside World (as defined in 50121-2) is compliant to BS EN 50121-2 requirements.
- To demonstrate compliance against Control of Electromagnetic Fields at Work Regulations 2016.

- To compile the evidence that supports the application of the Common Safety Method for the CSIE project.
- To present an EMC file to the NoBo for final validation of the design and commissioning of the line; and,
- To demonstrate that any hazards introduced at frequencies not covered by EN 50121-2 are controlled and mitigated via modelling or risk analysis.

2.3 Scope

The scope of this EMC strategy applies to all existing and new Network Rail infrastructure within the limits of Cambridge South Enhancement project, including domestic and commercial interfaces which could be or are affected by the EMC requirements of this strategy. The designer shall demonstrate that this strategy has been satisfied by detailing the design works which have been undertaken in compliance with the EMC Directive. The following areas shall be covered as a minimum requirement:

- Cable segregation and separation rules;
- EMC coupling considerations between infrastructures (radiated emissions, radiated immunity, conducted emissions and conducted immunity);
- Earthing and Bonding rules;
- Zoning principles;
- Risk Analysis ALARP/HAZID and mitigation measures;

2.4 Geographical Scope

Figure 1 and Figure 2 below show the geographic and aerial views of the proposed site.

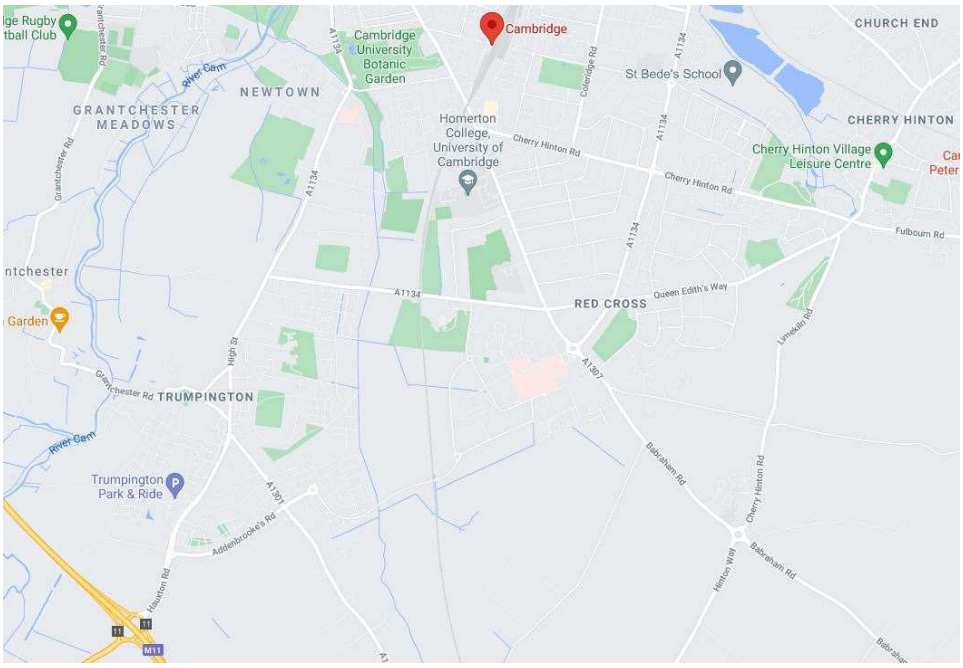


Figure 1. Geographic View of site plan

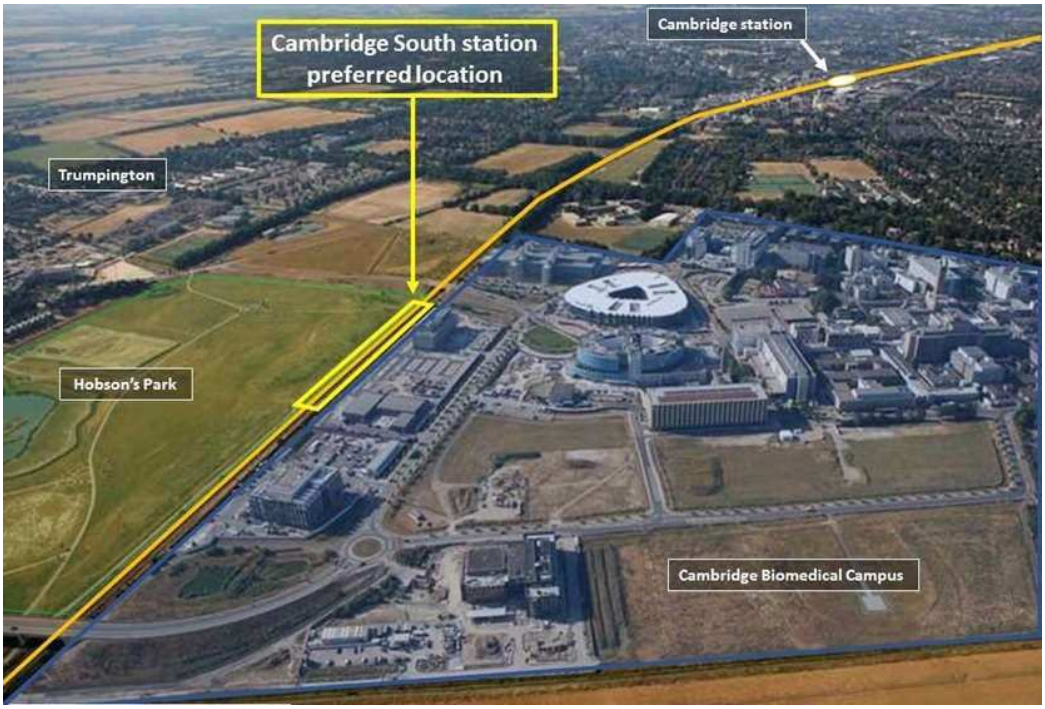


Figure 2. Close Aerial View of the Site

3 Reference Documents

Reference	Document Number	Document Title
Ref 1	158454-JMS-ZZ-ZZZ-STR-EDS-000004	Cambridge South Infrastructure Enhancement Earthing and Bonding Strategy
Ref 2	158454-JMS-ZZ-ZZZ-PLN-EDS-000003	Cambridge South Infrastructure Enhancement EMC Control Plan
Ref 3	158454-JMS-ZZ-ZZZ-DRG-EOH-00001	Ole Section Diagram

Table 3. Reference Documents

4 EMC Standards

4.1 Legislative Documents

Key statutory and legislative design documents are scheduled in Table 4

Code	Title
2014/30/EU	European EMC Directive
2014/53/EU	European Radio and Telecommunication Terminal Equipment (R&TTE) Directive
2013/35/EU	European Directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)
SI 2016 No. 1091	The UK Electromagnetic Compatibility Regulations 2016

Table 4. List of Legislative Documents

4.2 British Standards

Key British Standards are scheduled in Table 5.

Code	Title
BS 7430:2011	Code of practice for earthing
BS 7671, 18th Edition	18th Edition IET Wiring Regulations
BS 6701:2016	Telecommunication equipment and telecommunications cabling – specification for installation, operation and maintenance

Table 5. List of British Standards

4.3 Railway EMC Standards

Standards for EMC design for railway systems are scheduled in Table 6.

Code	Title
BS EN 50121-1	Railway applications- Electromagnetic Compatibility- Part 1: General
BS EN 50121-2	Railway applications- Electromagnetic Compatibility- Part 2: Emissions of the whole railway system to the outside world
BS EN 50121-3-1	Railway applications- Electromagnetic Compatibility- Part 3-1: Rolling stock train and complete vehicle
BS EN 50121-3-2	Railway applications- Electromagnetic Compatibility- Part 3-2: Rolling stock apparatus
BS EN 50121-4	Railway applications- Electromagnetic Compatibility- Part 4: Emissions and immunity of the signalling and telecommunications apparatus
BS EN 50121-5	Railway applications- Electromagnetic Compatibility- Part 5: Emissions and immunity of fixed power supply installations and apparatus
BS EN 50122-1	Railway applications- Fixed installations- part 1: Protective provisions relating to electrical safety and earthing
BS EN 50238	Railway applications- Compatibility between rolling stock and train detection systems

Table 6. List of Railway EMC Standards

4.4 EMC Product Standards

EMC Product standards are scheduled in Table 7.

Code	Title
BS EN 12015	Electromagnetic compatibility - Product family standard for lifts, escalators and moving walks - Emission
BS EN 12016	Electromagnetic compatibility - Product family standard for lifts, escalators and moving walks – Immunity
BS EN 50130-4	Alarm systems - Part 4: Electromagnetic compatibility — Product family standard: Immunity requirements for components of fire, intruder and social alarm systems
BS EN 50174-2	Information technology Cabling installation Part 2: Installation planning and practices inside buildings
BS EN 50310	Application of equipotential bonding and earthing in buildings with information technology equipment
BS EN 55015	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
BS EN 61547	Equipment for general lighting purposes — EMC immunity requirements
BS EN 55022	Information technology equipment – Radio disturbance characteristics - Limits and methods of measurement

Code	Title
BS EN 55024	Information technology equipment – Immunity characteristics – Limits and methods of measurement
BS EN 55103-1	Electromagnetic compatibility - Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use - Part 1: Emission
BS EN 55103-2	Electromagnetic compatibility - Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use - Part 2: Immunity
BS EN 60439-1	Low-voltage switchgear and control gear assemblies - Part 1: Type tested and partially type-tested assemblies.
BS EN 60947-1	Low-voltage switchgear and control gear - Part 1: General rules.
BS EN 60947-2	Low-voltage switchgear and control gear - Part 2: Circuit-breakers
BS EN 62040-2	Uninterruptible power systems (UPS) - Part 2: Electromagnetic compatibility (EMC) requirements
GT/TD INT100	Earthing and equipotential bonding of Telecommunications equipment.
BS EN 300 683	Radio Equipment and Systems (RES); Electromagnetic Compatibility (EMC) standard for Short Range Devices (SRD) operating on frequencies between 9 kHz and 25 GHz

Table 7. List of EMC Product Standards

4.5 Basic EMC Standards

Standards for EMC fundamentals are scheduled in Table 8.

Code	Title
BS EN 61000-3-2	Electromagnetic compatibility (EMC) — Part 3-2: Limits — Limits for harmonic current emissions (equipment input current ≤16 A per phase)
BS EN 61000-3-3	Electromagnetic compatibility (EMC) — Part 3: Limits — Section 3: Limitation of voltage changes, voltage fluctuations and flicker in public low voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection
BS EN 61000-4-2	Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrostatic discharge immunity test
BS EN 61000-4-3	Electromagnetic Compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radiofrequency, electromagnetic field immunity test

Code	Title
BS EN 61000-4-4:1995	Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrical fast transient/burst immunity test. Basic EMC publication
BS EN 61000-4-5:1995	Electromagnetic compatibility (EMC). Testing and measurement techniques. Surge immunity test
BS EN 61000-4-6:1996	Electromagnetic compatibility (EMC). Testing and measurement techniques. Immunity to conducted disturbances, induced by radiofrequency fields
BS EN 61000-4-8	Electromagnetic Compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test
BS EN 61000-4-9:1994	Electromagnetic compatibility (EMC). Testing and measurement techniques. Pulse magnetic field immunity test. Basic EMC publication
BS EN 61000-4-11	Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques — Voltage dips, short interruptions and voltage variations immunity tests
BS EN 61000-4-12	Electromagnetic Compatibility (EMC) – Part 4-12: Testing and measurement techniques – Oscillatory waves immunity test
BS EN 61000-4-16	Electromagnetic compatibility (EMC) - Part 4-16: Testing and measurement techniques — Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz
BS IEC 61000-5-2	Electromagnetic Compatibility (EMC) – Part 5: Installation and mitigation guidelines Section 2: Earthing and Cabling

Table 8. List Fundamental EMC Standards

4.6 Generic Environmental Standards

Standards for different environments are scheduled in Table 9.

Code	Title
BS EN 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments
BS EN 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
BS EN 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
BS EN 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments

Table 9. List of Generic EMC Standards

4.7 Radio Standards

EMC Standards for Radio Spectrum Matters are listed in Table 10.

Code	Title
ETSI EN 300 279	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for Private land Mobile Radio (PMR) and ancillary equipment (speech and/or non-speech)
ETSI EN 300 339	Electromagnetic compatibility and Radio spectrum Matters (ERM); General Electromagnetic Compatibility (EMC) for radio communications equipment
ETSI EN 300 386-2	Electromagnetic compatibility and Radio spectrum Matters (ERM); Telecommunication network equipment;
ETSI EN 301 489	Series of EMC standards applicable to Article 3.1 of the EU Radio Equipment Directive

Table 10. Table of Radio Standards

4.8 Railway Group Standards

Railway Group Standards for EMC design are scheduled in Table 11.

Code	Title
GE/RT8015	Electromagnetic Compatibility between Railway Infrastructure and Trains
GE/RT8217	Introduction and Use of Axle Counters. Managing the Risk 1
GE/RT8270	Route Acceptance of Rail Vehicles including changes in Operation or Infrastructure.
GK/RT0217	Technical Requirements for Axle Counters

Table 11. Table of Railway Group Standards

4.9 Network Rail Standards

Network Rail Company Standards for EMC design are scheduled in Table 12.

Code	Issue	Title
NR/L1/RSE/30040	Issue 69	EMC Strategy for Network Rail
NR/L2/RSE/30041	Issue 2; June 12	Electromagnetic Compatibility (EMC) Assurance Process

RT/E/PS/00009	Issue 1; May 01	Message Handling & Data Transmission Requirements between Processor Based Systems
NR/L2/ELP/23003	Issue 1; Mar 20	Technical Requirements for Transformers, Rectifiers, and
NR/SP/SIG/50002	Issue 2; Feb 07	Methodology for the Demonstration of Compatibility with Single Rail Reed Track Circuits on the AC Railway
RT/E/C/50005	Issue 1; Feb 03	Methodology for the Demonstration of Compatibility with 50 Hertz Single Rail Track Circuits
NR/SP/SIG/50006	Issue 1; Apr 06	Methodology for the Demonstration of Compatibility with 50 Hz Double Rail Track Circuits
NR/RT/E/C/50007	Issue 1; Feb 03	Methodology for the Demonstration of Compatibility with HVI Track Circuits
NR/RT/E/C/50008	Issue 1; Feb 03	Methodology for the Demonstration of Interaction with Neighbouring Railways
NR/GN/SIG/50011	Issue 2; Mar 20	Methodology for the Demonstration of Compatibility with Axle Counters
NR/SP/SIG/50012	Issue 2; Apr 06	Methodology for the Demonstration of Compatibility with TPWS Trackside Equipment
NR/GN/SIG/50013	Issue 2; Sep 19	Methodology for the Demonstration of Compatibility with Route Relay and Solid State Interlockings
NR/GN/SIG/50014	Issue 2; Aug 08	Methodology for the Demonstration of Compatibility with Lineside Equipment
NR/GN/SIG/50015	Issue 3; Sep 20	Methodology for the Demonstration of Compatibility with Reed FDM Systems on the AC and DC Railways
NR/SP/TEL/50016	Issue 3; Apr 06	Methodology for the demonstration of compatibility with Telecoms Systems
RT/E/C/50018	Issue 1; Feb 03	Methodology for the Demonstration of Interaction with Neighbouring Railways
NR/GN/TEL/31106	Issue 1; Jun 09	Overview of Electromagnetic Coupling Between Traction Systems and Telecommunications Cables
NR/L2/TEL/31107	Issue 2; Mar 10	Limits and test method of induced voltages on telecommunications cables due to electrification systems
NR/L2/TEL/30028	Issue 3; Mar 10	Installation of Operational Telecommunications Equipment

NR/L2/ELP/21085	Issue 4; Jun 20	Earthing and Bonding on AC electrified railways
NR/L2/RSE/02009	Issue 7; Mar 21	Engineering Management for Projects
NR/SP/ELP/27224	Issue 7; Mar 21	Specification for installation of cable routes forming part of the traction distribution system

Table 12. Network Rail Standards

5 Detailed Scope of Works

This section provides a summary of the works undertaken by different disciplines. Please note this is not an exhaustive list and only covers items which may cause EMC issues. Please note all like for like replacements or upgrades are unlikely to cause any new EMC issues.

5.1 Electrification

5.1.1 OLE

Fault current values imposed on equipment presently in service are the ones of a classic Booster Transformer System: 6 kA for 0.2 seconds.

5.1.2 Booster Transformers

It is currently assumed that the existing 25 kV booster traction power supply system will be retained on the project, however some significant changes will be brought to the OLE system around the CSIE with more tracks added, hence, a specific EMC assessment is needed on this project. This project can be considered as a major improvement project that will change the EMC characteristics of the area. The area around the Cambridge South station includes some sensitive sites (pharmaceutical laboratories) that are planned to be developed at proximity.

5.1.3 Neutral Sections

The existing neutral sections in the area of interest are not affected by the proposed works.

5.1.4 Sectioning and Switching

The proposed sectioning and switching arrangement are shown in drawing [Ref 3].

5.1.5 Designated Earth Points

All proposed Designated Earthing Point (DEP) locations shall be in accordance with NR/L2/ELP/27715 Module 02. A DEP is required on either side of an electrical sectioning point.

As a minimum requirement, the Aerial Earth Wire (AEW) shall be connected to the traction return system where it is terminated using high integrity (duplicate) bonds.

Within the CSIE area, DEPs are to be installed on each side of the insulated overlaps at each end of the platform which is compliant with the rules above.

5.1.6 RSC

As of today, the need for an RSC has not been confirmed yet. If required, this cable will be laid in the same containment route as the signalling and telecoms cables.

5.1.7 Earthing and Bonding Strategy

Aerial earth wires are provided along the Up and Down main line tracks throughout the proposed scheme. The aerial earth wire is connected to each OLE supporting structures and bonded to the traction return rail a maximum of 400 m intervals. The AEW is only required for OLE bonding.

Regarding the earthing and bonding of other lineside metallic structures such as platform footbridges and Return Screening Conductors (RSC's, if any) details, refer to the Earthing and Bonding Strategy [Ref 1]. In addition to the AEW, a return conductor shall be installed on each main line and connected to the existing RCs on each side of the station.

5.2 Signalling

The existing signalling system is currently a based on a relay interlocking system that is intended to be upgraded to a digital Smart I/O system on the mid-term as part of a separate project (C3R project). The exact commissioning date of the upgraded signalling system is unknown at the time of writing, hence both the existing and future systems are covered within the sections below.

5.2.1 Train Detection

The train detection system in the area is mostly based on axle counters.

Axle counters shall be installed as per the recommendations formulated in section 4 of NR/L2/SIG/11201 module B5, Issue 05 standard.

Axle counters are sensitive to magnetic fields. The axle counter design shall fully comply with the requirements of NR/L3/SIG/3082/002, Issue 01.

5.2.2 S&T Cable lengths

New cables shall be provided where signals are being relocated. New cables may be routed within the existing signalling cable routes if needed.

Signalling cabling design shall be undertaken in accordance with the NR/L2/SIG/11201 Module B12 Transmission Systems – Cable Terminations & Cable Routes, Issue 05.

Section 4.15 of the standard recommends that the lengths of cable should be limited to ensure the V_t is compliant to the BS EN 50122-1 criteria under traction fault conditions.

Tail cables design required for new and relocated signals, new and relocated AWS and TPWS shall be detailed in further design stages.

Recommended cable lengths are:

- For AWS and TPWS: 200 m maximum, as per NR/SP/SIG/10133 Issue 3
- For any other short copper tails: a maximum of 200 m is also the recommended value.

In the absence of route specific immunisation modelling, the recommended maximum cable length before gapping with DLITS and ISPUs shall be no more than 2 km as per SSI 8503.

In any case, for any change of any signalling copper cable, the cable troughs design shall ensure the cable segregation criteria in the EMC Control Plan [Ref 2] are met to ensure EMC.

It should be noted that the Smart I/O system will use fibre optic cables in the future. These are not sensitive to EMC effects; however, the above criteria on maximum lengths of copper cables and EMC cable segregation criteria shall still apply to ensure EMC.

5.2.3 Signalling Power

In case of an upgrade or renewals of the signalling power supply system, the signalling feeders shall be renewed to modern equivalent, and each feeder shall be sized to accommodate the additional load involved by the Cambridge Infrastructure Improvements project.

5.2.4 Relay rooms and Relocatable Equipment Buildings

It is currently assumed that this project doesn't feature any new relay rooms nor REBs at the time of writing.

This section shall be updated at the next GRIP stages should some changes occur in the area.

5.3 Telecoms

Lineside telephone circuits are served by copper cables, stump boxes and signalling locations which in turn are connected to the signal post telephone concentrator. Optical fibre based Fixed Telecom Network (FTN)

transmission access nodes have been previously installed throughout the project area with FTN copper cables and associated distribution cabinets also installed in parts of the area.

The following CSIE Telecommunication works are proposed:

- New cabling arrangements to utilise Fixed Telecoms Network where possible.
- Where new signals are being proposed that have a Red aspect, new Signal Post Telephones will be required.
- Existing cable route infrastructure to be realigned.
- On completion of the project, the existing legacy copper cable infrastructure and signal box telecoms equipment shall be recovered.

In the absence of route- specific immunisation modelling study, copper cables for telecoms equipment shall usually be limited to a maximum cable length of 1.9 km for classic rail return systems. This length can be extended to 5 km in areas with booster transformers as per FTN/HQ/ST/0001 requirements. Note FTN/HQ/ST/0001 requires 3.8 km FTN node spacing. This shall be subject to further design consultation with the NR Project Engineer at later GRIP design stages.

Metallic cable sheaths will need to be gapped at cable joints and before entry into cabinets and buildings, and moisture barriers are isolated at cabinets and buildings. Fibre-optic cables while having length restrictions, these are in 10's of kms the circuit distance being governed by the launch power of the optical transmitter, and the receive sensitivity of the receiver.

5.4 Station Information and Surveillance Systems (SISS)

A non-exhaustive list of electrical SISS equipment to be installed as part of the stations works is presented below.

- Closed Circuit Television Camera
- Public Address and Voice Alarm (PAVA) speakers
- Customer Information Screens
- Passenger Help Point
- WIFI access point for concourse coverage
- Data outlets for the Commercial Advertising Boards
- Ticket Vending machines
- Automated Teller Machine (ATM)
- Communications Equipment Room (CRE)
- Dynamic Ambient Noise Sensors (DANS) – DANS provide automatic level adjustments of announcements above operational ambient noise levels to compensate for noisy/quiet periods.
- Audio Frequency Induction Loops (AFILS) – Number = 10
- Passenger Help Point (PHP) – Cameras, Phones
- VOIP/Lift Telephones
- Emergency Voice Communications (EVC)
- Access Control Systems

5.5 LV Systems

A non-exhaustive list of LV systems being modified or newly installed is presented below:

- Points Heating
- Junction and Shunter Walkway Lighting
- Motor Operated Switches
- Power supply of Signalling and telecommunications equipment located within the vicinity of the station, if any
- DNO Supplies (for Trackside equipment and for stations equipment)
- LV cables

5.6 Interfacing Projects

At this stage of the project life cycle, two interfacing projects have been identified that can significantly impact the EMC characteristics of the design. These are listed below:

- The Cambridge South area is an area that is currently developing to accommodate medical laboratories with specific sensitive laboratory equipment, therefore, the EMC aspects of both the CSIE project and the wider Cambridge South area development project need to be carefully addressed to ensure a satisfactory Electromagnetic Compatibility;
- A major re-signalling scheme is currently ongoing in the area, which will necessitate appropriate coordination regarding EMC.

5.7 Staging Requirements

No major staging requirements have been identified during the design at this GRIP stage. Staging requirements will need to be considered at later GRIP stages.

5.8 Rolling Stock

The rolling stock currently planned to provide passenger services for Cambridge South Infrastructure Enhancement project are, as per the current iTSS timetable:

- Class 387
- Class 700
- Class 720
- Class 755

These types of rolling stock are already running on the route and no new rolling stock is to be introduced as a part of Cambridge South Infrastructure Enhancement project.

The platforms at the new station shall be 250 m useable length to allow use of up to 10-car formations of these trains. New rolling stock planned to stop at the new station will be fitted with train-based DOO CCTV.

6 Systems and EMC Assessment on Cambridge South Infrastructure Enhancement Project

6.1 EMC Assessment

This EMC Strategy covers:

- The changes and provision of 25 kV OLE over the area to be electrified;
- The changes to the existing DNOs of the provision of new DNOs if necessary;
- The impact on Signalling equipment;
- The impact on Telecom equipment;
- The impact on Stations' equipment;
- The impact on Rolling Stock;
- The impact on External third parties;
- The impact on members of public (Passengers and neighbours);
- The impact on members of staff.

The list below provides more details on the equipment to be considered in an EMC assessment for an AC-electrified railway line.

Further detail on the equipment and interfaces to be considered in the EMC assessment can be found below.

- Overhead Line Equipment: HV Substations and Feeder Stations, 25 kV overhead lines and Track Sectioning Cabins TSC, Neutral sections;
- Electrification and Plant: Points Heating, Signalling Power, OLE Motorised Switches and Fixed Earthing Devices, M&E services including lighting and low voltage power systems and associated containments, cable routing and separations to avoid potential EMI issues;
- Telecommunication: Multi-Protocol Label Switcher (MPLS), VoIP Telephones, HMI Interface – IP Trade Turrets and Station assets such as CIS, PA, Security CCTV, DOO Equipment, Help Points. Lineside SCADA, GSM-R/FTN Masts and Equipment;
- Signalling: Signalling Control Centre, Relay Rooms and REBs, Signals, Points Machines, Level Crossing Equipment, Track Circuits, TSS (TPWS) and AWS Suppressors;
- Rolling Stock: Considerations are given to classes of rolling stock to operate on the line and compatibility with the other systems.

The Booster Traction Return system will be retained at CSIE new station. Therefore, a specific EMC assessment at GRIP 5 is needed on this project since this is a major improvement project, which is not limited to a simple change of the type of OLE and increased lines, as some new areas with sensitive sites (pharmaceutical laboratories) are planned to be developed at proximity.

6.2 EMC HAZID Process

The hazard identification and management process includes the following activities:

- Definition of existing infrastructure.
- Definition of changes.
- Definition of the EMC requirements.

- Completion of the EMC Hazard matrices.
- Identification of potential hazards.
- Risk assessment and ranking.

Potential Hazards related to EMC on Cambridge South Infrastructure Enhancements Project are then divided into two groups: Generic Hazards and Specific Hazards The two corresponding EMC Hazard Logs shall be built discussed in collaboration with all relevant parties during EMC HAZID workshops.

6.3 HAZID Workshop

At GRIP5 design stage, the designers and contractors involved in the project will be required to attend the EMC hazard identification (HAZID) works prior to the proceedings of works, including contribution from the identified stakeholders. The Designer's EMC CRE and the Contractors CREs shall conduct these meetings collaboratively. All relevant EMC interfaces shall be considered including other Network Rail systems, third party systems, neighbouring railways, third party transmitters and the public. Following the EMC interface analysis, potential EMC Hazards will be identified clearly stating the source of EMI and the victim under consideration. Each risk will then be quantified, an owner assigned, and the proposed mitigation method shall be recorded in the Project EMC Hazard Log held by the Designer's EMC CRE. Good use of this EMC Hazard Log should drive EMC design and activities to enable the hazards to be closed at further GRIP stages of the Project. The Designer's EMC CRE shall collate the hazards generated from the HAZID workshop in an EMC Hazard Log.

The Designer's EMC CRE shall collate the hazards generated from the HAZID workshop in an EMC Hazard Log. Relevant hazards and genuine safety concerns should be added to the Project Master Risk Register held by the Project to raise Network rail's awareness of the main EMC issues encountered on the Project. In accordance with this HAZID process, each Contractor will be required:

- To attend the relevant meetings and clearly demonstrate compliance through written documentation and drawings.
- To demonstrate that the EMC aspects have been considered and discussed during the IDCs. The completed IDC certificates shall be submitted to the Designer's EMC CRE and included in the EMC Project file for evidence.
- To add a section within the design submission describing how EMC has been considered within the design and provide a statement stating that there are no EMC non-compliances identified.

The Designer's EMC CRE will request relevant documentary evidence from all the parties involved (e.g., but not limited to Contractors and equipment suppliers) to be collated within the EMC Project File. This consists in bringing evidence that good EMC practices have been followed:

- During design. This includes (but not limited to):
    - Attending the EMC HAZID Workshops to contribute in finding mitigations to the different EMC Hazards encountered on the Project;
    - Demonstrating that the good EMC practices recommended in the EMC Control Plan [Ref 2] have been followed, e.g. by adding a note regarding EMC to the IDC;
    - Providing documentary evidence for EMC compliance.

- During installation. This includes (but not limited to);
    - Using Network Rail approved equipment or providing a copy of the EMC Conformity certificates (if required by Network Rail in case further evidence is requested for specific items of equipment).
    - Demonstrating that the good EMC practices recommended in the EMC Control Plan [Ref 2] have been followed, e.g. by providing cabling checklists and test reports

6.4 Railway Systems Interface

No particular interface with other railway systems that could be operating nearby has been found in the area of interest.

6.5 Potential EMC Hazards

Generic and specific EMC Hazard Matrices shall be included as appendixes to the EMC Control Plan at GRIP5 stage and shall be discussed with all relevant parties during a dedicated EMC HAZID workshop.

6.6 Generic Hazards

The Cambridge South Electrification Project is subject to typical generic risks related to EMC which are common to most of the Railway development projects in the UK. Generic risks can usually be mitigated and closed out by applying generic procedures during the lifecycle of the System.

However, not all the Generic Risks of a Generic Railway Line apply, and some of these risks shall be disregarded and removed from the EMC Generic Hazard Log when not applicable to the Project.

6.7 Specific Hazards – Interfaces with Third Parties along the route

Specific risks apply due to the type of electrification, including, but not limited to:

- Risks on Workers working on or near the lines;
- Interference with Signalling and Telecommunications equipment;
- Presence of third parties near the line;
- Electric field generated by long parallel cables to OLE; etc.

In general, each section of the route shall be considered to identify areas of susceptibility e.g.:

- Long lengths of road parallelism giving rise to possible interference with Highways Agency traffic systems;
- Hospitals;
- Laboratories;
- Recording/broadcasting studios;
- Sensitive industrial sites;
- etc.

New interfaces between the existing and new signalling and power systems may be identified throughout the course of the project; which will need to be considered. All the impacted parties will need to be assured that the electrification or changes that will be introduced as part of the project will not impact on their operation. As such, these will be logged as part of the EMC HAZID process.

7 General EMC Requirements

This section describes how the main requirements described in the EMC Standards (See Section 3) shall be applied to the Project. It provides an assessment of the main standards and presents the main requirements the Project shall comply with.

7.1 UK EMC Regulations

The UK EMC Regulations 2016 implement the 2014/30/EU. The Regulations apply to equipment which includes apparatus and fixed installations. Applying the definition in the Regulations.

The railway system is considered as a fixed installation. The EMC Regulations requires that:

- The infrastructure does not cause interference to other systems, either on or off railway premises, with particular concern for radio and telecommunications equipment.
- The infrastructure does not suffer unacceptable degradation of performance due to electromagnetic disturbances from other systems in the area.
- Good engineering practice is applied in designing and constructing the installation.
- Manufacturers' information on the intended use of the systems is considered.
- A responsible person is defined with respect to the EMC Regulations.
- The engineering practices adopted to deliver electromagnetic compatibility are documented.
- The documentation is maintained for the life of the asset by the EMC responsible person.

In addition to the EMC Regulations, equipment and systems that can generate high levels of electric and/or magnetic fields must also demonstrate compliance with The Control of Electromagnetic Fields at Work Regulations. Where equipment incorporates a radio receiver or transmitter, compliance with the Radio and Terminal Telecommunications Equipment (R&TTE) Regulations is also mandatory.

7.2 Common Safety Method on Risk Evaluation and Assessment

EU Regulation 402/2013 on the "adoption of a common safety method on risk evaluation and assessment" (referred to as the 'CSM') sets-out a risk management process that applies to all significant technical, organisational and operational changes which may impact on the operating conditions of the railway system.

The CSM applies to significant changes to all railway sub-systems, significant changes to the operation of the railway and significant changes that could impact on the operating conditions of the railway system.

The CSM framework describes a common mandatory European risk management process for the rail industry and does not advise specific tools or techniques to be used. Risk assessment is a familiar process in the UK

and the Office of Rail and Road's (ORR) experience is that the principles of the Regulation are already being applied for most Projects.

The framework of the CSM is based on the analysis and evaluation of hazards using one or more of the following risk acceptance principles:

- Application of codes of practice.
- Comparison with reference systems; and,
- Explicit risk estimation.

7.3 Overview of applicable EMC standards

The EMC standards and requirements for equipment and installations are outlined in the following section, this is inclusive of BS, EN, Network Rail (NR) and other third-party standard organisations. It is the obligation of the Contractors to establish current knowledge with Designer's EMC CRE on the Official Journal standards released at the time of the design.

7.3.1 General

7.3.1.1 Electrical Systems Compatibility

Inter-system compatibility of electrical large installations including associated disturbances to third parties is addressed in European Commission Directive 2014/30/EU "The Electromagnetic Compatibility (EMC) Directive". As part of the EMC Directive, manufacturers and suppliers of all equipment and systems (excluding RED equipment) must demonstrate compliance with the EMC Directive. In addition, items of equipment, apparatus or systems which comprise a "Fixed installation" must individually comply with the regulations.

The British Standards (BS EN 50121 suite of standards) for railway applications, specify levels of emissions and immunity required for the infrastructure (including the power supply network), signalling and telecommunications systems and for all types of rolling stock (including locomotives and electrical multiple units). This suite of standards will be utilised by the manufacturers and suppliers as a basis for demonstrating compliance. However, these standards have not yet been published in the Official Journal of the European Union (OJEU), hence manufacturers and suppliers must continue to demonstrate compliance by compiling a technical file.

Residential, commercial, light industrial and heavy industrial environments are covered by the BS EN 61000–6–X suite of standards and are also governed by generic emissions and immunity standards.

Manufacturers and suppliers shall demonstrate compliance by self-certifying against these standards and shall demonstrate that these standards adequately cover the equipment and its intended operating environment.

Manufacturers and suppliers who intend to supply equipment or systems in accordance with the generic standards shall perform a gap analysis (where appropriate), identifying any shortfall between the generic standards and the BS EN 50121 series of standards. Where necessary, the manufacturer may have to undertake additional design work to ensure compliance with the European Directive.

7.3.1.2 Functional and Operational Frequencies defined by Network Rail, or as part of the Manufacturer's Equipment

Functional and Operational Frequencies' as defined by Network Rail are the frequencies where disturbances of the operational railway occur, typically less than 100 kHz e.g. disturbance to track circuits, low frequency and high frequency earthing arrangements and 50 Hz induction into lineside cables.

The emissions and immunity limits are normally defined in manufacturers' installation guidelines and railway codes of practice. In order to ensure that all the necessary safety and assurance evidence is available when the equipment is taken into service, it is essential that the EMC requirements are accurately defined so that a gap analysis can be performed against them.

Note the testing requirements depends on the EM zoning. The designer should perform zoning assessment and gap analysis with test performed by manufacturer (see Declarations of Conformity).

7.3.1.3 Disturbances in the Radio Frequency Spectrum

This refers to the interaction between Electrical Systems where the disturbances occur at frequencies that are not normally associated with the operating railway, typically greater than 100 kHz. The limits of emission and immunity are defined within European and BS Standards Primarily EN 50121 and EN 61000- X series.

7.3.1.4 Electricity At Work Act 1989

The document that brings this into effect as UK law is Statutory Instrument 1989 No. 635. The Electricity at Work Regulations 1989 came into force on 1 April 1990. Practical guidance on the regulations is given in the Memorandum of guidance on the Electricity at Work Regulations 1989 HS(R) 25.

The definitions of danger and injury are linked but distinguished to accommodate those circumstances when persons must work on or so near live equipment that there is a risk of injury, i.e. where danger is present and cannot be prevented.

The IET Wiring Regulation and BS 7671 have been extensively referred to in the HSE guidance over the years. Installations which conform to the standards laid down in BS 7671 18TH edition are regarded by the HSE as likely to achieve conformity with the relevant parts of the Electricity at Work Act 1989. Existing installations may have been designed and installed to conform to the standards set by earlier editions of the Wiring Regulations or BS 7671.

7.3.1.5 BS 7671 IEE Wiring Regulations 18th Edition

The IET Wiring regulations BS 7671 18th Edition apply to the electrical installations of domestic, commercial and industrial premises: exclusions include railway traction equipment, rolling stock and signalling equipment.

The requirements of the Regulations are "intended to provide for safety of persons, livestock and property against danger and damage which may arise in reasonable use of electrical installations".

These Regulations are non-statutory regulations. They may, however, be used in a court of law in evidence to claim compliance with a statutory requirement. The relevant statutory provisions include Acts of Parliament

and Regulations made there under. In some cases, Regulations may be accompanied by Codes of Practice approved under Section 16 of the Health and Safety at Work Act 1974.

Note: the introduction to BS7671 states that the Regulations are not suitable in association with Railway Signalling and Electrified Railways. BS EN 50122-1 should be referenced as well where there is an interface.

7.3.2 Railway Group Standards

Railway Group Standards are mandatory on all members of the Railway Group – i.e. Network Rail, Railway Safety, and the train and station operators.

GE/RT8015 mandates the requirement for EMC between railway infrastructure and trains. It also mandates the process to enable compatibility between infrastructure and trains to be demonstrated in order to meet route acceptance requirements.

7.3.3 Network Rail Standards

Section 3 of Network Rail's EMC Strategy NR/L1/RSE/30040 defines the Chief Engineer as the responsible person as required by the EMC Regulations for fixed installations. The responsibility for the practical implementation of the requirements and documentation is delegated to each Designated Project Engineer (DPE) with responsibility for each aspect of the project.

Network Rail's EMC Assurance Process specifies how NR manages the risk of asset failure associated with known uncontrolled electromagnetic phenomena. The assurance process and best practice specified in NR's EMC Assurance Process forms the basis of the processes and good EMC engineering practice.

7.3.4 Harmonised Railway EMC Standards

The BS EN 50121 series of railway EMC standards provide a framework for managing EMC for railway systems. They specify the limits for electromagnetic (EM) emissions of the railway system to the outside world and the EM emission and immunity requirements for equipment operating within the railway system.

Products selected for operation within the railway environment on Cambridge South Infrastructure Enhancements Project shall comply with product standards BS EN 50121-4 or BS EN 50121-5. Equipment that complies with other, non-railway, product EMC standards will need to be assessed for compatibility with reference to Appendix D of NR/L2/RSE/30041.

7.4 EMC and Safety Recommendations

An unsatisfactory EMC can have serious safety consequences. The following Sections provide basic recommendations to be followed.

7.4.1 General Recommendations for all disciplines

The following subsections give details of the principles that should be applied to ensure electromagnetic compatibility in the rail environment.

Refer to the Project's EMC Control Plan [Ref 2] for further detail on the following principles mentioned below.

- Use of Commercial of the Shelf (COTS) Equipment: The use of COTS equipment for safety critical function is prohibited if this equipment is not approved for compliance with Network Rail EMC Standards. When used in business-critical functions, it may be possible to make a justification for their acceptability. However, additional mitigation will almost always be necessary in order to ensure reliable operation. This may include the fitting of filters, operating the equipment from a UPS, placing the equipment in a shielded enclosure etc.
- Equipment Containing Radio Transceivers: Equipment containing radio transceivers shall comply with the R&TTE Directive, in addition to complying with European standards. Compliance is normally demonstrated by testing to the appropriate ETSI standards for the radio system under consideration.
- System Level Testing for Compliance with EN 50121: Whilst it is unnecessary to perform measurement along the full length of modified infrastructure, measurements shall be performed at the substations (if any) against the requirements of EN 50121-2 to demonstrate that the changes made within the existing electromagnetic environment do not give rise to unacceptable levels of induced voltages, electromagnetic fields and radio frequency interference.
- Equipment Location: Careful arrangement of equipment is critical to achieve EMC. This not only relates to products inside equipment cases but also between large distributed systems that form parts of the railway. In general, the overall design where space permits, should ensure that significant sources of interference are located as far away as practical from sensitive equipment. Where this is not possible, additional design measures shall be taken to reduce the levels of interference experienced by the victim systems.

Interference can be generated due to the following electro-magnetic coupling mechanisms:

- Conducted: Interference transmitted via a galvanic connection between two or more systems for instance via a shared power source, common signal connection or ground connection. The interference may be continuous in the form of harmonic and/or radio frequency conducted noise or discontinuous due to transient events and surges on the supply.
- Inductive: Coupling due to currents flowing in a cable or current return path resulting in an induced voltage on a victim cable. The level of the induced voltage is proportional to the exposure length and current flowing in the conductor, and inversely proportional to the separation distance between the conductors. Induction may also occur when systems are placed near wound components such as transformers and inductors.
- Capacitive: Capacitive coupling occurs due to the voltage gradient (potential difference) between a cable and the victim cable. This form of interference only manifests itself where high voltages are used.
- Radiated: Radiated interference may be from a number of sources including – but not limited to – the following:
    - Radio Transmitters.
    - Cables attached to systems acting as antennas at high frequency.
    - Direct radiation from tracks on PCB's.
    - Transient and discontinuous events including lightning and/or arcing due to disconnection of a system from its power source e.g. pantograph bounce, operation of switch gear etc.

EMC can be achieved by considering all of the above with respect to the installation and determining any necessary mitigation to prevent interference.

7.4.2 Overhead Line Equipment

Recommendations regarding Overhead Line Equipment (OLE) are presented hereafter.

- Equipment Containing Radio Transceivers: Equipment containing radio transceivers shall comply with the R&TTE Directive, in addition to complying with European standards. Compliance is normally demonstrated by testing to the appropriate ETSI standards for the radio system under consideration.
- Compatibility with Tunnels: not applicable to this Project;
- Structure Earthing Arrangements Near Axle Counters (if any, to be defined at next GRIP design stages): Lightning poses a significant risk to Axle Counters and therefore, the path of the Lightning should be controlled such that the lowest impedance path does not result in the lightning current flowing past the axle counter head. Where practicable, this can be achieved by ensuring that a section of running rail of around 30m is maintained between the location of the nearest structure bond and the axle counter head.
- Compatibility with other Traction Systems nearby: Not applicable to this Project.

7.4.3 Signalling

Recommendations regarding signalling are listed below.

- Compatibility with Train Detection System: Determine if all rolling stock servicing the route are compatible with the configuration of the train detection systems used. This will require review of the route acceptance cases to confirm that there are no restrictions.
- Selection and Modification of Track Circuits and Axle Counters: Where track circuits are replaced, they shall be selected such that they are immune to both the electrification system and rolling stock operating over them. Likewise, any modifications to the track circuit arrangements shall also be validated against the electrification system and rolling stock.
- Neutral Sections and Axle Counters: In case the Project intends to install at least one axle counter head near (within 50m) an APC magnet; Axle counter heads should not be installed in close proximity to the start or end of a neutral section due to the potential for interference caused by the sudden inrush of current into the rolling stock's main transformer and transient events due to the connection and disconnection of the pantograph from the OLE. In addition to the localised effects, Electro Magnetic line resonance may also occur at these locations which have been known to affect axle counter systems. Axle counter heads shall therefore be located at least 30 m away from the neutral section. Refer to NR/L2/SIG/30081 and to NR/L2/SIG/30082 for further information. Additional shielding measures should be taken if this is not possible.
- Points Machines, Clamp Locks and Point Detection in a.c. electrified areas: In accordance with NR/GN/SIG/11600, d.c. circuits running to point's machines and clamp locks should be restricted to less than 200 m. Point detection shall be fed by means of a 50 V d.c. supply and use a.c. immune relays.
- Signal Trackside Cables: In accordance with NR/GN/SIG/11600, trackside signalling cables and signal head circuits shall not exceed 200 m in length.

- AWS and TPWS System: In case of new AWS or AWS alterations, all AWS inductors should normally be placed at 180 m on the approach to the associated signals, unless specifically annotated for their placement due to site or scheme specific constraints. All new/modified signals shall be provided with TPWS fitment and details are mentioned in the TPWS fitment table in the Route Table and Aspect Sequence Charts (20-SO-055-Sheet 2). The TPWS fitment shall be in accordance with NR/SP/SIG/10133 – TPWS Signalling Interface Design Requirements, NR/SP/SIG/10137 - TPWS Selection of New Signals and Other Locations for Provision of TPWS, NR/SP/SIG/10138 - TPWS Transmitter Loop Requirements and Positioning and NR/GN/SIG/00028 - General Guidelines on Train Protection & the Provision of Signalling.
- AWS and TPWS System: AWS magnets shall not be collocated with APC magnets due to the risk of interference. Cables running to and from the TPWS equipment shall in general be limited to 200 m but shall under no circumstances exceed the limits given in Table 5 of NR/SP/SIG/10133. Additionally, where a TPWS unit incorporates a failure indication unit an internal repeat relay shall be fitted.
- Lineside Circuits and SSI: As a general rule, lineside circuits shall not exceed 2 km, where longer lengths are applied these shall be subject to a documented risk assessment. Data Link Isolation Transformers in accordance with SSI8503. Where required, Isolating surge protection units shall be fitted on long SSI data.

7.4.4 Telecoms

Recommendations regarding Telecoms are presented hereafter.

- **Compatibility with Radio Transmitters**: Determine if any high powered i.e. >50 W transmitters are located within 20 m of the installation location of the new telecom equipment. If transmitters are found, compatibility with enhanced levels at operating frequency shall be confirmed.
- **Compatibility with Signalling equipment**: Calculations shall be carried out to determine the levels of induced voltage on lineside copper cables. Telecommunications equipment connected to communications cables >1 km shall be subject to integration testing to confirm that the levels of induced voltage remain below the touch voltage limits in both normal and fault conditions. In addition, induced voltage measurements shall also be performed on long parallel power cables. This will require touch potential measurements to be performed on the longest physical length of trackside power cable under both normal operation and fault conditions.
- **Compatibility with Station assets**: In order to ensure that the existing station assets are compatible with the new a.c. traction system, a review will be undertaken to confirm that the systems present have been previously used in a.c. electrified areas.
- **Compatibility of Communications to other Wiring Systems**: In the event of crossing or proximity of underground telecommunication cables and underground power cables, a minimum clearance of 100 mm shall be maintained or the requirements of BS7671 regulations 528.2 must be satisfied.

7.4.5 Electrification and Plant

Recommendations regarding Electrification & Plant (E&P) are presented below:

- **FEDs:** Confirm that the FEDs have compliance evidence against the requirements of BS EN 50121-5.

- **Compatibility of Rolling Stock with the a.c. Traction System**: Confirm the rolling stock operating on wired lines will not cause resonances on the traction supply.
- **Compatibility of Electric Points Heating with Train Detection Systems**: Consideration must be given to the type of the train detection systems before specifying electric points heating. If there are compatibility issues must be resolved with signalling either by replacing the train detection system or providing gas heating.
- **Compatibility of Electrical Services to other Wiring Systems**: ELV / Voltage Class I (50 V a.c. or 120 V d.c. Max) and LV/Voltage Class II (1000 V a.c. / 1500 V d.c. line to line or 600 V a.c. / 900 V d. c. line to neutral) circuits must not be contained in the same circuit except where the conditions of BS 7671 regulations 528.1 are satisfied.

7.4.6 Rail and Induced Cable Voltages

Although low frequency (50 Hz to 150 kHz) conducted and induced interference is the greatest EMC threat to lineside systems, the railway EMC series of standards BS EN 50121 do not specify any tests to cover this risk.

Guidance received from Network Rail Electrification and Plant Design Group (EPDG) advises that safety-critical and performance affecting systems may be exposed to the running rail current and voltage levels listed in Table 13 and Table 14 if installed within 10 m of the line, or systems connected to copper line side cables.

An assessment should be made during the design for any existing, replaced or new equipment likely to be exposed to these levels. Should there be degradation of performance, then further EMC testing will be required. If a product fails any of the tests, the amplitude of the interfering source should be reduced until failure no longer occurs. This information will be critical when reviewing any non-compliance with these requirements.

The current generates a magnetic field which may affect any magnetically sensitive equipment in close proximity to the railway. Any critical system connected to the rails which may be affected by magnetic fields should be tested for immunity to low frequency current in the range 15 Hz to 150 kHz. The equipment shall continue to operate when the current specified in Table 13 is applied to the rail on which the equipment is connected or mounted. Where the coupling method is via magnetic field only, the rail current may be converted into a corresponding magnetic field at the equipment under test.

Condition	Frequency	Current in Running Rail	Duration
Normal	50Hz	1200A rms	60s
Normal	50Hz 150Hz	1200A rms 100A rms	60s
Normal	50Hz 250Hz	1200A rms 70A rms	60s
Normal	50Hz 350Hz	1200A rms 40A rms	60s
Normal	50Hz 15Hz – 10kHz	1200A rms 10A rms	100s per decade
Normal	50Hz 10kHz – 150kHz	1200A rms 3A rms	100s per decade
Fault	50Hz	12kA rms	200ms

Table 13. EMC Current Levels for (0Hz - 150kHz)

Due to the finite impedance between the rails and the traction supply, the current flowing in the rails generates a voltage on the rail with respect to earth.

Where equipment is connected directly to a rail, and a separate connection to local earth is made, the interference voltages in Table 14 should be applied between the rail and earth terminals of the equipment. If the equipment is only mounted on the rail and not galvanically connected to the rail, then the equipment should be mounted in a way that represents normal installation practice and the voltage should be applied between the rail and the earth terminal.

Condition	Frequency	Current in Running Rail	Duration
Normal	50Hz	100V rms	60s
Normal	50Hz 150Hz	60V rms 30V rms	60s
Normal	50Hz 250Hz	60V rms 20V rms	60s
Normal	50Hz 350Hz	60V rms 20V rms	60s
Normal	50Hz 10Hz – 150kHz	60V rms 10V rms	100s per decade
Fault	50Hz	1000V rms	200ms

Condition	Frequency	Current in Running Rail	Duration
Lightning Fault	(10/700)μs	5kV applied in accordance with EN 61000-4-5	5 positive surges 5 negative surges

Table 14. EMC Voltage Levels for (0Hz - 150kHz)

8 Project EMC Deliverables

This section presents the mandatory deliverable requirements for the Project. These have been established in accordance with the requirements set in Network Rail's standards NR/L1/RSE/30040 and NR/L2/SIG/30041 as shown in Figure 3 below.

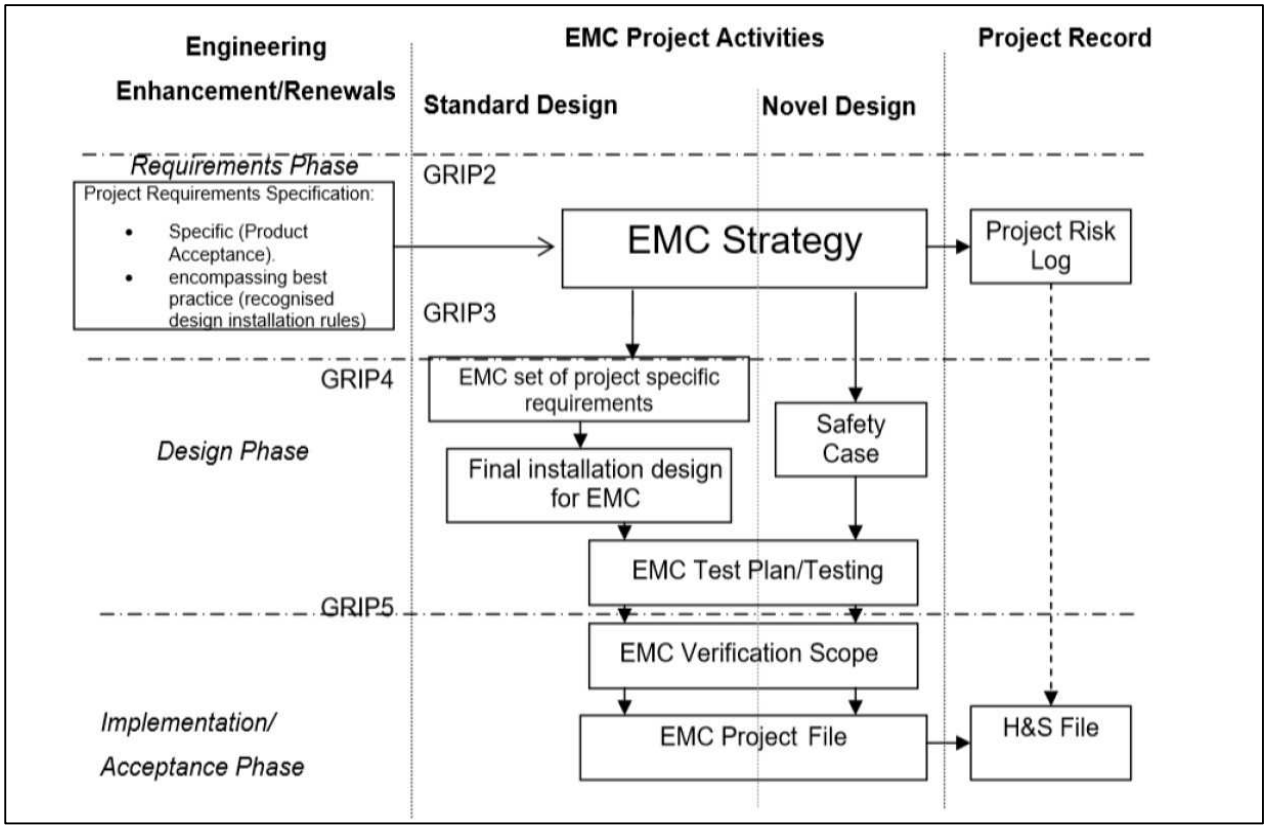


Figure 3. Control scheme of Project EMC activities and deliverables requested by Network Rail.

Arcadis has developed a rigorous EMC design process in line with Network Rail's Standards NR/L1/RSE/30040; EMC Strategy for Network Rail requirements and NR/L2/RSE/30041; EMC Assurance Process for Network Rail requirements. That process includes the delivery of several EMC documents: the EMC Strategy, the EMC Control Plan, which includes the EMC Hazard Logs (Generic and Specific EMC Hazard Matrices) and the EMC Test Plan.

The EMC deliverables are detailed in Figure 4 below.

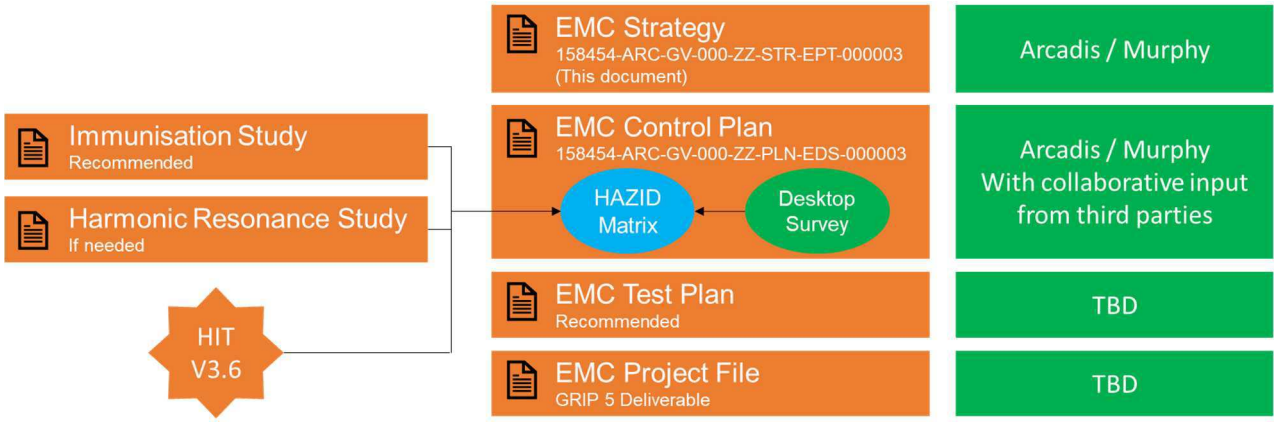


Figure 4. Proposed EMC documentation

HIT = Hazard Identification Tool

The EMC design process that is currently proposed is based on the V-model presented below. It is an essential process which enforces a rigorous quality assurance for each step of the EMC demonstration to ensure all requirements have been met and are compliant with relative standards. Refer to Figure 5 for the Verification and Validation of Arcadis EMC deliverables to cover the life cycle of projects across all GRIP stages.

These documents correspond to the left-hand side of the V-Cycle presented in Figure 5 below.

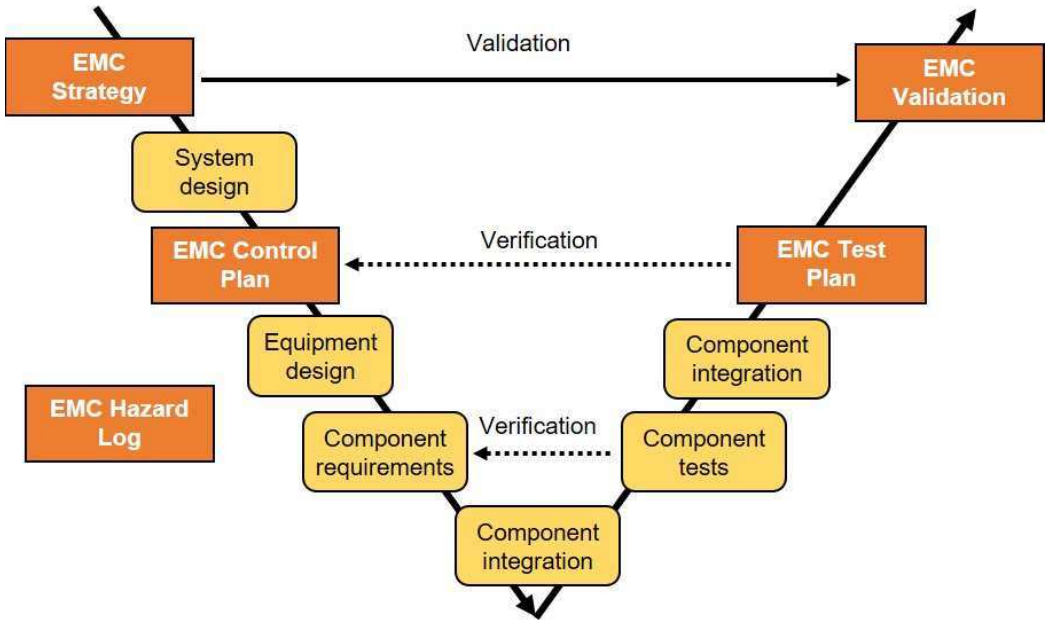


Figure 5. Arcadis EMC Verification & Validation model for project Lifecycle

8.1 EMC Control Plan

The Designer's EMC CRE shall update the EMC Control Plan [Ref 2] at GRIP5 stage to demonstrate how the requirements of this EMC Strategy will be fulfilled by the design.

The Control Plan shall detail the following, as a minimum:

- Proposed works undertaken by the Project that affect the EMC (electrification, signalling, telecoms, station systems, interfacing Project, etc.).
- Equipment requirements.
- Design installation guidelines for good EMC practices.
- Methodology to identify and mitigate against any EMC Hazard that can arise on the Project.

8.2 Immunisation Study

An immunisation study shall be conducted at GRIP 5 stage of the Project.

This report or any separate report will present the results of the modelling assessment of the proposed design to fulfil the following requirements:

- Verify the proposed earthing and bonding arrangement and demonstrate that the design will mitigate the risks of Touch Potentials and Accessible Voltages. This is essential for the design to demonstrate compliance with the requirements of BS EN 50122 and G12/4 standards.

- Assess the impact of the proposed design on Signalling, Telecom (S&T) and LV cables and equipment by calculating longitudinal induced voltages, both in normal conditions (steady state) and under short circuit conditions.
- Determine the expected magnetic fields along the line in normal conditions (steady state) and under short circuit conditions to inform the impact of the proposed changes on third parties.

This document is part of the Project's EMC demonstration of compliance. The simulation results will aim at demonstrating that the proposed design is satisfactory in normal operation and degraded modes.

These results will be used to inform the ongoing EMC Hazard Log described in section 8.3.

8.3 EMC Hazard Log

Please refer to the EMC Hazard Log provided in the EMC Control Plan [Ref 2]. This Hazard Log shall be update at GRIP5 design stage to enable an accurate assessment of all Generic and Specific Hazards that apply to the Project.

8.3.1 Generic Hazards

The Cambridge South Infrastructure Enhancements Project is subject to typical generic risks related to EMC.

Generic risks can usually be mitigated and closed out by applying generic procedures during the life of the installation. However, not all the generic risks of a railway line apply, and these risks shall be selected when deemed applicable to the Project.

8.3.2 Specific Hazards

Specific risks apply due to the type of electrification, signalling and telecommunications that affect the third parties near the line.

As the forecasted developments in the Cambridge South area will lead to dense areas with sensitive sites, many interfaces and possible interferences with third parties along the route may request to be assessed to define appropriate mitigation measures.

A desktop route survey will be performed to identify all potentially sensitive installations located in the vicinity of the line. This survey will be part of the EMC Control Plan [Ref 2] and will be discussed during the HAZID workshop and reported in a Specific EMC Hazard Log.

In general, each section of the route will be considered to identify areas of susceptibility e.g.:

- Hospitals;
- Laboratories;
- Recording/broadcasting studios;
- Sensitive industrial sites;
- Road traffic systems alongside railway line;
- Telecommunications lines, and;
- Conductive cabled or piped services which run parallel to the track for significant distances.

Compatibility with third parties is governed by compliance with BS EN 50121-2 standard, which provides emission limits on a frequency range from 150 kHz to 1 GHz, measured at the boundary of the railway (10 m from the centre line of the outermost track).

Non-power frequency emissions are mainly governed by the harmonic emissions of the Rolling Stock. The Rolling Stock emissions are governed by compliance with BS EN 50121-3-1, which should facilitate compliance with BS EN 50121-2 for the whole railway.

No limits are set for emissions at 50 Hz, however, there are installations containing systems which can be adversely affected by traction power frequency emissions. Installations such as schools, hospitals and scientific research institutions can utilise medical equipment or electron microscopes which are sensitive on a wide range of magnetic field frequencies including 50 Hz.

8.4 EMC Test Plan

The Designer's EMC CRE shall produce the EMC Test Plan at GRIP 5-6 stages should the EMC HAZID workshops show measurements are necessary.

The EMC Test Plan will include the following:

- The basic test requirements of the items of equipment which will be installed.
- The test requirements after integration of the different items of equipment and rolling stock to demonstrate the Electromagnetic Compatibility on the Project. This may include undertaking some measurements in some targeted areas which will be identified in the EMC Hazard Log.
- The tests to be undertaken on each item of equipment include fixed High Voltage installations, Signalling equipment, Telecommunication system equipment and Station's equipment. All these separate items must be EMC tested or certified individually before being integrated along the railway. Integration tests and measurements must be undertaken along the railway. Where areas at risk have been identified, measurements shall be undertaken before and after energisation of the railway system to show the impact of the new electrification on its electromagnetic environment and to ensure that EMF levels are below maximum permissible levels within these areas. The results of the measurements will also be used:
- To communicate with third parties (hospitals, schools, electricity DNOs etc.),
- To check that the new railway equipment as a system (i.e., including rolling stock) will not be disturbed by its electromagnetic environment and that it will not disturb that environment itself.
- To bring relevant evidence of the Electromagnetic Compatibility of the system.

8.5 EMC Project File

The EMC project file is a required deliverable as per Network Rails EMC Assurance (NR/L2/RSE/30041). The EMC team will start compiling this document at GRIP stage 5. The EMC Project file shall consist of the following:

- The EMC Strategy (this document);
- The EMC Control Plan [Ref 2]. This document provides guidance and information of the process that will be required to manage the EMC on the Project.

- The EMC Hazard Log: This document will be presented as a table giving the list of all EMC hazards which may arise on the Project. For each hazard, it gives the standards to be applied and mitigation measures.
- The EMC Test Plan. If necessary, this document explains which tests and measurements have to be done in order to validate the EMC.
- The EMC Project File report itself, that will present the EMC evidence of the project and the methodology that has been implemented for that demonstration.

9 EMC Roles & Responsibilities

The following section outlines the designers & contractors' roles and responsibilities in the CSIE Project. The spoke contractors responsible for their technical discipline will ensure that their design meets the project EMC requirements.

All parties involved have a requirement to:

- Be aware of this EMC strategy and implementation plan.
- Showcase a clear understanding of how to achieve compliance with the programme and the project EMC requirements; and,
- Comply with the Programme and Project's EMC requirements

Role	Role Description
DPE	The DPE is responsible for managing EMC under delegated authority from Network Rail's Director of Engineering during alterations to the infrastructure or new build unless an alternative appointment is made and recorded.
Designer	The Designer will ensure that the EMC process is established & maintained through distribution of the EMC documentation. The Designer is responsible to appointment a Designer's EMC CRE and co-ordinate regular meetings including the HAZID.
Designer CEM	The Designer CEM will as part of the EMC assurance activities conduct meetings with the Designer's EMC CRE and the Contractors' CREs which will enable each of the contractor's designs and other stakeholder's design to be reviewed for EMC compliance.
Designer's EMC CRE	The Designer's EMC CRE shall review, record and document that the Contractors designs meet the requirements of the EMC Directive by coordination of an EMC Control Plan, EMC HAZID and EMC Test Plan.
Contractors' CEM and CREs	The CEM and CREs of each contractor will ensure that their design meets the requirements of the EMC Directive and the Project EMC strategy. Documentary evidence of compliance shall be provided to the Designer's EMC CRE in order to collate the data for EMC technical file.

Table 15. EMC Roles and Responsibilities

The Contractors retain the responsibility that their designs meet and comply with the EMC Directive through documented evidence. They shall also retain the responsibility to ensure that their designs are compatible with all interfaces, internal and external, as part of the compliance with this strategy.

Emphasis shall be placed on the compliance of Fixed Installations in a railway environment as well as that of individual apparatus to show that interaction between new and existing applications, including the rolling stock, do not result in the overall or any part of it, failing to meet the EMC requirements.

- The requirements of the Contractor's CEM and CREs is as follows.
- The installation and components of the design shall not interfere with licenced radio services.
- The installation shall operate satisfactorily in its intended environment.
- The system shall ensure that adequate test levels are specified for the installed designs in its specified environment.
- The system procurement shall be compliant with all equipment and environment CE marks and EMC tests standards.

It shall be demonstrated that the installers have installed the equipment according to the manufacturers and designers' drawings and specifications.

The Designer's CEM, Contractor's CEM, CREs and Designer's EMC CRE shall conduct regular reviews to ensure that the design being produced remains EMC Compliant. The Contractor's CEM and CRE should ensure that they have spoken and have documented communication with the Designer's EMC CRE to confirm that they have been advised on the requirements for system compatibility. The meetings shall be documented to record all actions and applications of the EMC details to the design. Where issues are identified, the EMC Hazard Logs shall be updated accordingly.

9.1 Responsibilities for EMC Deliverables

Table 16 presents the responsibilities for each of the EMC deliverables.

Role	Role Description
Designer's EMC CRE	EMC Strategy
	EMC Control Plan
	EMC HAZID and Regular review meeting coordination for EMC
	EMC HAZID Log and implementation records
	EMC Test Plan
	EMC Project File
	EMC File Report
Construction/Contractors' CEM and CREs	Contribute to EMC HAZID workshops

Role	Role Description
	Attend EMC Meetings as required by the Designer's EMC CRE Provide documentary evidence for EMC compliance (DofC, EMC Test Reports, etc.)

Table 16. EMC Deliverables responsibilities

9.2 EMC RACI Matrix

The EMC RACI Matrix is a means of representing the level of involvement and responsibility that hub and spoke shall have at different Project stages.

This matrix sums up responsibilities for all parties involved in the Project. Letters R-A-C-I are used as:

- R: Responsible. The individual(s) who perform an activity (responsible for action and implementation). Although usually only one, Responsibilities can be shared.
- A: Accountable. The individual who is ultimately accountable (including yes/no decision) and power of veto. Only one 'A' can be assigned.
- C: Consulted. The individual(s) to be consulted prior to a final decision being made or action take (two-way communication).
- I: Informed. The individual(s) who need to be informed after a decision is made or action taken (one-way communication).

The RACI Matrix for the whole Project's lifecycle is shown in is shown in Table 17 below.

RACI Details	Network Rail		Murphy / Arcadis	
R: Responsible A: Accountable C: Consulted I: Informed	RAM	DPE	Designer CEM/EMC CRE	Construction/ Contractors CEM/ CRE
GRIP 4 & 5 - EMC Design				
EMC Control Plan - Producing the document	I	A	R	C
EMC Control Plan - Defining good EMC engineering practice	I	A	R	C
Applying Good EMC Practices	C	A	C	R
EMC HAZID Workshop	I	A	R	R
EMC Generic Hazard Log	I	A	R	R
EMC Specific Hazard Log	I	A	R	R
EMC Test Plan - Defining EMC Tests	I	A	R	C
EMC Project File – Producing the outline of the EMC Project File	I	A	R	C
GRIP 6 - Construction				
Reviewing list of residual actions in EMC Hazard Log transferred from GRIP 5	I	A	R	R
Collating EMC compliance documents for inclusion within EMC Project File	I	A	R	R
Reviewing Design EMC Documentation for procurement requirements, validation tests and assessments	I	A	R	R
Acquiring relevant EMC test data	I	A	C	R
Providing EMC Test Reports for inclusion within EMC Project File	I	A	C	R
GRIP 7 & 8 - Handover				
Project Completion Certificate	R	A	C	I
Final accountability in Revenue Service	A	I	I	I

Table 17. Table of EMC RACI Matrix

10 Conclusion

The EMC strategy presented in this document provides the guidelines that shall be followed to manage the EMC for the CSIE Project, and to provide substantial evidence to the DeBO (and other accredited parties if any) before final commissioning. As required by Network Rail in the EMC Assurance Process (NR/L2/RSE/30041), the EMC strategy in this document:

- Defines the installations on Cambridge South Infrastructure Enhancement Project.
- Describes management of the different EMC activities at various GRIP stages and forthcoming steps of the Project;
- Outlies the EMC Roles and Responsibilities for each party involved in the project; and,
- Accordingly, the following deliverables from Arcadis will contribute to the Projects' global EMC process:
    - EMC Control Plan
    - EMC hazard log

The EMC Project file will then collate all documents directly related to the EMC on the CSIE project.

Page 1 of 6	Document Review Notice (DRN)					
	Form Ref	NR/L2/INI/02009/F0044	Issue Date	05/09/2015	Issue	8.0

Project Number:	158454	**Project Name:**	Cambridge South Infrastructure Enhancements		
Project Manager:	Kevin Sullivan		**Principal Contractor:**	J Murphy & Son	
Engineering Deliverable Owner:	J Murphy & Son		**CEM Name:**	James Drury	
Submission Discipline:	Multi-Discipline		**CRE Name:**	Andrew Ratcliffe	
Document Number:	158454-JMS-ZZ-ZZZ-STR-EDS-000002			**Revision No:**	1.0
Document Title:	Strategy - Cambridge South Infrastructure Enhancements (CSIE) - EMC Strategy GRIP 4			**GRIP:**	4
NR DPE Name: Steve Jones				**CSM Significant:**	Yes
Document Transmittal/Submission No:	158454-JMS-00-ZZZ-TRN-PDC-000145/001				
Date Received:	29/10/2021		**Date Return Required:**	29/11/2021	
REVIEWERS:-	**DRN No:**	158454-NRS-ZZ-ZZZ-DRN-EDS-000001 Rev 01		**DRN Date:**	16/11/2021

Name	Position	Discipline	Signature
Steve Jones	DPE	Buildings Civils - (Lead)	S.P.J
Simon Lane	PE MEP	Building Services	S.L
Alexandros Gavrilakis	SPE EMC	EMC	A.G

DISTRIBUTION LIST (of completed review):-

Name	Position	Action Required
Pierre Fayet	CRE-EMC	Response
James Drury	CEM	Response
Andrew Rartcliffe	CRE-C	Response
Niamh Leonard	Project Devemopment Manager	Information
Kevin Sullivan	Senior Programme Manager	Information

Document Details:	**PDF** ☒	**Source Data** ☐	**Two Dimensional** ☐	**Model** ☐
Number: 158454-Jms-Zz-Zzz-Str-Eds-000002	**Document Title:** Strategy - Cambridge South Infrastructure Enhancements (Csie) - Emc Strategy Grip 4			
Document URL: 158454-Jms-Zz-Zzz-Str-Eds-000002			**Revision:** A01	
DOCUMENT REVIEW:-			**Risk Review Level:**	Basic

Overall DRN Category	Rejected Non-compliant to contract	Accepted	Accepted with Amendments	Not Accepted Revise & Resubmit
2	**0**	**1**	**2**	**3**

- Acceptance of these documents by Network Rail is not be deemed as validation of the submission, nor does it infer fitness for purpose. Network Rail does not accept any liability for the submission.
- Any changes to the documents should be undertaken in accordance with change control procedures adopted by individual contracting organisations. Such variations are required to be formally recorded and evidence should accompany any resubmission.
- Without relieving the originating organisation of their contractual responsibilities my comments are as follows:
  - Overall DRN Category 0 rejected and a category 3 non acceptance requires the whole document(s) to be revised and resubmitted to address the comments. Prior to any re-work a way forward shall be agreed between supplier and the Designated Project Engineer
  - Overall DRN Category 2 acceptance with amendments requires the appropriate responses with additional information to be submitted to address the comments
  - Comment type 0 is used to capture comments if the submission is an overall DRN Category 0
  - Comment types 2A, 2B, 3A and 3B require a written response & Comment type 4 is for information only
  - Comment type 5 is used to identify an aspect of a submission which shows a 'Safe by Design' feature
- For comments types 2 or 3 a suffix is added to the comment type: **A**) Quality of Supplier's submission or **B**) Client preference/changes.

****Issued By:**	Steve Jones	**Signature:**	S.P.J	**Date:**	29/11/2021

DRN ACCEPTANCE AND/OR CLOSED OUT (including Supplier's responses)**:-**

****Closed By:**		**Signature:**		**Date:**	

Page 2 of 6	Document Review Notice (DRN)					
	Form Ref	NR/L2/INI/02009/F0044	Issue Date	05/09/2015	Issue	8.0

**Only to be signed by the Project Designated Project Engineer or person with such formally recorded delegated authority. Review comments to be returned to Supplier via control process agreed between the Project Manager and Supplier.

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*
1	4.2 – Please include within the table which version of the standards apply to this contract	SL	2A		Yes	This comment applies to both the EMC strategy and EMC Control plan. Both the EMC Strategy reference 158454-JMS-ZZ-ZZZ-STR-EPT-000003 and the EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 have been amended accordingly.	Fayet		
2	5.2.3 Table 15 – Two of the sites are listed as 'high' EMC impact, how is this addressed?	SL	2A		Yes	We understand this comment applies to the EMC Control Plan rather than the EMC Strategy (comments have been swapped between the two DRNs). We confirm those sites will need to be adressed. Both of them are owned by third-party stakeholders for which a specific approach is currently being setup, in which additional assessments will be undertaken to address those issues. Please refer to our response to comments 10 and 11 on the EMC Control Plan DRN for more details	Fayet		
3	6.4.1 – The touch and step voltages of the existing system should be assessed and verified prior to carrying out works, following good practice	SL	2A		Yes	We understand this comment applies to the EMC Control Plan rather than the EMC Strategy. This is correct, therefore we are proposing those calculations at GRIP5, i.e. once the design is more mature and still before construction starts.	Fayet		
4	9.2 – Consultations should be held with the third parties to understand the specific sensitive systems in place	SL	2A		Yes	We understand this comment applies to the EMC Control Plan rather than the EMC Strategy. Agreed. We have revised this section to insist on this aspect. The EMC Control Plan 158454-JMS-ZZ-ZZZ-PLN-EDS-000003 has been	Fayet		

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*
						amended accordingly.			
5	9.1 – Reference to Section 9, should this be Section 10?	SL	2A		Yes	We understand this comment applies to the EMC Control Plan rather than the EMC Strategy. The EMC Control Plan 158454-JMS-ZZ-ZZZ-PLN-EDS-000003 has been amended accordingly.	Fayet		
6	10.1 – Where specific risk are identified, consultation should be held with the local owners	SL	2A		Yes	We understand this comment applies to the EMC Control Plan rather than the EMC Strategy. We have added one note to section 10.1 to address this. The EMC Control Plan 158454-JMS-ZZ-ZZZ-PLN-EDS-000003 has been amended accordingly.	Fayet		
7	10.3 – Should the word ‘parament’ say parameter?	SL	2A		Yes	We understand this comment applies to the EMC Control Plan rather than the EMC Strategy. The EMC Control Plan 158454-JMS-ZZ-ZZZ-PLN-EDS-000003 has been amended accordingly.	Fayet		
8	General – Needs spelling and grammar checking	SL	2A		Yes	Both the EMC Strategy reference 158454-JMS-ZZ-ZZZ-STR-EPT-000003 and the EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 have been amended accordingly.	Fayet		
9	Section 2.4: Should the geographical scope/maps include the areas of the four-tracking too?	AG	2A		Yes	More detailed maps can be included at GRIP5 stage.	Fayet		
10	Section 5.1.2: Will any booster transformers be added/removed?	AG	4		Yes	See section 5.1.2. A couple of booster transformers are located in the area and could be removed, however, the current assumption is to keep the traction system as is it is today. The current assumption is	Fayet		

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*
						that booster transformers will not be removed.			
11	Section 5.1.6: Who will define the requirement for RSC? As it is an existing booster transformer system, is there a MSC installed?	AG	4		Yes	Presence of an MSC in the area is currently unknown, to be confirmed at GRIP5 stage. The ELSSA study will help in defining the requirement for RSC, however it is currently not in our GRIP4 scope. Note Arcadis have the simulation tool and capability to undertake immunisation studies with a level of detail that is equivalent to ELSSA if needed.	Fayet		
12	Section 5.2.2: Are the existing legacy cables compliant and will they remain as such? If not , what remedial actions are required?	AG	2A		Yes	This information is not available at this stage. It shall be adressed at GRIP5 stage during the HAZID workshops, in presence of the signalling contractor.	Fayet		
13	Section 5.3: Note that the 1.9 km length refers to classic rail return systems. FTN/HQ/ST/0001 allows 5 km for boostered areas.	AG	2A		Yes	The EMC Strategy 158454-ARC-GV-000-ZZ-STR-EPT-000003 has been amended accordingly.	Fayet		
14	Figure 3: Figure states EMC strategy at GRIP 2/3 but this is a GRIP 4 one. Add commentary for the reason of deviation.	AG	2A		Yes	An EMC strategy has been delivered at GRIP3, that has been updated at GRIP4 to better reflect the evolutions of the project. Hence, this issue would not qualify as a deviation to NR standards	Fayet		
15	Figure 4: Who will define if a harmonic resonance study is needed and at what stage? Will the HIT tool become available to the GRIP 5 designer?	AG	4		Yes	The harmonic resonance study is usually done at GRIP5. Based on our experience on recent electrification projects, our sensitivity studies have shown that the railway line's harmonic impedances car vary significantly in case booster transformers are removed, or in case new rolling stock is introduced on the line. Each railway line has got its own harmonic impedance characteristics that are variable from one project to another. We would recommend it as soon as some	Fayet		

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*
						significant changes are brought to the traction power supply system to provide additional assurance to Network Rail on the risk of harmonic resonance overvoltages. This can also be undertaken to demonstrate compliance against the DNO requirements on harmonic distortion on the extra high voltage network, especially if there are some known issues in the area. Regarding the HIT tool, all EMC findings so far will be shared with the GRIP5 designer.		

To Perform Spelling Check on the Protected Form Click Here:

* Click in the last Cell (Column) to add a new row after the selected cell or to delete the selected row

END

Proof of Evidence – Electromagnetic Compatibility (Mr Rasheed R. Hameed) Appendix 03
EMC Control Plan [158454-JMS-ZZ-ZZZ-PLN-EDS-000003]
DRN [158454-NRS-ZZ-ZZZ-DRN-EDS-000002]

(Inquiries Procedure (England & Wales) Rules 2004

January 2022

[This page is left intentionally blank]

Client	Network Rail
Project Title	Cambridge South Infrastructure Enhancements – Electromagnetic Compatibility (EMC) Control Plan (GRIP 4)
Project Number	158454
Operating Unit	M2 - CP6

REPORT

CAMBRIDGE SOUTH INFRASTRUCTURE ENHANCEMENT

EMC CONTROL PLAN

(GRIP 4)

MAIN AUTHOR	REVIEWER	APPROVER
		
Ayad Al-Khoury	**Abubakar Tariq**	**Pierre Fayet**
E&P (HV) Senior Engineer	E&P (HV) Principal Design Engineer	E&P (HV) Associate Technical Director
22/10/2021	22/10/2021	22/10/2021

ISSUE CONTROL

DOCUMENT No.	158454-JMS-ZZ-ZZZ-PLN-EDS-000003

CURRENT REVISION	CURRENT STATUS CODE	SECURITY CLASSIFICATION
A01	S3 – Suitable for Review and Comments	Public

REVISION HISTORY

REVISION	STATUS CODE	DATE	REVISION DESCRIPTION
P01	Draft Issue	14/05/2021	Draft Document
A01	First Issue	22/10/2021	First Issue

Reviewers

NAME	Position	Date Reviewed	Outcome
James Drury	CEM		

Document History

Revision	Date	Summary of Change
P01	29/09/2021	Draft document
A01	22/10/2021	First Issue

Distribution List

NAME	JOB TITLE / COMPANY
James Drury	CEM, Murphy

Contents

1 Abbreviations and Definitions 10
1.1 Abbreviations 10
1.2 Definitions 12
2 Introduction 13
2.1 Project Background 13
2.2 Purpose 14
2.3 Scope 14
2.4 Geographical Scope 15
3 Reference Documents 19
4 EMC Standards 20
4.1 Legislative Documents 20
4.2 British Standards 20
4.3 Railway EMC Standards 21
4.4 EMC Product Standards 22
4.5 Basic EMC Standards 23
4.6 Generic Environmental Standards 24
4.7 Radio Standards 24
4.8 Railway Group Standards 24
4.9 Network Rail Standards 25
5 Systems and EMC Assessment on Cambridge South Infrastructure Enhancements Project 27
5.1 EMC Control Plan 27
5.2 Third Party EMC Assessment 28
5.2.1 Third Party Sources 28
5.2.2 Radar System 32
5.2.3 Third Party Victims 33
6 Overall Assessment of the possible EMC issues on the Project 35
6.1 Electrical Rolling Stock Compatibility 35
6.1.1 Rolling Stock Harmonic Currents 35
6.1.2 Track Circuit Immunity 35
6.2 Earthing and Bonding 36
6.3 Tunnels 36
6.4 Immunisation Assessment 36
6.4.1 Touch and Step Voltages 36
6.4.2 Induction and S & T Circuits 36

6.4.3 Inductive Coupling from Feeder Cables 37
6.5 EMC for Station Equipment 37
6.6 EMC for Station Equipment 37
6.7 Radiated Emissions from GSM and GSM-R Base stations 38

7 EMC Requirements on Equipment 39
7.1 EMC Directive 39
7.2 Product Approval Process 39
7.3 Specific installation Requirements for Signalling 40
7.3.1 Selection of Track Circuits 40
7.3.2 Points Machines, Clamps Locks and Points Detection in electrified areas 40
7.3.3 Signal Trackside Cables 40
7.3.4 AWS and TPWS System 40
7.3.5 Lineside Circuits 40
7.3.6 TPWS System 41
7.4 Specific installation Requirements for Power Assts 41
7.4.1 Trackside Power Supplies and REBs 41

8 Basic EMC Rules 42
8.1 Generic Principles 42
8.2 Equipment Location 42
8.3 Equipment Enclosure Design and Layout 43
8.4 Cabling and Cable Routes 45
8.4.1 BS 7671 IET Wiring Regulations 45
8.4.2 BS IEC 61000-5-2 Earthing and Cabling 46
8.4.3 Application of the Guidance to Cambridge South Infrastructure Enhancement Project 47
8.4.4 Return Screening Conductor 47
8.4.5 Cable Separation 47
8.5 Cable Transits 50
8.6 Shielded and Armoured Cables Termination 51

9 EMC Hazards for Cambridge South Infrastructure Enhancement Project 53
9.1 EMC Interface Matrix 53
9.2 Desktop Study – Identified Areas at Risk 56

10 EMC HAZID Process 58
10.1 Introduction to the Process 58
10.2 Methodology 59
10.3 Criteria to be applied during HAZID Process 61

11 EMC Action List for next GRIP Stages 63
11.1 General GRIP Action List 63
11.2 EMC Methodology – System Design 65
Appendix A 66
EMC Hazard Log 66

Tables

Table 1 List of Abbreviations 11
Table 2: List of Definitions 12
Table 3 - Reference Documents 19
Table 4: List of Legislative Documents 20
Table 5: List of British Standards 20
Table 6: List of Railway EMC Standards 21
Table 7: List of EMC product Standards 22
Table 8: List of Basic EMC Standards 23
Table 9: List of Generic Environmental Standards 24
Table 10: List of Radio Standards 24
Table 11: List of Railway Group Standards 24
Table 12: List of Network Rail Standards 26
Table 13 - List of Nearby EMC Sources 29
Table 14 - List of Nearest Airports and Radar Systems 32
Table 15 - List of Nearby Victim Sites 34
Table 16: Table showing Enclosure Selection Based upon Frequency 43
Table 17 - Cable classification based on BS IEC 61000-5-2 for Cable Types Used on the Project. 47
Table 18 - Recommended Minimum Cable Separations for Cable Runs over 35 m in Non-Metallic Trunking 48
Table 19 - EMC Interface Matrix 55
Table 20 - Hazards and Evaluation Scale 59
Table 21 - Evaluation of EMC Hazards 60
Table 22 - Acceptance of the EMC Hazards 60
Table 23 - General EMC Action List 64
Table 24 - EMC Hazard Matrix 74

Figures

Figure 1 - Geographic View of site plan 15
Figure 2 - Close Aerial View of the Site 15
Figure 3 - Addenbrooke's bridge current South view from the CSIE Site 16
Figure 4 - Addenbrooke's bridge current East and West views from the CSIE Site 16
Figure 5 - Planned Elevation Views of the Cambridge South Infrastructure Enhancement 17
Figure 6 – Planned CSIE External View from Francis Crick Avenue 18
Figure 7 – Planned CSIE External View from Hobson's Park 18
Figure 8 - Location of Nearest overhead HV Lines 28
Figure 9 - Map Showing the Nearest Telecommunications Masts 29
Figure 10 - View of the O2 Telecom Mast 30
Figure 11 - View of the Vodafone Telecom Mast 30
Figure 12 - View of the EE (T mobile) Telecom Mast 31
Figure 13 - Aerial view showing the distance between Cambridge South New station and the two nearest airports 32
Figure 14 - Arial view showing the location of the new Cambridge South railway station 33
Figure 15 - Zoning concept in an Enclosure 44
Figure 16 - Level of mitigation required. 44
Figure 17 - Recommended Cable Management Arrangement 49
Figure 18 - Recommended Bonding of Cable Trunking 50
Figure 19 - Preferred Shielded Cable Transmission 51
Figure 20 - Examples of Peripheral Cable Screen Bonding 52
Figure 21 - Example of Pigtail Bonding 52
Figure 22 - EMC Zoning Principle as per NR/L2/RSE/30041 61
Figure 23 - Additional recommended assumption on Electromagnetic fields to be used during HAZID Process. 62
Figure 24 - Process Chart- EMC Methodology 65

1 Abbreviations and Definitions

1.1 Abbreviations

Table 1 below outlines a list of Abbreviations applicable to this document.

Abbreviations	Description
AC	Alternating Current
AFIL	Audio Frequency Induction Loop
ALARP	As Low As Reasonably Practicable
APC	Automatic Power Control
AWS	Automatic Warning System
BS	British Standard
CCTV	Closed Circuit Television
CRE	Communications Equipment Room
CIS	Customer Information Service
CSIE	Cambridge South Infrastructure Enhancement
DC	Direct Current
DeBo	Designated Body
DOO	Driver Only Operation
EHV	Extra High Voltage
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Interference
ETSI	European Telecommunications Standards Institute
EN	European norm
FDM	Frequency Division Multiplexing
FTN	Fixed Telecom Network
GRIP	Governance for Railway Investment Projects
HAZID	Hazard Identification
HV	High Voltage
iTSS	Indicative Train Service Specification
kV	kiloVolt
LV	Low Voltage
M&E	Mechanical & Electrical
Murphy	J. Murphy and Sons Limited
NR	Network Rail
OLE	Overhead Line Equipment

PA	Public Address
PCB	Printed Circuit Board
PHP	Passenger Help Point
REB	Relocatable Equipment Building
RACI	Responsible - Accountable - Consulted - Informed
R&TTE	Radio and Telecommunication Terminal Equipment
RF	Radio Frequency
S&T	Signalling and Telecom
SCADA	Supervisory Control and Data Acquisition
SSI	Solid State Interlocking
SFAIRP	So Far As Is Reasonably Practicable
TOC	Train Operating Company
TSC	Track Sectioning Cabin
TSI	Technical Specifications for Interoperability
TSS	Train Stop Sensor
VOIP	Voice Over Internet Protocol

Table 1 List of Abbreviations

1.2 Definitions

The Table below outlines the list of definitions applicable to this document.

Definitions	Meaning
Critical Systems	Systems or products that, when installed, would be safety-critical or performance-affecting.
Deviation / Variation	A departure or alternative approach from the originally specified requirement.
GRIP 3 – Option Selection & Approval in Principle	Sufficiently developed options which may be supported by survey and analysis showing ability to achieve specification, integration across disciplines, constructability and highlighting land purchases and other long lead items. This would be the stage when Approval of Single Option Selection is achieved for each affected discipline
GRIP 4 – Single Option Development	Development of the chosen single option. This is the stage when the assurance activities of the suppliers should enable Network Rail to use a risk-based assurance process.
GRIP 5 – Detailed Design	Drawings and documentation that enable the infrastructure to be constructed, tested and commissioned.
GRIP 6 – Construction, Testing and Commissioning	To enable the works to be brought into service with evidence showing correct construction, testing and commissioning records and results including details of any changes to design and outstanding works/defects
Engineering Compliance Certificate (ECC)	A compliance certificate to be produced to comply with the NR/L2/INI/02009 in the production of a Design or Construction package
Engineering Deliverables	Designs, specifications, reports, certificates, data and other information that fulfil the requirements of the Project Engineering Requirements (CRD/RRD/DRRD).
Hazard	Situation with potential to cause harm or loss
Project Engineering Requirements (CRD/RRD/DRRD)	The Project Engineering Requirements are included as part of the Sponsors Instructions (SI) and shall be updated by the sponsor whenever the Sponsors Instruction is issued (Previously known as Project Requirements Specification PRS)
Risk	Something that may happen in the future with an adverse effect on the Project
Sponsor	A Network Rail person who acts as the single point of contact between the Client and the Project or Development Manager.
Supplier	Any provider (internal or external to Network Rail) of engineering deliverables or functions.

Table 2: List of Definitions

2 Introduction

The Cambridge South Infrastructure Enhancements (CSIE) Project is a multi-disciplinary project being undertaken by Arcadis for the client, J. Murphy & Sons Limited (JMS). The aim of the CSIE Project is to develop infrastructure options to improve connectivity in the Cambridgeshire region. As outlined by Network Rail, the objective of GRIP 4 is to complete deliverables and surveys to an Approval in Principle (AiP) Design for all disciplines (including provision of agreed surveys) that will enable the project to proceed to GRIP 5 and achieve a successful decision to deliver following Full Business Case (FBC) submission. Alongside this the project needs to secure the necessary consents to proceed, namely Network Change Approval and a Transport and Works Act Order (TWAO).

2.1 Project Background

Cambridge is a successful and fast-growing city and by 2020, the Cambridge Biomedical Campus is expected to house the largest concentration of biomedical expertise in Europe. Over the next four years many new jobs are expected to be created and the Cambridge Southern Fringe will be further developed. This is expected to place significant pressures on an already close to capacity transport system. There are local and national stakeholder aspirations for a new station to the south of Cambridge in the vicinity of Addenbrooke's Hospital.

The aim of the Cambridge South Infrastructure Enhancements Project is to develop infrastructure options to improve connectivity and capacity in the Cambridgeshire region meeting rail demand forecast up to 2043. The baseline infrastructure for this work will be based on 2020.

Cambridge is served by both the East Coast Main Line (via the Shepreth Branch) and the West Anglia Main Line. Both routes offer services to and from London. In addition, the city is served by Cross Country services which provide connectivity between Stansted Airport and Birmingham as well as several intermediate locations. Thameslink services on the East Coast Main Line provide direct trains across central London to Maidstone East and Brighton via Gatwick Airport.

Early stage operational feasibility work and timetable analysis undertaken by Network Rail and train operating companies in 2017, identified the need for several interventions to accommodate long term capacity needs:

- Four-tracking of the West Anglia Main Line between Shepreth Branch Junction and the existing Cambridge Station.
- Reconstruction of the A1134 Long Road overbridge (Structure BGK/1544a) to facilitate Four-tracking.
- A new station at Cambridge South.
- Grade separation at Shepreth Branch Junction to provide for future East West Rail requirements.

2.2 Purpose

The purpose of this document is to provide guidance and information of the process that will be required to manage Electromagnetic Compatibility (EMC) for the project in accordance with the NR EMC Assurance Process reference NR/L2/RSE/30041.

This EMC control plan is identifying potential areas which could be impacted by EMC issues and provides recommendations regarding what should be done to reduce this potential impact.

This EMC Control Plan is intended to provide details of how the electromagnetic compatibility will be demonstrated for the completion of the project. Key stages of this document will cover the following points:

- The risks associated with incorrect operation of the existing or new systems by not achieving electromagnetic compatibility are identified and appropriate controls (mitigation) are implemented such that the safety requirements and operational availability of the system are not compromised. The overall risks of EMI are therefore reduced to be considered tolerable or SFAIRP.
- All EMC aspects of equipment/sub-systems/systems supplied under the contract will be addressed.
- The responsible parties are identified for each phase of the project and the key deliverables are clearly defined.
- There is documentary evidence that a controlled process has been followed to identify the EMI threats, ascertain the risk of these threats and to provide suitable and sufficient mitigation that is appropriate to the safety criticality of the system, sub-system or product.
- Equipment taken into service meets the EU Directives relating to EMC, Human Exposure and where applicable the European Radio Equipment Directive (RED) 2014/53/EC.
- All Equipment and the installation meet the relevant NR and public standards.
- The processes have been followed to ensure that the equipment is integrated into the railway in a manner that ensures continued compliance of the railway and its infrastructure to the appropriate standards.

2.3 Scope

The scope of this EMC Control Plan to applies to all existing and new Network Rail infrastructure within the limits of Cambridge South Infrastructure Enhancement project, including domestic and commercial interfaces which could be or are affected by the EMC requirements of the EMC strategy [Ref 1]. The designer (or designers) shall demonstrate that this control plan has been satisfied by detailing the design processes which have been carried out in compliance with the EMC directive. The baseline coverage for this control plan must include the following:

- Cable segregation and separation rules.
- EMC coupling considerations between infrastructures (radiated emissions, radiated immunity, conducted emissions, and conducted immunity.
- Earthing and Bonding rules.
- EMC installation good practices.
- Zoning principles.
- Risk analysis ALARP/HAZID and mitigation measures.

2.4 Geographical Scope

Figure 1 and Figure 2 show the geographic and aerial views of the proposed site.

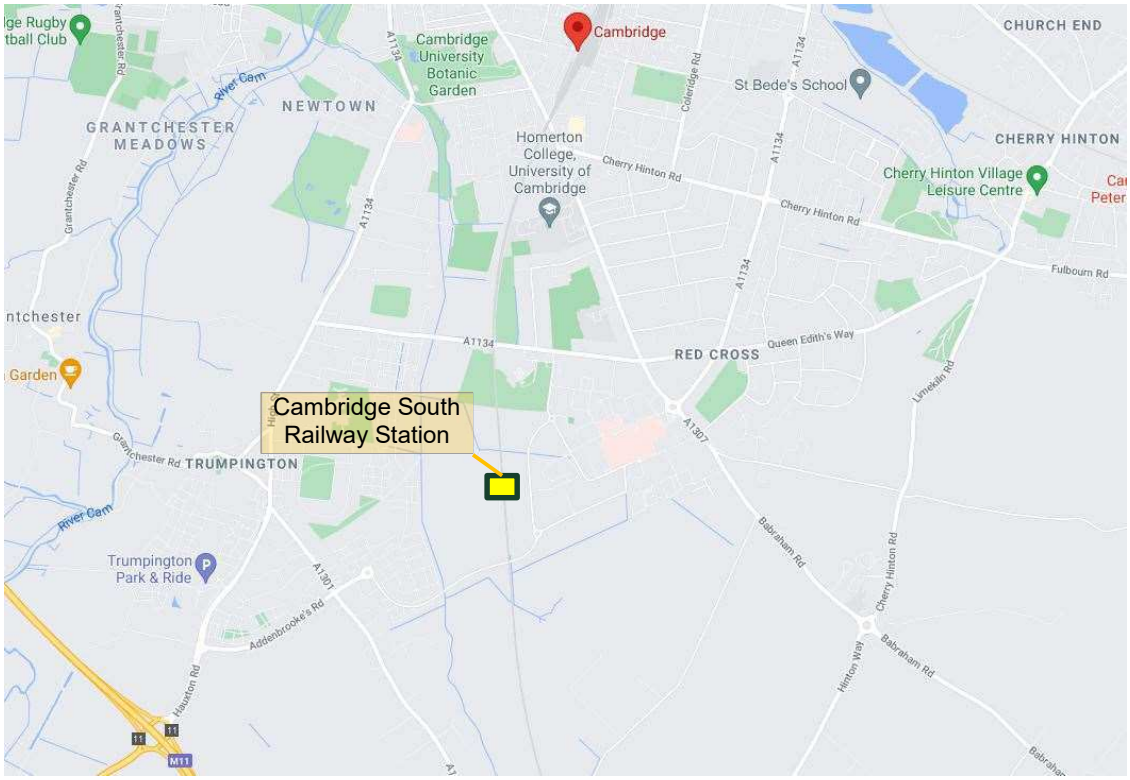


Figure 1 - Geographic View of site plan

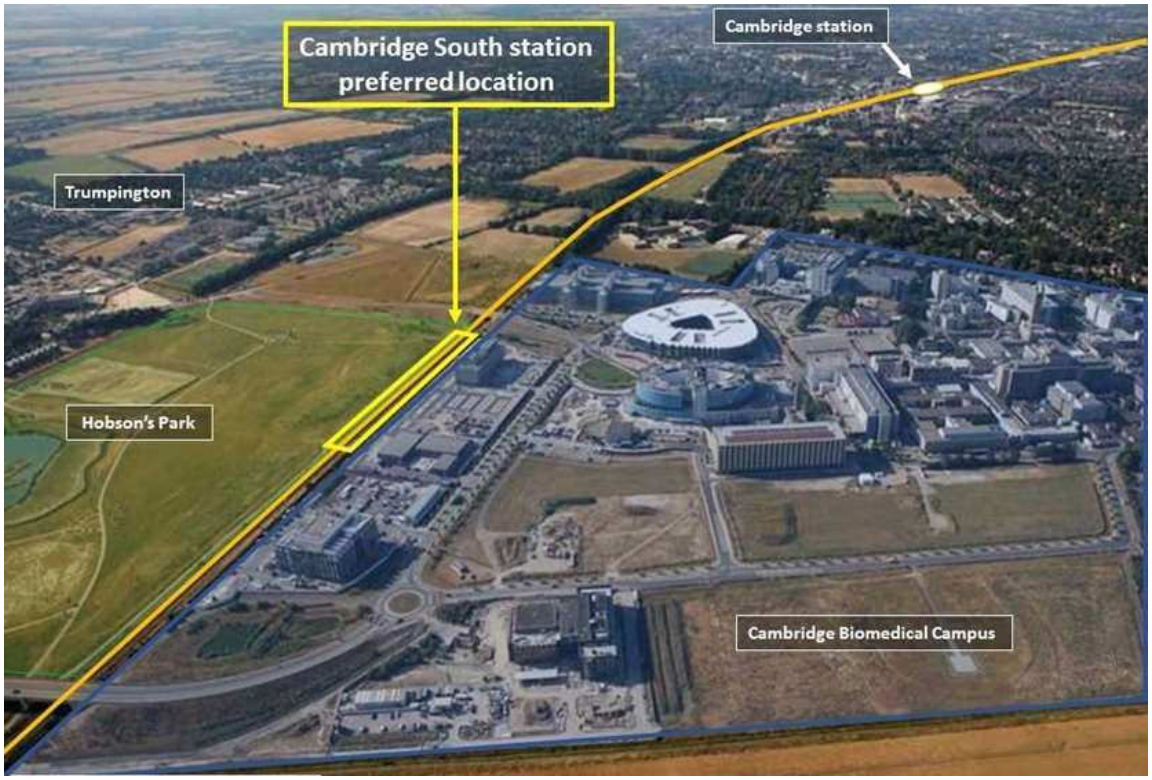


Figure 2 - Close Aerial View of the Site

Figure 3 and Figure 4 show side views of the Addenbrooke's bridge from the CSIE site.



Figure 3 - Addenbrooke's bridge current South view from the CSIE Site



Figure 4 - Addenbrooke's bridge current East and West views from the CSIE Site

Figure 5 shows planned elevation view of the CSIE railway station.



Figure 5 - Planned Elevation Views of the Cambridge South Infrastructure Enhancement

Figure 6 and Figure 7 show external views of the planned entrances to the CSIE railway station.



Figure 6 – Planned CSIE External View from Francis Crick Avenue



Figure 7 – Planned CSIE External View from Hobson's Park

3 Reference Documents

Reference	Document Number	Document Title
Ref 1	158454-JMS-ZZ-ZZZ-STR-EDS-000002	Cambridge South Infrastructure Enhancement EMC Strategy
Ref 2	158454-JMS- ZZ-ZZZ-STR-EDS-000004	Cambridge South Infrastructure Enhancement Earthing and Bonding Strategy

Table 3 - Reference Documents

4 EMC Standards

4.1 Legislative Documents

The key Statutory and legislative design documents are presented in Table 4 below.

Code	Title
2014/30/EU	European EMC Directive
2014/53/EU	European Radio and Telecommunication Terminal Equipment (R&TTE) Directive
2013/35/EU	European Directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)
SI 2016 No. 1091	The UK Electromagnetic Compatibility Regulations 2016

Table 4: List of Legislative Documents

4.2 British Standards

The key British standards are presented in Table 5 below.

Code	Title
BS 7430:2011	Code of practice for earthing
BS 7671, 18th Edition	18th Edition IET Wiring Regulations
BS 6701:2016	Telecommunication equipment and telecommunications cabling – specification for installation, operation and maintenance

Table 5: List of British Standards

4.3 Railway EMC Standards

The Standards for EMC design for railway systems are listed in Table 6 below.

Code	Title
BS EN 50121-1	Railway applications- Electromagnetic Compatibility- Part 1: General
BS EN 50121-2	Railway applications- Electromagnetic Compatibility- Part 2: Emissions of the whole railway system to the outside world
BS EN 50121-3-1	Railway applications- Electromagnetic Compatibility- Part 3-1: Rolling stock train and complete vehicle
BS EN 50121-3-2	Railway applications- Electromagnetic Compatibility- Part 3-2: Rolling stock apparatus
BS EN 50121-4	Railway applications- Electromagnetic Compatibility- Part 4: Emissions and immunity of the signalling and telecommunications apparatus
BS EN 50121-5	Railway applications- Electromagnetic Compatibility- Part 5: Emissions and immunity of fixed power supply installations and apparatus
BS EN 50122-1	Railway applications- Fixed installations- part 1: Protective provisions relating to electrical safety and earthing
BS EN 50238	Railway applications- Compatibility between rolling stock and train detection systems

Table 6: List of Railway EMC Standards

4.4 EMC Product Standards

The EMC product Standards are all listed below in Table 7 below.

Code	Title
BS EN 12015	Electromagnetic compatibility - Product family standard for lifts, escalators and moving walks - Emission
BS EN 12016	Electromagnetic compatibility - Product family standard for lifts, escalators and moving walks – Immunity
BS EN 50130-4	Alarm systems - Part 4: Electromagnetic compatibility — Product family standard: Immunity requirements for components of fire, intruder and social alarm systems
BS EN 50174-2	Information technology Cabling installation Part 2: Installation planning and practices inside buildings
BS EN 50310	Application of equipotential bonding and earthing in buildings with information technology equipment
BS EN 55015	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
BS EN 61547	Equipment for general lighting purposes — EMC immunity requirements
BS EN 55022	Information technology equipment – Radio disturbance characteristics - Limits and methods of measurement
BS EN 55024	Information technology equipment – Immunity characteristics – Limits and methods of measurement
BS EN 55103-1	Electromagnetic compatibility - Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use - Part 1: Emission
BS EN 55103-2	Electromagnetic compatibility - Product family standard for audio, video, audio-visual and entertainment lighting control apparatus for professional use - Part 2: Immunity
BS EN 60439 1	Low-voltage switchgear and control gear assemblies - Part 1: Type tested and partially type-tested assemblies.
BS EN 60947-1	Low-voltage switchgear and control gear - Part 1: General rules.
BS EN 60947-2	Low-voltage switchgear and control gear - Part 2: Circuit-breakers
BS EN 62040-2	Uninterruptible power systems (UPS) - Part 2: Electromagnetic compatibility (EMC) requirements
GT/TD INT100	Earthing and equipotential bonding of Telecommunications equipment.
BS EN 300 683	Radio Equipment and Systems (RES); Electromagnetic Compatibility (EMC) standard for Short Range Devices (SRD) operating on frequencies between 9 kHz and 25 GHz

Table 7: List of EMC product Standards

4.5 Basic EMC Standards

The basic Standards for EMC fundamentals are listed below in Table 8.

Code	Title
BS EN 61000-3-2	Electromagnetic compatibility (EMC) — Part 3-2: Limits — Limits for harmonic current emissions (equipment input current ≤16 A per phase)
BS EN 61000-3-3	Electromagnetic compatibility (EMC) — Part 3: Limits — Section 3: Limitation of voltage changes, voltage fluctuations and flicker in public low voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection
BS EN 61000-4-2	Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrostatic discharge immunity test
BS EN 61000-4-3	Electromagnetic Compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radiofrequency, electromagnetic field immunity test
BS EN 61000-4-4:1995	Electromagnetic compatibility (EMC). Testing and measurement techniques. Electrical fast transient/burst immunity test. Basic EMC publication
BS EN 61000-4-5:1995	Electromagnetic compatibility (EMC). Testing and measurement techniques. Surge immunity test
BS EN 61000-4-6:1996	Electromagnetic compatibility (EMC). Testing and measurement techniques. Immunity to conducted disturbances, induced by radiofrequency fields
BS EN 61000-4-8	Electromagnetic Compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test
BS EN 61000-4-9:1994	Electromagnetic compatibility (EMC). Testing and measurement techniques. Pulse magnetic field immunity test. Basic EMC publication
BS EN 61000-4-11	Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques — Voltage dips, short interruptions and voltage variations immunity tests
BS EN 61000-4-12	Electromagnetic Compatibility (EMC) – Part 4-12: Testing and measurement techniques – Oscillatory waves immunity test
BS EN 61000-4-16	Electromagnetic compatibility (EMC) - Part 4-16: Testing and measurement techniques — Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz
BS IEC 61000-5-2	Electromagnetic Compatibility (EMC) – Part 5: Installation and mitigation guidelines Section 2: Earthing and Cabling

Table 8: List of Basic EMC Standards

4.6 Generic Environmental Standards

The Standards for different environments are listed below in Table 9.

Code	Title
BS EN 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments
BS EN 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
BS EN 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
BS EN 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments

Table 9: List of Generic Environmental Standards

4.7 Radio Standards

The EMC Standards for radio spectrum matters are listed below in Table 10.

Code	Title
ETSI EN 300 279	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for Private land Mobile Radio (PMR) and ancillary equipment (speech and/or non-speech)
ETSI EN 300 339	Electromagnetic compatibility and Radio spectrum Matters (ERM); General Electromagnetic Compatibility (EMC) for radio communications equipment
ETSI EN 300 386-2	Electromagnetic compatibility and Radio spectrum Matters (ERM); Telecommunication network equipment;
ETSI EN 301 489	Series of EMC standards applicable to Article 3.1 of the EU Radio Equipment Directive

Table 10: List of Radio Standards

4.8 Railway Group Standards

The Railway Group Standards for EMC deign are scheduled in below in Table 11.

Code	Title
GE/RT8015	Electromagnetic Compatibility between Railway Infrastructure and Trains
GE/RT8217	Introduction and Use of Axle Counters. Managing the Risk 1
GE/RT8270	Route Acceptance of Rail Vehicles including changes in Operation or Infrastructure.
GK/RT0217	Technical Requirements for Axle Counters

Table 11: List of Railway Group Standards

4.9 Network Rail Standards

The Network Rail Company Standards for EMC design are listed below in Table 12.

Code	Issue	Title
NR/L1/RSE/30040	Issue 69	EMC Strategy for Network Rail
NR/L2/RSE/30041	Issue 2; June 12	Electromagnetic Compatibility (EMC) Assurance Process
RT/E/PS/00009	Issue 1; May 01	Message Handling & Data Transmission Requirements between Processor Based Systems
NR/L2/ELP/23003	Issue 1; Mar 20	Technical Requirements for Transformers, Rectifiers, and
NR/SP/SIG/50002	Issue 2; Feb 07	Methodology for the Demonstration of Compatibility with Single Rail Reed Track Circuits on the AC Railway
RT/E/C/50005	Issue 1; Feb 03	Methodology for the Demonstration of Compatibility with 50 Hertz Single Rail Track Circuits
NR/SP/SIG/50006	Issue 1; Apr 06	Methodology for the Demonstration of Compatibility with 50 Hz Double Rail Track Circuits
NR RT/E/C/50007	Issue 1; Feb 03	Methodology for the Demonstration of Compatibility with HVI Track Circuits
NR/RT/E/C/50008	Issue 1; Feb 03	Methodology for the Demonstration of Interaction with Neighbouring Railways
NR/GN/SIG/50011	Issue 2; Mar 20	Methodology for the Demonstration of Compatibility with Axle Counters
NR/SP/SIG/50012	Issue 2; Apr 06	Methodology for the Demonstration of Compatibility with TPWS Trackside Equipment
NR/GN/SIG/50013	Issue 2; Sep 19	Methodology for the Demonstration of Compatibility with Route Relay and Solid State Interlockings
NR/GN/SIG/50014	Issue 2; Aug 08	Methodology for the Demonstration of Compatibility with Lineside Equipment
NR/GN/SIG/50015	Issue 3; Sep 20	Methodology for the Demonstration of Compatibility with Reed FDM Systems on the AC and DC Railways
NR/SP/TEL/50016	Issue 3; Apr 06	Methodology for the demonstration of compatibility with Telecoms Systems
RT/E/C/50018	Issue 1; Feb 03	Methodology for the Demonstration of Interaction with Neighboring Railways
NR/GN/TEL/31106	Issue 1; Jun 09	Overview of Electromagnetic Coupling Between Traction Systems and Telecommunications Cables

NR/L2/TEL/31107	Issue 2; Mar 10	Limits and test method of induced voltages on telecommunications cables due to electrification systems
NR/L2/TEL/30028	Issue 3; Mar 10	Installation of Operational Telecommunications Equipment
NR/L2/ELP/21085	Issue 4; Jun 20	Earthing and Bonding on AC electrified railways
NR/L2/RSE/02009	Issue 7; Mar 21	Engineering Management for Projects
NR/SP/ELP/27224	Issue 7; Mar 21	Specification for installation of cable routes forming part of the traction distribution system

Table 12: List of Network Rail Standards

5 Systems and EMC Assessment on Cambridge South Infrastructure Enhancements Project

5.1 EMC Control Plan

This EMC Control Plan Covers the following:

- The changes and provision of 25 kV OLE over the area to be electrified;
- The changes to the existing DNOs or the provision of new DNOs if necessary;
- The impact on Signalling equipment;
- The impact on Telecom equipment;
- The impact on Stations' equipment;
- The impact on Rolling Stock;
- The impact on External third parties;
- The impact on members of public (Passengers and neighbours);
- The impact on members of Staff.

The list below provides more details on the equipment to be considered in an EMC assessment for an AC-electrified railway line.

- **Overhead Line Equipment:** HV Substations and Feeder Stations, 25 kV overhead lines and Track Sectioning Cabins TSC, Neutral sections;
- **Electrification and Plant:** Points Heating, Signalling Power, OLE Motorised Switches and Fixed Earthing Devices, M&E services including lighting and low voltage power systems and associated containments, cable routing and separations to avoid potential EMI issues;
- **Telecommunication:** Multi-Protocol Label Switcher (MPLS), VoIP Telephones, HMI Interface and station assets such as CIS, AFIL, PA, Security CCTV, DOO Equipment, Help Points. Lineside SCADA, GSM-R/FTN Masts and Equipment, lineside phones;
- **Signalling:** Signalling Control Centre, Relay Rooms and REBs, Signals, Points Machines, Level Crossing Equipment and CCTV, Track Circuits, TSS (TPWS) and AWS Suppressors;
- **Rolling Stock:** Considerations are given to classes of rolling stock to operate on the line and compatibility with the other systems.

It is currently assumed that the existing 25 kV booster traction power supply system will be retained on the project, however some significant changes will be brought to the OLE system around the CSIE with more tracks added, hence, a specific EMC assessment is needed on this project. This project can be considered as a major improvement project that includes some sensitive sites (pharmaceutical laboratories) that are planned to be developed at proximity.

5.2 Third Party EMC Assessment

An EMC assessment of third-party sources and victims has been undertaken. The key findings from that assessment are detailed in the following section.

5.2.1 Third Party Sources

This subsection covers the third-party sources (HV overhead lines, TV transmitters and mobile masts).

5.2.1.1 HV Overhead Lines

Figure **8** shows the location of the nearest overhead HV lines to CSIE. There are a number of 11 kV and 33 kV lines that could interfere mostly by inductive coupling mechanism, however, these are located at a distance of more than 3 km as shown below. Therefore, the risk of interference from those lines to the railway system can be considered as low and this risk can be closed.

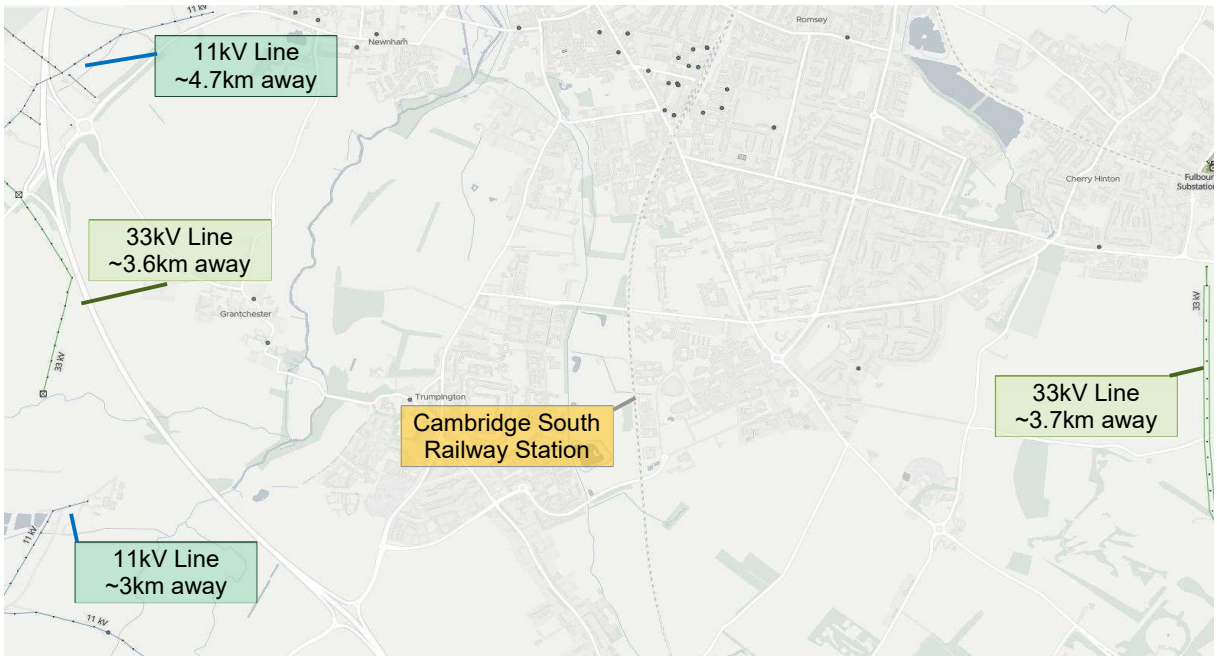


Figure 8 - Location of Nearest overhead HV Lines

Based on the map above, it is therefore assumed that the other 11 and 33 kV lines around the station area are buried lines, that are unlikely to cause interference issues towards the railways nor to be disturbed by the railway when compared to overhead lines of equivalent ratings. Hence, the risk of electromagnetic interference from and towards third-party overhead HV lines is deemed quite low and this risk can be fully closed.

5.2.1.2 Telecommunications Masts

Figure **9** shows the locations of the nearest telecommunications masts (marked in red circles) to the station (marked in orange).

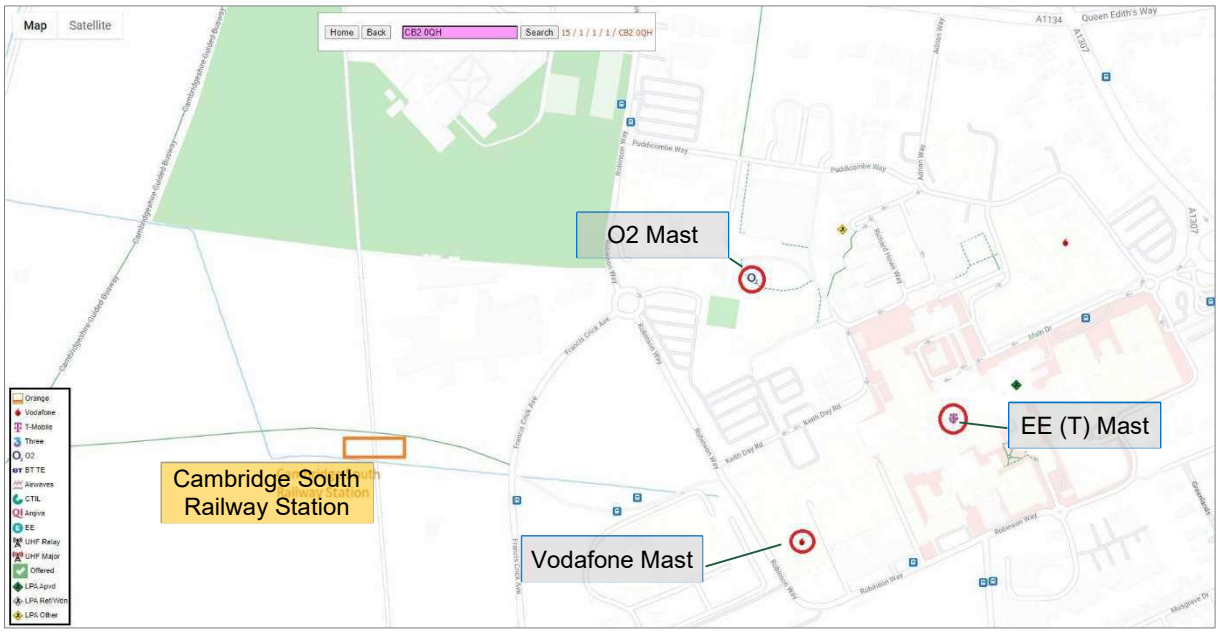


Figure 9 - Map Showing the Nearest Telecommunications Masts

Table 13 details these telecommunication masts.

Site Name	Distance [m]	EMC Impact
O2 Mast	370	Moderate
Vodafone Mast	420	Moderate
T (EE) Mobile	600	Low

Table 13 - List of Nearby EMC Sources

As these masts are over 100 m away from the CSIE site, they are unlikely to cause any EMC issues, however a specific calculation of the electromagnetic fields generated by those antennas, and any new antennas in the area shall be undertaken at the next design stage. The results shall be assessed against the criteria from BS EN 50121-4. If compliant, the risks related to the antennas can be closed.

Figure 10 shows a view of the O2 mast.



Figure 10 - View of the O2 Telecom Mast

Figure 11 shows a view of the Vodafone mast.



Figure 11 - View of the Vodafone Telecom Mast

Figure 12 shows a view of the EE (T) mast.



Figure 12 - View of the EE (T mobile) Telecom Mast

5.2.2 Radar System

Our desktop survey shows that the nearest possible airports and radar systems to Cambridge South station are Cambridge airport (~3.65 km) and London Stanstead Airport (~32.2 km). These are shown in Figure **13** and listed in Table 14 below. Due to the distance, these airports should not be impacted by the proposed changes at CSIE.

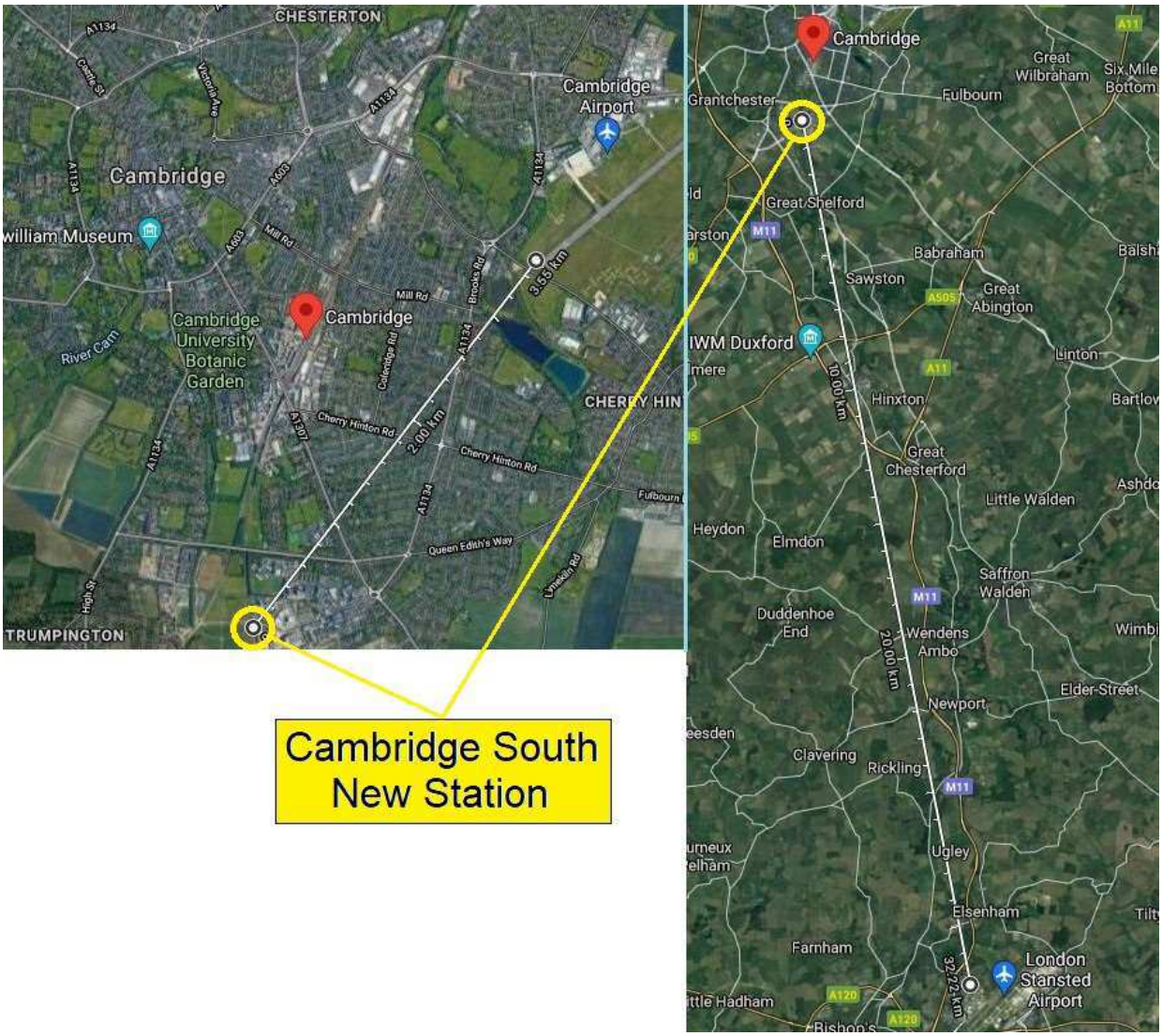


Figure 13 - Aerial view showing the distance between Cambridge South New station and the two nearest airports

Site Name	Distance	EMC Impact
Cambridge Airport	3.55 km (2.2 miles)	Moderate
Stanstead Airport	32.2 km (20 miles)	Low

Table 14 - List of Nearest Airports and Radar Systems

5.2.3 Third Party Victims

Figure 14 and Table 15 show the details of the third-party buildings and plans located in the vicinity of CSIE project and the associated distances from the railway.



Figure 14 - Arial view showing the location of the new Cambridge South railway station

A preliminary assessment of the expected EMC impact is also provided Table 15.

Site Name	Nature of risk	Distance [m]	EMC Impact
Narrow bridge	No particular risk, except if the bridge accommodates sensitive equipment (e.g., but not limited to, CCTV cameras)	25	Moderate
MRC Laboratory of Molecular Biology	Risk of disturbances from the railway on sensitive laboratory equipment.	25	High
Astra Zeneca	Risk of disturbances from the railway on sensitive laboratory equipment.	35	High
Royal Papworth Hospital	Risk of disturbances from the railway on sensitive laboratory equipment.	90	Moderate
Cambridge Biomedical Campus	Risk of disturbances from the railway on sensitive laboratory equipment.	250	Low
Cambridgeshire Guided Busway	Risk of disturbances from the railway on sensitive laboratory equipment.	335	Low
Long Road Sixth Form College	Risk of disturbances from the railway on sensitive laboratory equipment.	350	Low
Cancer Research UL Cambridge Institute	Risk of disturbances from the railway on sensitive laboratory equipment.	360	Low
Rosie Hospital	Risk of disturbances from the railway on sensitive laboratory equipment.	400	Low
Cambridge Academy for Science and Technology	Risk of disturbances from the railway on sensitive laboratory equipment.	450	Low
Trumpington Community College	Risk of disturbances from the railway on sensitive laboratory / educational equipment.	520	Low
Addenbrooke's Hospital	Risk of disturbances from the railway on sensitive laboratory equipment.	540	Low

Table 15 - List of Nearby Victim Sites

6 Overall Assessment of the possible EMC issues on the Project

The following sections focus on the specific EMC issues which may occur on the project. Its aims at defining possible EMC issues which need to be assessed in the preparation of the hazard identification process detailed in Section 9.

6.1 Electrical Rolling Stock Compatibility

The rolling stock currently planned to provide passenger services for Cambridge South Infrastructure Enhancement project are, as per the current iTSS timetable:

- Class 387
- Class 700
- Class 720
- Class 755

These types of rolling stock are already running on the route and no new rolling stock is to be introduced as a part of Cambridge South Infrastructure Enhancement project.

6.1.1 Rolling Stock Harmonic Currents

The rolling stock produce harmonic currents in the traction system, which may have the following potential adverse effects:

- Interference with the normal operation of track circuits. A compatibility assessment shall be required at GRIP 5, between the rolling stock and track circuits.
- If the harmonic currents are at, or near, the infrastructure resonance frequencies then severe harmonics distortion would result.

A specific compatibility assessment (Harmonic Resonance Study) is therefore recommended to be undertaken at GRIP5 design stage to determine if resonance is expected to materialize and to assess the consequent adverse effects if any.

6.1.2 Track Circuit Immunity

It is currently assumed that no new types of rolling stock will be introduced in the area of interest, therefore, no major impact is expected on track circuits. In case some new types of rolling stock would be introduced in the future, then, the electromagnetic compatibility between the new types of Rolling Stock and the Track Circuits in the Cambridge South area shall be assessed at the next GRIP design stages to ensure that the performance of the trains' detection systems will not be altered by the new trains; which can either lead to some interruptions of service (Right Side Failure) or fatalities in case some track circuits report wrong indications (Wrong Side Failure).

Compatibility against APC Magnets (if any) shall also be assessed.

Note it is the responsibility of the TOCs to demonstrate compliance of their rolling stock.

6.2 Earthing and Bonding

All recommendations and requirements stated in the Project's Earthing and Bonding Strategy [**Ref 2**] shall be implemented.

The recommendations made within NR/L2/ELP/20185 shall apply, with connection of signalling equipment to the Return Screening Conductor.

6.3 Tunnels

Not applicable for this project.

6.4 Immunisation Assessment

At the time of writing, it is currently assumed that the main characteristics of the traction power supply system will remain identical to the ones of the existing system (6 kA) short circuit current, booster transformer traction power supply system. However, an immunisation assessment ("ELSSA-Equivalent" study) is highly recommended due to the additional tracks in the station area and the proximity of medical / pharmaceutical laboratories nearby.

The aim is to produce sufficient EMC evidence that will enable Network Rail to demonstrate that a satisfactory EMC process has been instigated and that all aspects of EMC have been addressed, including the immunisation aspects.

6.4.1 Touch and Step Voltages

It is currently assumed that the existing traction power supply system is already compliant with respect to touch and step voltages under normal and fault conditions within the route boundaries against the safety limits defined in EN 50122-1. The proposed changes in the new station area are currently deemed unlikely to make it non-compliant, however a more comprehensive demonstration is recommended and should be undertaken at GRIP5 design stage, based on specific simulations.

Controlling the touch voltages also limits the EMC risks to LV systems by minimising the effects of uncontrolled currents through systems under fault or normal operational conditions.

6.4.2 Induction and S & T Circuits

Inductive coupling between the AC traction supply and lineside S&T cables produce longitudinal voltages and harmonics which can either exceed the immunity level of the terminating equipment (transverse voltages) or exceed the safe limits of touch voltage (longitudinal voltages) specified in EN 50122-1. Signalling and Telecoms lineside circuits should be assessed in a specific immunisation study to be undertaken as soon as the design is mature enough to enable an accurate modelling of the system. It is currently assumed that the existing traction power supply system is already compliant with respect to the transverse voltages and longitudinal voltages. The proposed changes in the new station area are currently deemed unlikely to make it non-compliant, however a more comprehensive demonstration is recommended and should be undertaken at GRIP5 design stage, based on specific simulations.

V_L/V_T testing is recommended on this project to verify compliance with EN 50122-1 and to provide evidence for the EMC Project file. It is a recommended good practice to undertake those tests on the existing system

prior to the changes to get a record of the existing V_L/V_T and enable an assessment of the changes in the future that is based on a reference situation.

6.4.3 Inductive Coupling from Feeder Cables

To better manage the risk for inductive coupling from HV cables to SCADA telecoms or S&T cables, the following rules shall be applied to the design at GRIP 4 in accordance with the separation requirements instructed in Letter of Instruction NR/BS/LI/217:

- Where possible, power cable troughs shall be placed on the side of the track opposite to S&T troughs;
- If not possible, a minimum separation distance of 1m shall be maintained between HV and S&T troughs;
- Troughs containing traction power cables running parallel to S&T troughs (including SCADA pilot cables) may be laid at a distance less than 1 m under condition the length of parallelism does not exceed a maximum of 200 m;
- A specific assessment (induced voltages calculations) shall be undertaken if none of the conditions above can be met to ensure that the EMC of the terminating equipment will not be adversely affected. As a last resort, some Electromagnetic shielding materials can be used as a separator between the source and victim cables to reduce the mutual coupling effects.

6.5 EMC for Station Equipment

All new equipment procured for use within the boundaries of the railway shall be procured with consideration to EMC standard framework presented in Appendix D of NR/L2/RSE/30041. EMC Zoning principles shall be applied.

Where equipment is not compliant with the above requirements, a gap analysis shall be carried out as described in NR/L2/RSE/30041, with appropriate technical reasoning for suitability of equipment and/or mitigation measures required to make the equipment suitable.

6.6 EMC for Station Equipment

Many stations systems and services are unlikely to be influenced or suffer from interference due to direct coupling from the Traction Power Supply System.

The most sensitive systems to inductive coupling are Audio Frequency Induction Loop Systems (AFILS). These are usually utilised by passenger help points, ticket offices and in some passenger waiting areas.

EN 60118-4, ‘Magnetic field strength in audio induction loops for hearing aid purposes’ defines the tolerance levels for background magnetic fields to ensure adequate functionality of the induction loop system. From the standard, the magnetic fields can be derived from the tolerance Signal to Noise Ratio:

$$SNR = \frac{Reference\ magnetic\ field\ strength\ level}{A-weighted\ magnetic\ background\ noise\ level}$$

The reference magnetic field strength level defined within the standard is 400 mA/m. EN 60118-4 defines a SNR of 32 dB, beyond which remedial measures will be required. This equates to a maximum magnetic field background noise level of 0.01 A/m or 0.0126 µT. However, the document also indicates that if the noise is mostly low frequency (i.e. harmonics of a power supply) then the SNR can be as low as 22 dB. This would

equate to a maximum background magnetic field strength of 0.034 A/m or 0.036 µT. These figures are broadly consistent with those within Table 1 of BS 7594-2011, where a 22 dB SNR is allowable for short periods.

GM/RC/1500 states that peak magnetic fields have been measured within the UK railway environment up to 20 A/m at 10 m from the centre of the nearest track. More typical levels would be in the region of 0.5 to 7 A/m at 2 m from the edge of the platform where the closest AFILS is likely to be located. Therefore, where AFILS are located within 10 m of the track, it is likely that they will suffer from periodic interference, particularly when trains are pulling into (due to regenerative braking) or out of the station platforms.

6.7 Radiated Emissions from GSM and GSM-R Base stations

In case some GSM or GSM-R Base stations are located in close vicinity to the track, a specific calculation is recommended to be undertaken to check that the level of Radiated Emissions from the GSM-R stations meet the standard requirements set out in BS EN 50121-4.

This calculation can be done using usual empiric formulas for electric fields. Useful input information data about the existing third-party GSM antennas is available on Mastdata.com. A desktop survey shall be undertaken to define the areas at risk at the next GRIP design stages, once the design will be more mature.

In case of a deviation to the standard's requirements, Network Rail shall be kept informed of such deviations to liaise with the owners of the assets to find a mitigation to these issues.

It is recommended that the results of the calculations for radiated emissions are included within the Project's documentation, either as an appendix to this EMC Control Plan, or directly as a standalone document within the Project's EMC file to keep a traceability of the work that has been undertaken and enable producing appropriate evidence in case of an audit by a DeBo or any other Third Party.

7 EMC Requirements on Equipment

7.1 EMC Directive

Electromagnetic Compatibility (EMC) applies to all electrical and electronic devices, equipment, systems and installations containing active components that may produce electromagnetic emissions or may be sensitive to electromagnetic disturbances.

The statutory requirement is to demonstrate compliance with the new EMC Directive 2014/30/EU which is implemented in the United Kingdom from 20th April 2016 in accordance with the statutory instrument SI 2006/3418.

The essential requirements state that equipment shall be designed and manufactured, having regard to the state-of-the-art rules, to ensure that:

- The electromagnetic disturbance generated does not exceed the level above which radio and telecommunication equipment or other equipment cannot operate as intended (Emissions).
- Equipment has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use (Immunity).

A fixed installation shall be installed applying good engineering practices (see section below) and respecting the information on the intended use of its components, with a review to meet all applicable EMC requirements. Those good engineering practices shall be documented, and the documentation shall be held by the person(s) responsible at the disposal of the relevant national authorities for inspection purposes for as long as the System will be in operation.

The railway systems of Cambridge South Infrastructure Enhancement Project are considered as fixed installations as per the European EMC Directive (2014/30/EU) and the UK EMC Regulations (SI 2006/3418) and as such, the essential requirements of this legislation as stated above must be fulfilled.

To demonstrate EMC compliance, all parties involved on the project shall bring a specific care to the definition, selection, procurement and installation of equipment and systems and more generally to the design of the sites and adjoining systems with respect to equipment location and cable routing. The process and design guidelines for this are detailed further in this EMC Control Plan and in the Cambridge South Infrastructure Enhancements EMC Strategy [**Ref 1**].

7.2 Product Approval Process

Items of equipment to be installed on Cambridge South Infrastructure Enhancement project which would require to be product-approved shall have relevant documentary evidence to demonstrate compliance with the approval process defined by the NR standard NR/L2/RSE/100/05.

Globally, the process proposed by NR/L2/RSE/100/05 focuses on safety-related items of equipment and describes the process to be followed for approval.

The design which is currently proposed for Cambridge South Infrastructure Enhancement project does not include any items of equipment that are not already proven and as such, no additional Product Approval Process is expected to be undertaken as part of this Project.

7.3 Specific installation Requirements for Signalling

Reference should be made to the Signalling Immunisation and Compatibility Specification which will be done by others as it defines the scope of the signalling works required to be taken forward to GRIP 5 and beyond. It shall specifically detail all signalling immunisation and configuration works that are necessary to support the Cambridge South Infrastructure Enhancements Project.

Particular care shall be given to signalling equipment susceptible to EMI; such as points machines/detection, track circuits and relays, signal heads, point machines, AWS, TPWS, solid state interlocking data links, FDM/TDM/CCTV transmission systems and location cases to ensure immunity levels are acceptable.

7.3.1 Selection of Track Circuits

In accordance with NR/L2/SIG/11201 – Mod B5, NR/L2/SIG/30081, NR/SP/SIG/11752, NR/PS/SIG/11755 are summarised below:

Where track circuits are replaced, they shall be selected in such a way that they are immune to both the electrification system and rolling stock operating in the area of interest.

Any modifications to the existing track circuit arrangements shall also be validated against electrification system and Rolling Stock changes.

7.3.2 Points Machines, Clamps Locks and Points Detection in electrified areas

In accordance with NR/L2/SIG/11201, DC circuits to points machines and clamp locks should be restricted to less than 200 m to achieve EMC compliance.

Point detection system shall be fed by means of a 50 V DC supply and use AC immune relays.

7.3.3 Signal Trackside Cables

In accordance with NR/L2/SIG/11201 and SSI8500D, it is preferred that trackside signalling cables and signal head circuits do not exceed 200 m in length although longer lengths can be allowed, pending upon the results of a specific assessment.

7.3.4 AWS and TPWS System

In accordance with GE/RT8035 and NR/SP/SIG/10133, AWS magnets shall not be collocated with APC magnets due to the risk of interference.

Cables running to and from the TPWS equipment shall in general be limited to 200 m but shall under no circumstances exceed the limits given in Table 5 of NR/SP/SIG/10133. Additionally, where a TPWS unit incorporates a failure indication unit an internal repeat relay shall be fitted.

7.3.5 Lineside Circuits

In accordance with NR/L2/SIG/11201 and SSI8503, lineside circuits shall not exceed 2 km. Where longer lengths are applied these shall be subject to a documented risk assessment.

The relay line circuits shall employ 50V DC, AC-immune relays.

7.3.6 TPWS System

Cables running to and from the TPWS equipment shall in general be limited to 200 m parallel running with the overhead line system but shall under no circumstances exceed the limits given in Table 5 of NR/SP/SIG/10133.

Additionally, where a TPWS unit incorporates a failure indication unit an internal repeat relay shall be fitted.

7.4 Specific installation Requirements for Power Assts

7.4.1 Trackside Power Supplies and REBs

In accordance with NR/L2/SIG/11201, REBs & Signalling and telecommunications power supplies shall be designed to avoid bringing conducted and radiated disturbances to the sub-system they feed.

8 Basic EMC Rules

The following sections provide details of the basic rules and recommended best practices approach for producing an acceptable EMC design.

The correct implementation of these rules shall be checked during any design review across the Project's Lifecycle.

8.1 Generic Principles

Confirmation of compliance with the requirements will be sought from the respective CRE's responsible for installing new assets on the railway.

It should be noted that failure to follow the guidelines in the following sections, up to and including section 8.6 will not necessarily result in an unreliable railway under normal conditions but under some circumstances a lack of availability or safety incidents may occur. Hence, our recommendation is to apply the guidelines hereafter to improve the robustness of the Railway System.

Installation principles for achieving electromagnetic compatibility within the EMC zones defined in Network Rail standard reference NR/L2/RSE/30041 between systems and equipment can be found in the following standards:

- BS IEC 61000-5-2 - EMC - Part 5 Installation and mitigation guidelines, Section 2 – Earthing and cabling.
- BS EN 50174-2:2001 – Information technology Cabling Installation Part 2: Installation planning and practices inside buildings.
- BS EN 50310:2006 - Application of equipotential bonding and earthing in buildings with information technology equipment.
- BS 7671 - IET Wiring Regulations; and,
- BS 6701 - Telecommunications equipment and telecommunications cabling – Specification for installation, operation and maintenance.

Additionally, compatible NR standards also provide instructions where specific identified issues exist to ensure that the given systems being integrated operate in a safe and reliable manner. Examples include installation standards for track circuits, signalling and telecoms. Where specific requirements exist in these standards, they shall take precedence.

The following subsections detail the principles that should be applied to ensure electromagnetic compatibility in the Rail environment.

8.2 Equipment Location

Careful arrangement of equipment is critical to meet the Project's EMC requirements. This not only relates to products inside equipment cases but also between large distributed systems that form parts of the railway.

In general, where space permits, the overall design should ensure that significant sources of interference are located as far away as practical from sensitive equipment. Where this is not possible, additional design measures should be taken to reduce the levels of interference experienced by the victim systems.

Interferences can couple by the following mechanisms:

- Conducted Interference: Conducted Interference is transmitted via a galvanic connection between two or more systems for instance via a shared power source, common signal connection or ground connection. The interference may be continuous in the form of harmonic and/or radio frequency conducted noise or discontinuous due to transient events and surges on the supply.
- Inductive coupling: Inductive Coupling is due to currents flowing in a cable or current return path, resulting in an induced voltage on a victim cable. The level of the induced voltage is proportional to the exposure length and current flowing in the conductor, and inversely proportional to the separation distance between the conductors. Induction may also occur when systems are placed near wound components such as transformers and inductors.
- Capacitive coupling: Capacitive coupling occurs due to the voltage gradient (potential difference) between a source cable and the victim cable. This form of interference only manifests itself where high voltages are used.
- Radiated interference: Radiated interference may be generated by a number of sources including:
  - Radio Transmitters.
  - Cables attached to systems acting as antennas at high frequency.
  - Direct radiation from tracks on PCBs; and,
  - Transient and discontinuous events including lightning and/or arcing due to disconnection of a system from its power source e.g. pantograph bounce, operation of switch gear etc.

Thus, EMC can be achieved by considering all the above, with respect to the installation and determining ay necessary mitigation to prevent interference.

8.3 Equipment Enclosure Design and Layout

In addition to providing environmental protection, metallic enclosures also provide shielding from electromagnetic interferences. To ensure the enclosure provides good shielding, it is important to minimise the number and size of apertures in the metal. The following rules should therefore be applied:

- Hole sizes should be kept to the minimum that still permits entry of the cables into the enclosure as the shielding effectiveness of any enclosure degrades with increasing aperture size.
- For Sensitive Equipment, the use of specifically designed shielded enclosures is recommended. Shielded enclosures normally incorporate conductive finger strips or gaskets along door edges to form as near as possible a solid conductive enclosure. Their use however should be limited as they are expensive and not suitable for installation outside without additional environmental protection. In addition, periodic maintenance is also requested.
- Where cooling vents are required, the use of metallic mesh grilles that are electrically connected to the rest of the enclosure via a low impedance connection is recommended.

Field Characteristic	Frequency Range	Necessary Material Properties	Results
Electric field	DC to 100 MHz	High conductivity	Effective attenuation up to high frequencies
LF magnetic field	DC to 100 Hz	High permeability significant material thickness	No significant skin effect usable; effective attenuation only by flux guidance in combination with sufficient material thickness
MF and RF magnetic field	100 Hz to 100 MHz	High conductivity and permeability at lower frequencies reduction of thickness with increasing frequency	Skin effect becomes effective with higher frequencies more effective attenuation at higher frequencies
Plane electromagnetic wave	Beginning from 100 MHz	High conductivity cubicle dimensions and discontinuities become important	No further improvement of attenuation holes, slots and surface resonances reduce shielding effectiveness

Table 16: Table showing Enclosure Selection Based upon Frequency

Planning the layout of equipment inside an enclosure is critical to achieving EMC and best practice normally recommends the use of a “zoning concept.” This identifies where significant sources of interference such as power supplies or motor drive circuits are segregated from other more sensitive systems like transducers and low-level signal lines. The zoning concept is shown graphically in **Figure 15** and **Figure 16**.

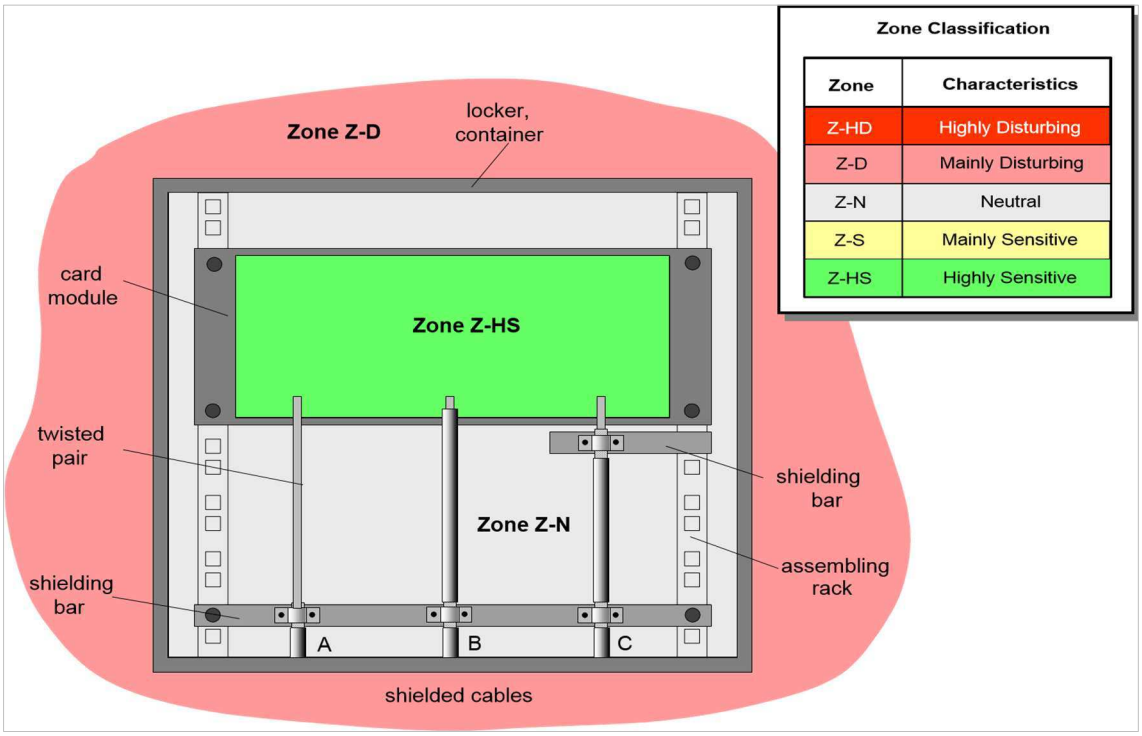


Figure 15 - Zoning concept in an Enclosure

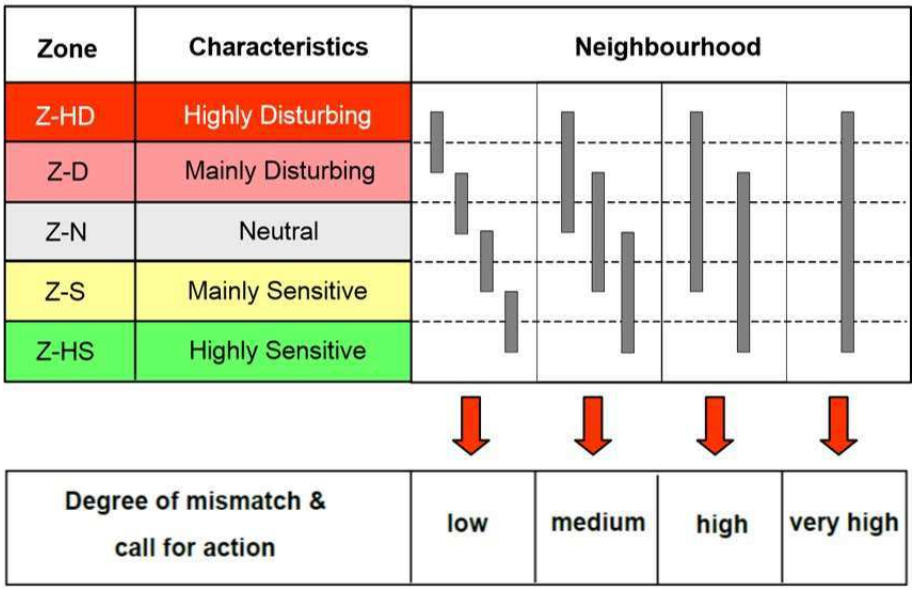


Figure 16 - Level of mitigation required.

Where there is an interface between equipment which results in a high or very high degree of mismatch additional filtering and/or shielding will be required to ensure EMC.

8.4 Cabling and Cable Routes

Cable routes shall be designed in accordance with relevant Network Rail standards, ensuring adequate segregation and separation of sensitive and/or safety critical cabling (e.g. signalling and communications) from potential sources of EMI. Typical cable management processes for EMC include using separate conduits or trunking, orthogonal crossings and minimisation of parallel paths.

Various standards and codes of practice deal with cable segregation for the purposes of both safety and EMC. Some of them are presented and discussed in the following sections.

8.4.1 BS 7671 IET Wiring Regulations

For reasons of electrical safety, the IET wiring regulations distinguish between Voltage Band I and Voltage Band II circuits as follows:

- Band I: Extra Low Voltage (ELV) will normally fall within voltage band I. ELV normally not exceeding 50 VAC. Or 120 V ripple-free DC whether between conductors or to earth.
- Band II: Low voltage (LV) will normally fall within voltage band II. LV Normally exceeding ELV but not exceeding 1000 VAC. Or 1500 VDC between conductors, or 600 VAC. Or 900 VDC between conductors and earth.

BS 7671 Clauses 528-01-01 and 528-01-02 are provided for reference as follows:

- **528-01-01** Neither a band I or band II circuit shall be contained within the same wiring system as a circuit of nominal voltage exceeding that of low voltage (>1000 VAC. or 1500 VDC) unless every cable is insulated for the highest voltage present or one of the following methods is adopted.
  - Each conductor in a multi core cable is insulated for the highest voltage present in the cable, or is enclosed within an earthed metallic screen of current-carrying capacity equivalent to that of the largest conductor enclosed within the screen, or
  - The cables are insulated for their respective system voltages and installed in a separate compartment of a cable ducting or cable trunking system or have an earthed metallic covering.
- **528-01-02** A band I circuit shall not be contained in the same wiring system as band II voltage circuits unless one of the following methods is adopted:
  - Every cable is insulated for the highest voltage present.
  - For a multicore cable or cord, the cores of the band I circuit shall be insulated individually or collectively for the highest voltage present in the band II circuit.
  - For a multicore cable or cord, the cores of the band I circuit shall be separated from the cores of the band II circuit by an earthed metal screen of equivalent current carrying capacity to that of the largest core of the band II circuit.
  - The cables are insulated for their system voltage and installed in a separate compartment of a cable ducting or trunking system.
  - The cables are installed on a tray or ladder where physical separation is provided by a partition.
  - A separate conduit, trunking or ducting is employed.

8.4.2 BS IEC 61000-5-2 Earthing and Cabling

The BS IEC 61000-5-2 standard provides the following details on the classification of cable types:

- **Class A Very sensitive -** Class A generally applies to all low-level signals such as thermocouples, thermistors, RTDs, strain gauges, load cells, microphones, etc.; also, high-rate digital and analogue communications such as Ethernet, video, RF receiver cables from antennae and all other signals with full-scale range less than 1 V, 1 mA, or where their source has an impedance higher than 1 kOhms, or their signal frequency or rate is greater than 1 MHz.
- **Class B sensitive** - This covers ordinary analogue (e.g. 4-20 mA, 0-10 V, less than 1 MHz) and low-rate digital bus communications (e.g. RS232, RS422, RS485, Centronics).

Class B also covers digital (i.e. on/off) inputs and outputs such as limit switches, encoders, non-data-bus low rate signals, etc., and the outputs of internal DC power supplies (but not the DC links of power convertors or motor drives, which are Class D).

- **Class C Indifferent** - Class C covers externally supplied AC. (230/415 V) or DC power which does not also supply noisy external equipment, e.g. welders, drives, power convertors, etc. Class C also covers control circuits with resistive and inductive loads where all inductive loads (e.g. the coils of solenoids and contactors) are fitted with suppressors recommended by their manufacturers.

Induction motor (e.g. squirrel cage) cables are Class C providing they are on/off controlled or run from adjustable speed drives with sinusoidal output filters and providing their AC. supply is itself CLASS 3 or better.

- **Class D Noisy** - Applies to the cables associated with the power inputs and outputs and DC links of adjustable speed motor drives (DC, AC., steppers, servos, etc.), welding equipment, and similar electrically noisy equipment.

Cables to on/off controlled DC motors or slip-rings are also Class D, although sparkless types such as pancake motors, or motors fitted with spark suppressed rotors or integral filters could be Class C.

Class D also covers control cables to unsuppressed inductive loads (relays, contactors, solenoids, etc.), which may use unscreened twisted pairs but only as long as they operate infrequently (every few minutes or longer). If they operate more frequently than every few minutes, they should either be suppressed, or use screened cables.

CLASS D can include all LV supplies which also power external noisy electrical equipment (e.g. drives, power convertors, welding, etc.) which may not meet their relevant harmonized EMC emissions standard, or which lack supply filters.

Cables to RF transmitting antennae are also Class D.

- **Class E and F, Very Noisy** (for MV and HV) - Cables carrying supplies at voltages higher than 630 V are commonly called High Voltage (HV), although more correctly these should be divided into Medium Voltage (MV) and HV according to the IEC's definitions. MV and HV cables are much more exposed to external disturbances such as lightning and powerful transients and surges caused by the operation of heavy-duty switchgear, than are LV cables. MV power distribution cables are Class E, and HV power distribution cables are Class F.

8.4.3 Application of the Guidance to Cambridge South Infrastructure Enhancement Project

Table 17 provides guidance for the categorisation of cables on Cambridge South Infrastructure Enhancement Project.

Class	Application / System Cables
Class A - Very sensitive	Copper Telephone Video and Low-Level Audio
Class B - Sensitive	Ethernet Cable 10/100 and Twisted Pair PA Audio Signaling Circuits/Point Detection RS 422 / RS 485 /RS 232 Proprietary Data (PHP) Analogue Sensor 4-20 mA PLC/SCADA Cables without an inductive load (e.g. door contacts/interlocks)
Class C - Indifferent	110 V AC.,230 V AC. < 13 A Control Cables for inductive loads DC Power Cables (<50 V)
Class D - Noisy	230 V AC, 415 V AC, 630 V AC Power Cables > 13 A Control Cables for inductive loads
Class E and F - Power Distribution MV / HV Power cables	Low level feeders, Traction power feeders

Table 17 - Cable classification based on BS IEC 61000-5-2 for Cable Types Used on the Project.

8.4.4 Return Screening Conductor

No RSC is currently planned to be installed as part of this project.

Depending on the results from the immunisation (“ELSSA” or “ELSSA-Equivalent”) study and the results from the V_l-V_t measurements, some additional protection of the S&T cables may be required and the associated protection mitigation solutions (e.g. but not limited to: MSC, RSC, use of shielded cables) might need to be defined at GRIP5 stage.

8.4.5 Cable Separation

As an EMC requirement, the minimum separation distance between cables in order to avoid disturbance coupling is dependent on many factors including the types of cables (shielded/unshielded/twisted pair), the balance of the cable, source and termination impedances, signal levels, use of metal dividers, the inherent immunity of the equipment ports etc.

Any high voltage cable routes installed as part of Cambridge South Infrastructure Enhancement Project shall be positioned and installed in accordance with NR/BS/LI/217. Where HV AC feeder cables and S&T cables run in parallel for lengths exceeding 200 m, they shall be separated from each other by distance greater than 1 m.

Table 18 gives cable separations to be followed for all cables used as part of the Cambridge South Infrastructure Enhancement project and are based on the requirements of BS IEC 61000-5-2 and BS EN 50174-2. Where cables run parallel for less than 35 m, categories A to D may be run together.

Cable Class	A	B	C	D	E/F
A					
B	20 mm				
C	125 mm	50 mm			
D	450 mm	300 mm	50 mm		
E/F	1000 mm	1000 mm	1000 mm	300 mm	

Table 18 - Recommended Minimum Cable Separations for Cable Runs over 35 m in Non-Metallic Trunking

The distances given in Table 18 assume the cables are unshielded. The separation distance may be reduced if shielding is fitted to cable class A to D as follows:

- Shielding fitted to either cable – half separation distance e.g. class A to class D = 225 mm
- Shielding fitted to both cables – quarter separation distance e.g. class A to class D = 125 mm

It should be noted that as a rule:

- Fibre optic connections can be run with any other cable.
- The larger the physical separation between cables, the lower the level of induced voltages.
- Class A or B (Ethernet/Twisted Pair and Simple Pairs) shall be segregated from HV power cables by >1 m to minimise the potential for coupling. Where cables must run parallel to high power cables due to cable route limitations their parallel run lengths should be minimised. Under these circumstances the appointed EMC engineer shall be consulted, and additional design mitigation may be required. A quantitative analysis shall be performed to verify that the proposed separation distances are adequate. The analysis shall consider disturbances including DC short-circuit and AC earth fault on the Class E/F cable.
- Cables of different types, where they cross shall where possible be run at right angles to one another.
- 230 V and 110 V AC feeds can be run with other similar power feeds.
- The send and return wires of power and signal circuits should be as compact as possible to minimise loop areas.

Additional points:

- BS EN 50174-2 states that the minimum distance between Sensitive Cables and fluorescent, neon and mercury vapour (or other high-intensity discharge) lamps shall be 130 mm.
- Where the use and characteristics of third-party cables is unknown, a separation of 500 mm shall be maintained between the third-party cables.

Figure 17 illustrates the recommended cable segregation and separation requirements.

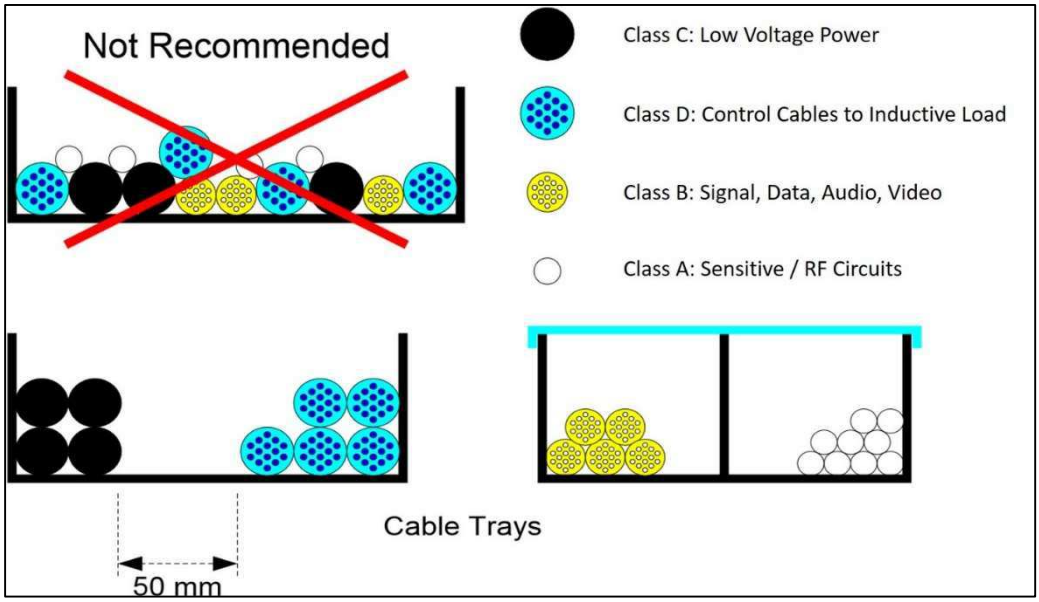


Figure 17 - Recommended Cable Management Arrangement

8.5 Cable Transits

Where metal cable trays are used, they can provide satisfactory shielding for the enclosed cables by diverting common-mode disturbance currents away from the differential mode signal circuit; whether the victim cable is shielded or unshielded. Where possible, they should be bonded to other metallic structures to reduce the level of induced voltages.

The use of fully enclosed cable trunking and conduits of high integrity EMC performance is not always practicable. Trunking and conduits shall be considered in areas where appropriate separation distances between power cables is not achievable, and where additional electromagnetic protection is considered necessary for high-speed signal cables which would normally be run on a cable ladder rack.

The following installation guidelines shall be implemented to maximise the EMC performance of cable transit (Racking, Trunking and Conduit).

- A fully circumferential tubular conduit provides the best EMC performance, followed by a U-shaped cable tray with cover, followed by a plate ground plate and then a metallic cable rack.
- Cable Trunking and cable Rack shall be bonded to earth at multiple points along its length. To be effective at high frequencies, cable transit shall form a continuous well conducting metallic structure over its full length. When the cable is made of several shorter sections, care will be taken to ensure continuity by correct low impedance bonding between individual sections (**Figure 18**).
- Excessive high frequency common mode disturbance currents flowing in the loop formed between the cable shield and the cable transit can be reduced with the use of ferrite chokes where necessary.

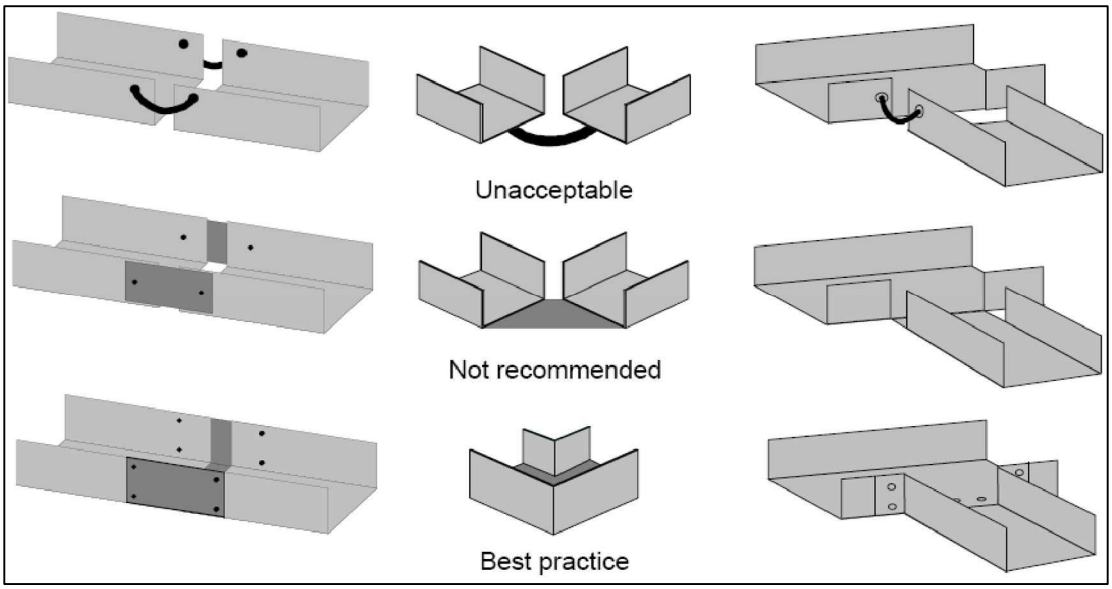


Figure 18 - Recommended Bonding of Cable Trunking

8.6 Shielded and Armoured Cables Termination

EMC standards recommend that cable screens are bonded to earth at both ends of their run e.g. BS IEC 61000-5-2 Section 7.3d, BS EN 50310 Section 5.5 and BS EN 50174-2 Section 6.3.2.

Bonding the screen at one end provides protection against low frequency electrostatic coupling only, which, in most cases, is not the primary coupling mechanism in a railway environment. Bonding at both ends provides protection against low frequency electrostatic and induction fields, and when the screen is terminated peripherally protection is also provided against high frequency electromagnetic fields (through skin effect). In terms of preference, 360° peripheral termination is best for short runs of cable, see **Figure 19.**

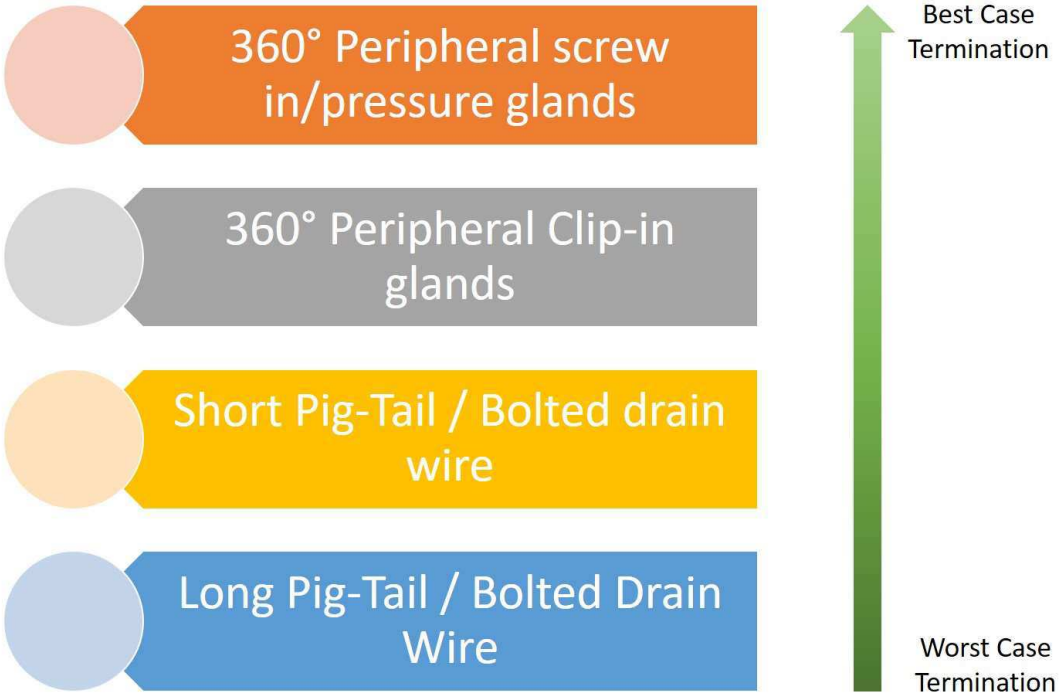


Figure 19 - Preferred Shielded Cable Transmission

Electronic equipment manufacturers commonly recommend that cable screens are connected to earth at one end only, to remove possible earth loop currents (primarily at power frequency). Earth loops will be present in cases where the earth impedance (across a wide frequency range) between any two separate reference points is significantly different.

In general, screened cables running locally, with cable length typically < 15m, will not suffer earth loop problems. Where issues exist with high levels of screen current on cables running distances of up to 100m, the shield shall be disconnected at the receiver end of the cable and terminated at the transmit end. Where particularly sensitive circuits are involved, double shielded cables can be used on runs of 100m or greater the shields should be terminated.

Cable screens may be terminated to earth in several ways as follows:

- **Peripheral Bonding:** 360° termination of the cable screen is the preferred method of cable screen bonding. Peripheral bonding essentially provides an RF termination of the screen. The separation of the wanted signal on the inside and the disturbance signal on the outside of the conductor is maintained by skin effect at the radio frequencies of interest. Any extraneous RF coupled to the cable will be on the outside of the outer conductor and decoupled by the bonded connector at the cabinet wall or earthed trunking. Peripheral bonding methods are illustrated in **Figure 20**.

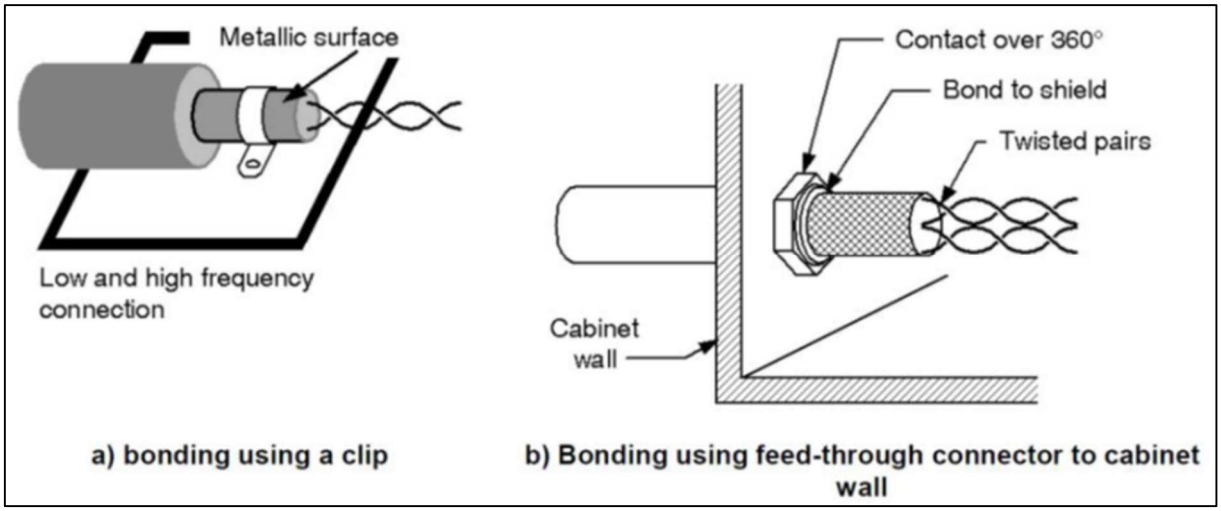


Figure 20 - Examples of Peripheral Cable Screen Bonding

- **Pigtail Bonding:** Screens connected to earth using drain wires or pigtails (Figure 21) will provide adequate screening for low frequencies (<150 kHz) but the bonding wire inductance will present a higher impedance to noise currents as the frequency increases. Pigtail length shall be as short as possible to minimise the bonding impedance.

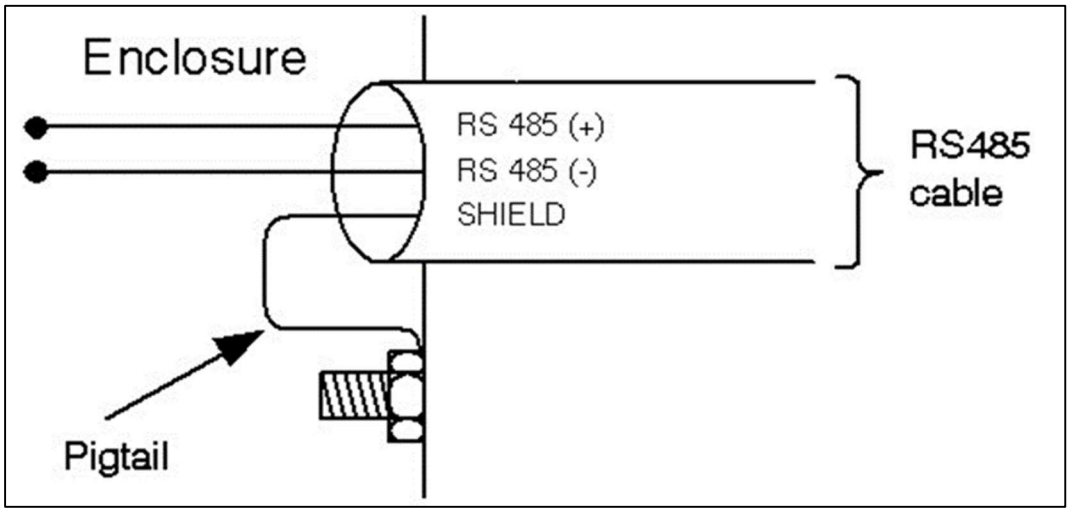


Figure 21 - Example of Pigtail Bonding

9 EMC Hazards for Cambridge South Infrastructure Enhancement Project

9.1 EMC Interface Matrix

The first stage of the hazard identification for EMC is the production of an interface matrix for the CSIE project. The matrix considers all probable sources, from the traction and distribution supply systems within the railway boundary to equipment installed and/or sources generated externally from third party or neighbouring locations. All systems potentially impacted by the new works both within and external to the railways boundary will also be considered as victims.

The interface matrix shown in Table 19 should be read as follows:

- A "✓" means that there is potentially an EMC interface between a given source and a given victim;
- A "✗" means that no plausible EMI interaction should occur between two systems, either because the equipment is not sensitive to the source of disturbance, or the source of interference is too far from the victim to exceed the immunity test levels required to place the product on the market.

With this interface matrix, the potential EMC issues are highlighted allowing the further development of a detailed and quantitative register of risks known as the EMC Hazard Log.

A preliminary EMC Hazard Log based on the limited information available at GRIP 4 stage is presented in Appendix B.

Note this matrix shall be revised as the design will progress at next GRIP stages.

The interface matrix below identifies the potential EMC issues. This matrix will be used as a source to establish the EMC Hazard Log during the EMC HAZID (details in Section 0) to be held at GRIP 5.

EMC CONTROL PLAN

victims: Columns = / Rows = sources:	AC Traction System (A)	Protection & Control (B)	Station Systems PA, PIS, CCTV, DOO CCTV Lighting	Signalling Power Supplies (B)	LV DNO, other DNOs (G)	66kV / 33kV / 11kV Cables (G)	Train Detection (B)	SSI, CBI (B)	Wired Interlocking & Lineside Circuits (B)	Points Heating & Control (B)	Telecoms FTN, WAN, Copper, SCADA Connectivity	Radio GSM-R, Station Radio, Wireless Comms (C)	3rd Party Radio Stations (G)	Rolling Stock (E)	Lightning (K)	Staff (I)	Public (H)
AC Traction System (A)	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓
Protection & Control (B)	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Station Systems PA, PIS, CCTV, DOO CCTV, Lighting Columns (D)	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓	✓	✓	✗	✗	✓	✓
Signalling Power Supplies (B)	✗	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
LV DNO, other DNOs (G)	✗	✗	✓	✓	✗	✗	✓	✓	✓	✗	✓	✓	✓	✗	✗	✗	✗
66kV / 33kV / 11kV Cables (G)	✓	✗	✗	✗	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	✗	✗	✗
Train Detection (B)	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗
SSI, CBI (B)	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Free Wired Interlocking & Lineside Circuits (B)	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗
Points Heating & Control (B)	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

victims: Columns = / Rows = sources	AC Traction System (A)	Protection & Control (B)	Station Systems PA, PIS, CCTV, DOO CCTV Lighting	Signalling Power Supplies (B)	LV DNO, other DNOs (G)	66kV / 33kV / 11kV Cables (G)	Train Detection (B)	SSI, CBI (B)	Wired Interlocking & Lineside Circuits (B)	Points Heating & Control (B)	Telecoms FTN, WAN, Copper, SCADA Connectivity	Radio GSM-R, Station Radio, Wireless Comms (C)	3rd Party Radio Stations (G)	Rolling Stock (E)	Lightning (K)	Staff (I)	Public (H)
Telecoms FTN, WAN, Copper, SCADA Connectivity (C)	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Radio GSM-R, Station Radio, Wireless Comms (C)	✗	✓	✓	✓	✓	✗	✓	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗
3rd Party Radio Stations (G)	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✓	✗	✓	✓
Rolling Stock (E)	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓
Lightning (K)	✓	✓	✗	✗	✗	✗	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
Staff (I)	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Public (H)	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

Table 19 - EMC Interface Matrix

To simplify the identification of sources and victims related to EMC on Cambridge South Infrastructure Enhancements Project, a coding system has been used as described below:

A: 25 kV electrification (e.g. OLE, cables) with rolling stock as a traction load. In this case, the rolling stock is seen as a passive load of the global 25kV electrification system.
B: Signalling and Plant (e.g. signals, train detection, Protection & Control, S&C, 650V signalling supply, cables, SSI, lineside circuits).
C: Telecommunications (e.g. GSM-R, FTN).
D: Stations/Depot Building Services (e.g. CCTV, CIS, PA, help points, telephone systems, lifts, lighting, fire alarm, LV and small power, cables).
E: Rolling Stock. In this case, rolling stock is considered as an active load which generates an electromagnetic field and harmonic currents.
F: Interfacing railways (Network Rail).
G: Non-railway third parties (e.g. cables, RF transmitters, DNO, LV & traction supply electricity suppliers).
H: Public and third-party workers.
I: NR Workers.
J: DC electrification systems. Noting that at present, no adjacent DC systems exist but the Cambridgeshire Guided Busway could be converted to a DC tram network in the future.
K: Lightning.

These letters will then be used for the coding of each EMC Hazard identified during the HAZID process described in section 10.

9.2 Desktop Study – Identified Areas at Risk

A desktop survey shall be carried out at GRIP 5 to ensure any existing and potential third-party neighbours close to the vicinity of the proposed works (i.e. within a radius of 100 m approximately) are clearly identified as well as the related EMC Hazards.

This desktop study can be performed using the satellite views available on Google Earth © to identify possible sources and victims and www.mastdata.com tool to locate the GSM antennas nearby.

Areas around the railway which might be impacted by EMI shall then be logged in the EMC Specific Hazard Log, as well as their proposed mitigations. This EMC Control plan should then be updated to include the EMC Specific Hazard Log as an appendix.

Note: minimum distances to be shown in the EMC Hazard Log will be taken from the outer limit of the property considered to the outside rail of the track.

Although few systems are sensitive to low frequency magnetic fields generated by the Traction Power Supply System, the fields generated will be compared with known susceptibility levels of systems likely to be utilised within these buildings. Therefore, an estimate of the peak magnetic field strengths likely to be seen at the building boundary shall be calculated using loading data taken from traction modelling which applied to an equivalent rail return electrification scheme.

The risk of interference to sensitive systems installed within the third-party buildings needs to be considered further during next GRIP stages.

As per the preliminary desktop survey shown earlier in this document, this Cambridge South Improvement Project will require some specific care on EMC due to the presence of sensitive laboratories at proximity of the railway. Those laboratories and universities use measurement/educational equipment, with the risk that the proposed changes in the area may impact on their operation.

Our current recommendations are:

a) Undertake EMC background measurements at selected places before and after construction to be able to demonstrate the impact of the proposed change on the electromagnetic environment;
b) Undertake some specific magnetic field calculations on a wide range of frequencies (50 Hz to 150 kHz) to evaluate the impact of the proposed changes on the levels of magnetic field that will be emitted by the railway;
c) Assess the results from measurements and calculations against the immunity levels of the equipment that is owned by the laboratories and universities located in the area, which also involves continuous coordination with third parties;
d) Update the GRIP5 EMC documentation accordingly, including this EMC Control Plan.

10 EMC HAZID Process

10.1 Introduction to the Process

Following on from the EMC Interface Matrix, a HAZID process shall be undertaken in GRIP 5. The process will use a combination of technical experience, generic EMC hazards and addressing the issues raised in Section 0.

This EMC HAZID process is one of the fundamental processes to identify the EMC requirements that should be applied to systems and subsystems to ensure electromagnetic compatibility between the equipment and its intended operating environment.

Satisfaction and closure of the EMC hazards which could be met on the Project will be achieved:

- By performing a detailed hazard analysis of the **Generic Hazards** usually met on similar electrification projects. Our recommendation is to use Network Rail's Generic Hazard Matrix template.
- By performing a **detailed hazard analysis** of each of the potential EMC areas at risk along the line at GRIP 5. This will be done by creating a Project-Specific Hazard Matrix.
- All remaining hazards will be transferred to the project risk log which shall then be tracked and closed out throughout the remaining GRIP stages. Any items that cannot be closed out or demonstrated to be ALARP will be transferred as a residual risk to Network Rail.

Notes:

- Closure of EMC Hazards is dependent upon the execution of the Works which will be done at GRIP6-8 stage. Many of the EMC Hazards that will be identified at this stage might be left open and shall be closed by others at further GRIP stages.
- The list of potential EMC areas at risk identified on the Project will shall be done based on the most up-to-date list, which can be established at the time of writing. However, some new areas at risk may be found during the next stages of the Project and shall be considered using the same methodology as the one described hereafter to guarantee an acceptable Electromagnetic Compatibility on the Project and for further approval by the relevant accredited parties.
- The identification of potential areas at risk during the Specific Hazard identification process will provide a guidance to Network Rail regarding the sites at which measurements are required. Based on this list, it will be Network Rail's responsibility to select the final number and locations of sites for measurements if needed; the overall aim being to provide relevant evidence for the demonstration of the EMC of the Project.
- Where specific EMC risks are identified that can impact third-party equipment, consultation should be held with local owners.

The following sections detail the specific EMC processes which shall be used to derive any additional EMC requirements over and above those mandated by NR, National and international standards.

After the production of the EMC Hazard Log, all hazards shall be reviewed considering the mitigations that will be applied at later GRIP stages to reduce the level of risk to ALARP. An indication of the GRIP stage at which the hazard is expected to be closed shall be provided.

10.2 Methodology

To carry out the HAZID assessment, each source of EMI shall be identified (whether it is a generic source commonly met on AC electrification Projects or a source specific to the project), and the EMI threats that these sources pose to each of the possible victim sub-systems shall be considered.

Threats in this context are defined as electromagnetic disturbances which compromise the functionality of the victim sub-systems and/or safety.

This is achieved by listing all possible EMI sources and all possible items of equipment under threat and assessing the risks of EM incompatibility within one EMC Hazard matrix.

This list of equipment is non-exclusive. All identified items of equipment shall be included within the analysis even if it is assumed that some of these items of equipment will results in a low-risk classification.

An initial interface matrix has been constructed and the potential threats due to EMI ranked on a scale of 1-5 to rationalise the equipment that needs assessment. The rationalised list will then form the basis of the HAZIDs.

The assessment is performed by providing an estimation of both:

- The severity of the hazard.
- The likelihood of the hazard to happen.

The assessment also considers what electromagnetic disturbances the new and existing sub-system(s) are exposed to as a result of the project. The following questions are derived from the assessment.

- What are the potential coupling mechanisms?
- What are the potential side effects of such disturbances being introduced to the sub-system(s)?
- How might emissions emitted by the equipment / system affect other systems (Railway systems and near neighbours) both existing and planned under the project?
- What are the safety implications of such effects/disturbances?
- What are the potential economic constraints of such effects / disturbances?
- What level of confidence is required that the above have been fully considered and all actions taken to achieve the desired level of safety?

The scale of evaluation to be used during the EMC HAZID workshop is shown below in **Table 20**.

SEVERITY		LIKELIHOOD		
1	Minor injury, damage, sickness or other loss (with no time off)	1	Very unlikely	<0.01 per year
2	First Aid injury or illness, minor damage or loss (and/or up to 3 days off) Lost time injury	2	Unlikely	0.01- 0.10 per year
3	Reportable injury or illness, substantial damage or loss (or over 3 days off)	3	Likely	0.20-1 per year
4	Major injury, long term absence	4	Very Likely	2-10 per year
5	Fatality, catastrophic damage or loss (Death)	5	Certain	>10 per year

Table 20 - Hazards and Evaluation Scale

According to standard NR/L2/RSE/30041 – EMC Assurance Process, the risk factor is calculated by summing the severity and likelihood factors for each hazard. Therefore, **Table 21** and Table 22 are used for the global assessment (likelihood /severity combined):

Likelihood	5	6	7	8	9	10
	4	5	6	7	8	9
	3	4	5	6	7	8
	2	3	4	5	6	7
	1	2	3	4	5	6
		1	2	3	4	5
	Severity					

Table 21 - Evaluation of EMC Hazards

Table 22 below shows the final acceptance criteria of the EMC Hazards.

KEY			ALARP CRITERIA
High	7-10	Hazard must be avoided (or the level of risk reduced significantly and reliably by controls)	Intolerable risk
Moderate	5-6	Hazard should be avoided (or the level of risk reduced significantly and reliably by controls)	Within the ALARP region, but the higher the number the greater the criticality of risk reduction
Low	0-4	Risks to be controlled	Tolerable

Table 22 - Acceptance of the EMC Hazards

Any risks identified by the risk assessment to be in the medium - high category, would then cause the designer to introduce specific control measures to reduce the risk to ALARP.

10.3 Criteria to be applied during HAZID Process

The **zoning principle** presented in Network Rail's EMC Assurance Process reference NR/L2/RSE/30041 and shown on Figure 22 shall be used to identify possible EMC areas at risk before commissioning the Railway.

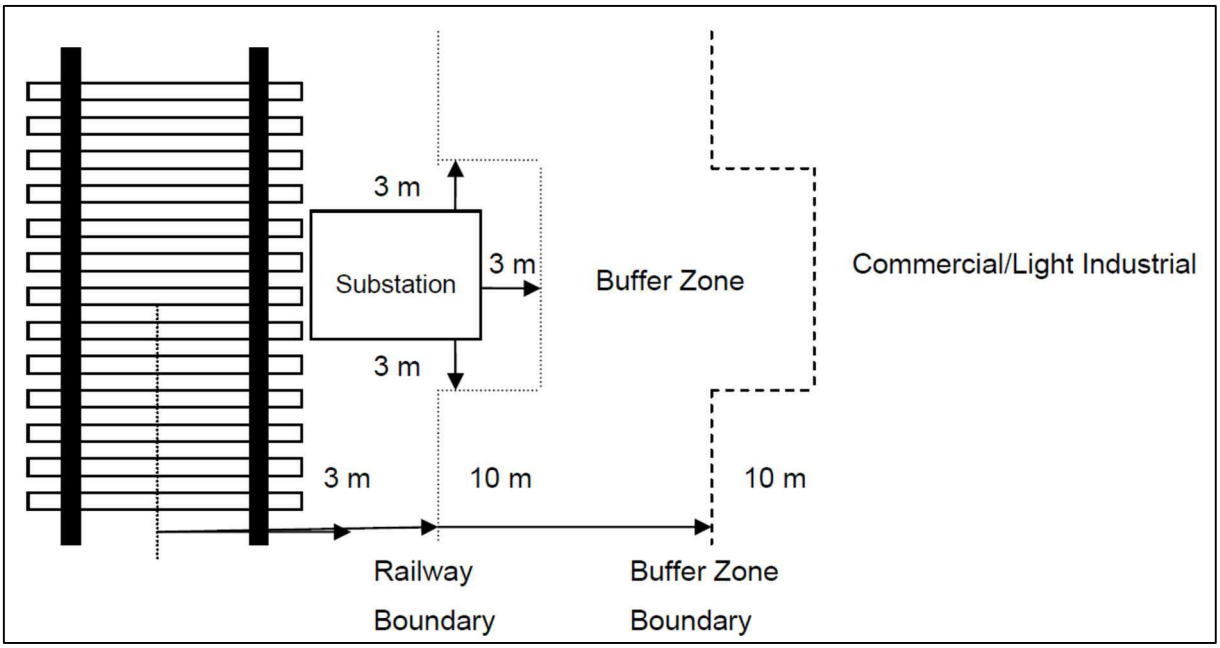


Figure 22 - EMC Zoning Principle as per NR/L2/RSE/30041

The approach of the EMC HAZID Matrix is to compile all possible EMC risks around the railway infrastructure. **Figure 22** above defines distances limits on horizontal surface. There is no definitive distance limit from where no electromagnetic fields are generated. The reason for this is that the electromagnetic fields tend to fade following an inverse-exponential curve.

It is to be noted that the distance is not the only parameter which dictates any possible EMC risks. It is entirely possible that equipment further from the railway line can be more sensitive than equipment closer to the railway line. Therefore, the specific Hazard Matrix should be designed whilst taking these aspects into careful consideration in addition to the different EMC standards criteria. Consequently, the border can in some cases been extended beyond 20 m:

- To give the most comprehensive list of impacted sites.
- To give the most possible precise evaluation of the EMC risks.
- To raise awareness on the EMC risks for the future GRIP stages.

Due to the nature of the electromagnetic field and from past experience on previous projects, it has been found more relevant to use a radial distance limit, which proved to be particularly suitable on previous projects as many areas at risk identified in previous desktop studies are located above (or below) the level of the railway line. We can consider that the distances from the zoning principles provided within NR/L2/RSE/30041 apply radially. **Figure 23** sums up the approach proposed by Arcadis with a cross-section drawing.

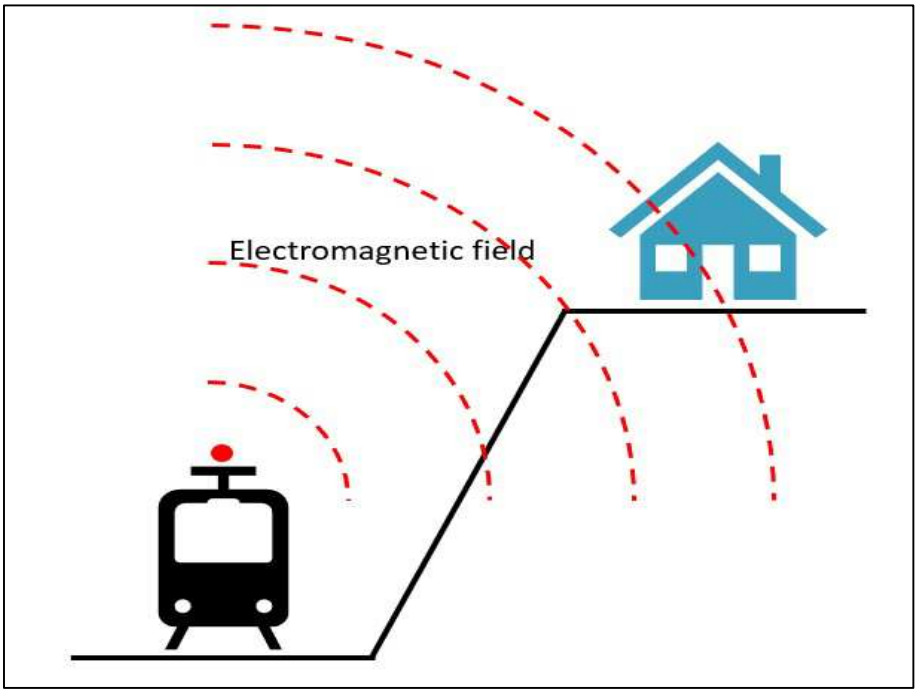


Figure 23 - Additional recommended assumption on Electromagnetic fields to be used during HAZID Process.

Appendix D of Network Rail's EMC Assurance Process reference NR/L2/RSE/30041 provides a comprehensive EMC standards framework per subsystem which will be applied to the Project.

11 EMC Action List for next GRIP Stages

11.1 General GRIP Action List

The list of key actions required at GRIP 5 through to GRIP 6, as an output of the HAZID process (GRIP 5) and because of the EMC considerations highlighted at GRIP 4, is stated within Table 23 below. It should be noted that the detailed mitigations, which should be applied to each hazard, will be stipulated within the EMC Hazard Log (EMC Generic and Specific HAZID Matrices). Also included is an indication of, at which GRIP stage the design verification will be applied and what will be required to validate that the mitigation has been implemented satisfactorily at GRIP 6. This would then allow final close out of the hazard.

All the actions presented hereafter should be undertaken in compliance with the EMC requirements presented in Appendix A.

Stage	Actions
GRIP 4:	**Single Option Development**
1.	Undertake GRIP 4 design verification exercises to mitigate design risks identified in the Hazard Log and update hazard log as design progresses.
2.	Carry out immunization assessment as detailed in Section 5.4.
3.	Review the EMC for Station Systems as detailed in Section 5.6.
4.	Review third party interfaces along the route as detailed in Section 8.2.
5.	Discuss all hazards identified and mitigations during EMC HAZID Workshops.
6.	Compile a detailed EMC Actions list (this list) for GRIP 5 and 6 once GRIP 4 design verification exercises are complete.
GRIP 5:	**Detailed Design**
7.	Design AC electrification system & bonding to comply with requirements of the Earthing and Bonding Strategy. Undertake compliance assessment.
8.	Undertake an assessment to identify the fields generated by the GSM-R masts as detailed in Section 5.7.
9.	Discuss all hazards identified and mitigations during EMC HAZID Workshops.
10.	For each DNO supply point involved, define whether the DNO earth should be connected to traction return circuit or kept segregated.
11.	Follow feeder cable separation recommendations as defined within Section 7.4.5 and undertake EMC assessment where required.
12.	Record compliance of all systems being introduced in an EMC Product List. Ensure that all procured equipment is compliant with the requirements of Section 5.5.
13.	Further detail the Verification and Validation program to ensure EMC hazards are adequately mitigated.
14.	Update GRIP 4 EMC Control Plan to GRIP 5 and produce Project EMC File.
GRIP 6-8:	**Construction, Testing & Commissioning**

Stage	Actions
15.	Procure E&P equipment to EN 50121-5 and test shortfalls where identified by the compliance gap analysis within the EMC Product List.
16.	Produce applicable test specifications and test plans (if needed), method statements and resultant test reports to demonstrate the EMC according to the series of standards defined in NR/L1/SIG/30040 – Table 2.
17.	Compile EMC checks into appropriate inspection check sheets and carry out inspections and record findings.
18.	Maintain hazard log and formally close out all EMC hazards following the Verification and Validation program.
19.	Define maintenance requirements within the O&M manual to ensure on-going EMC.
19.	Compile and complete the final Project EMC File. This file shall include all the EMC evidence that has been gathered during the lifecycle of the project.

Table 23 - General EMC Action List

This action list will therefore ensure the Project EMC compliance process to be followed under surveillance of the EMC team.

11.2 EMC Methodology – System Design

The process chart below outlines the EMC activities (Green boxes on the chart below) that shall be undertaken by the contractors as part of their design.

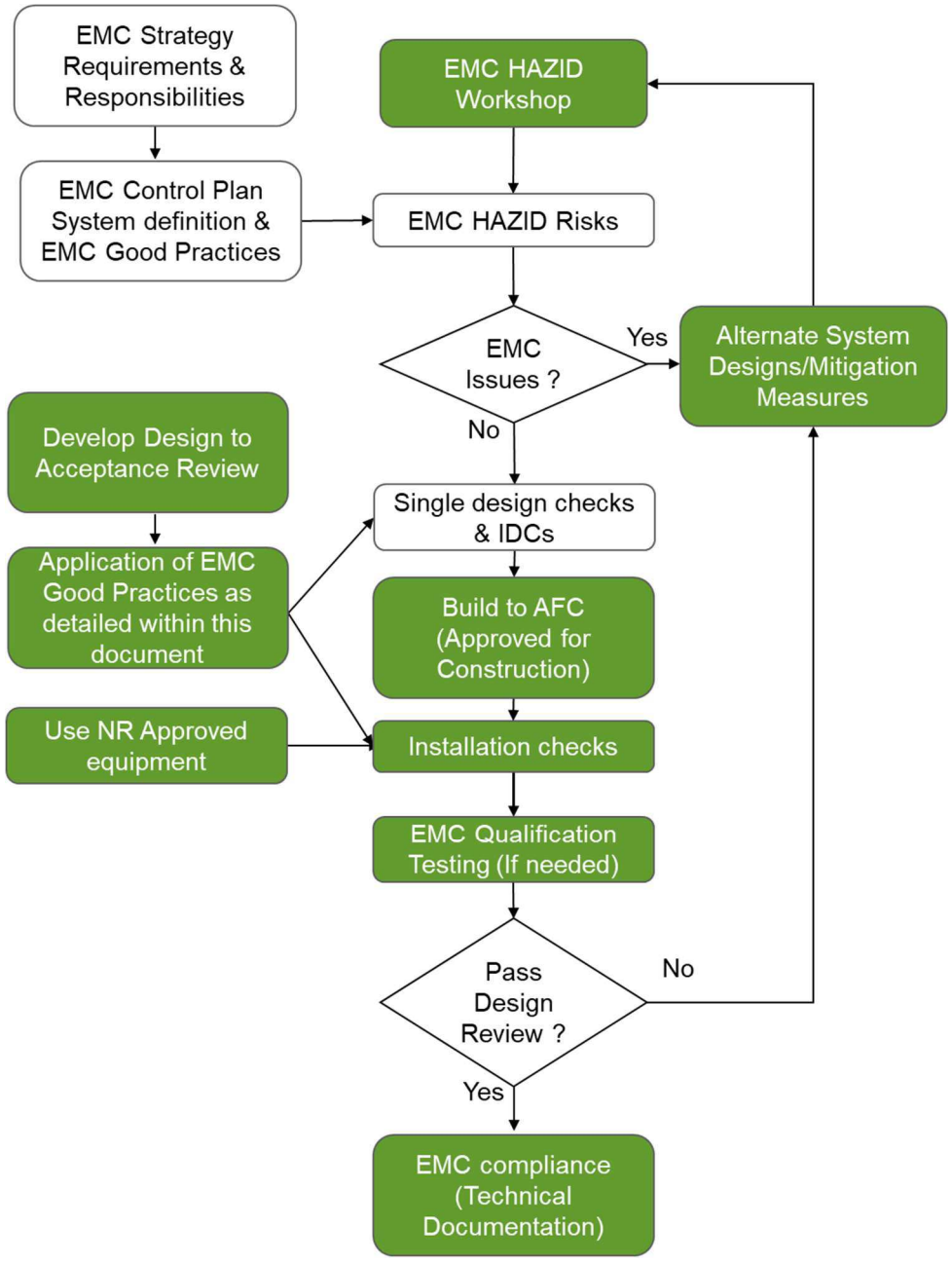


Figure 24 - Process Chart- EMC Methodology

Appendix A

EMC Hazard Log

EMC CONTROL PLAN

RISK DEFINITION							RATING			MITIGATION	RATING			CSM Approach			RISK MANAGEMENT		
ID No	Hazard Type	Source of Hazard	Cause or Description of Hazard	Consequence	Immediate Victim (system or people)	Primary Business Objectives	Severity	Frequency	Combined	Safety Measures (Mitigations)	Severity	Frequency	Combined	Code of Practice	Reference System	Evaluation	Standard to Apply and/or comments	Validation/ Verification	Implementation Hazard Open / Close / Transferred
1	EMC	AC Traction System	Proposed change from two tracks to four tracks may generate electromagnetic interferences to third-party equipment and induced voltages on metallic assets.	Risk of electric shock and reputational issues.	Members of the public, staff and third party companies.	Safety	3	3	6	Implement rigorous EMC process over the life cycle of the project.	3	1	4						
2	EMC	AC Traction System	Timetable changes increase the induction between energised and non-energised cables.	Risk of electric shock	AC Traction System	Safety	3	4	7	Strict operational procedures to be revised and implemented.	2	3	5						
3	EMC	AC Traction System	Timetable changes generate higher induction level on sensitive Railway assets. A few examples include: Poor train detection by the track circuits (or axle counters); Loss of Signalling Remote Terminal Units; Loss of telecommunication systems; Points heating failure; Temporary loss of GSM-R, i.e. the train-signaller communication. Degradation of the Signal-Noise ratio of radio communications.	Equipment maloperation. Delays, or Wrong Side Failure of the Signalling system in some extreme cases.	E&P Plant, Telecoms and Signalling	Performance / Financial	3	4	7	Keep circuit lengths within permitted limits: Cable lengths should be kept within 1km and RSC installed in cable troughs if needed. Keep a minimum spacing of 1 m between HV and other sensitive cables as much as possible. Check that the EMC good practices recommended within the EMC Control Plan have been applied during the design (IDC meetings) and installation phases. Use PADS approved equipment. Detailed HAZID workshop to be undertaken at GRIP 5 (currently assumed by others).	2	3	5						
4	EMC	AC Traction System	Timetable changes generate higher induction level on Station Systems: Passenger Information System; Public Address; CCTV; Ticket Vending Machines, Automatic defibrillator, Lifts and escalators, Computers and telecommunication equipment Phones	Maloperation of Equipment	Station Systems	Performance	4	4	8	Check that the EMC good practices recommended within the EMC Control Plan have been applied during the design (IDC meetings) and installation phases. Use PADS approved equipment.	2	3	5						

RISK DEFINITION							RATING			MITIGATION	RATING			CSM Approach			RISK MANAGEMENT		
ID No	Hazard Type	Source of Hazard	Cause or Description of Hazard	Consequence	Immediate Victim (system or people)	Primary Business Objectives	Severity	Frequency	Combined	Safety Measures (Mitigations)	Severity	Frequency	Combined	Code of Practice	Reference System	Evaluation	Standard to Apply and/or comments	Validation/ Verification	Implementation Hazard Open / Close / Transferred
										Detailed HAZID workshop to be undertaken at GRIP 5 (currently assumed by others).									
5	EMC	AC Traction System	Non-compatibility between traction system and rolling stock: Harmonic resonance effects Transients	Trains' Delays	Rolling Stock	Performance / Financial	3	3	6	Check compliance with TSIs for infrastructure and train safety case.	2	2	4						
6	EMC	AC Traction System	Electrical noise on neighbouring telecommunications circuits: Analogue phone lines GSM cell towers	Reputational issues	Third Party Telecommunication systems	Reputation	3	3	6	Cable routing to be designed to prevent excessive noise. Third party telecommunication towers and landlines to be identified as being at risk during surveys (GRIP5 – currently assumed by others). Network Rail to liaise with the owners.	2	2	4						
7	EMC	AC Traction System	Nuisance to 3rd party telecommunication systems that are used for safety/public security purposes.	Reputational issues	3rd party radio and Police/Firemen TETRA communication System	Safety / Reputation	4	3	7	Cable routing to be designed to prevent excessive noise. Third party telecommunication towers and landlines to be identified as being at risk during surveys (GRIP5 – currently assumed by others). Network Rail to liaise with the owners.	2	2	4						
8	EMC	AC Traction System	Induced voltages on third party distribution lines, especially if these lines are laid out parallel to the Railway over a long distance. Higher induction level to lines when de-energised.	Risk of electric shock	3rd party utility owners	Safety	5	4	9	Strict Earthing procedures when deenergised. Test Before Touch. Network Rail to liaise with the owners.	3	3	6						
9	EMC	AC Traction System	Voltage on DNO earths exceeds ENREC G12 issue 4 limits at the point of connection. AC current & fault voltages into DNO earths.	Risk of electric shock	DNO Supplies	Safety	5	4	9	Strict Earthing procedures when deenergised. Test Before Touch. Network Rail to liaise with the owners. Some specific studies may be required at GRIP5 in some cases.	3	3	6						

RISK DEFINITION							RATING			MITIGATION	RATING			CSM Approach			RISK MANAGEMENT		
ID No	Hazard Type	Source of Hazard	Cause or Description of Hazard	Consequence	Immediate Victim (system or people)	Primary Business Objectives	Severity	Frequency	Combined	Safety Measures (Mitigations)	Severity	Frequency	Combined	Code of Practice	Reference System	Evaluation	Standard to Apply and/or comments	Validation/ Verification	Implementation Hazard Open / Close / Transferred
10	EMC	AC Traction System	Higher induction level to long (>1 km) conductors near track. For elevated conductors (e.g. in signal box), shorter conductors may be of concern.	Risk of electric shock	Lineside Conductors (e.g. long fences)	Safety	5	4	9	E&B design in accordance with NR/L2/ELP/21085. Lineside conductors to be bonded to traction return. Lengths of other conductors to be minimised as much as possible, using appropriate segregation criteria and minimum distance criteria from the track.	3	3	6	Yes	No	No	NR/L2/ELP/21085		
11	EMC	AC Traction System	Radiated and conducted disturbances may cause malfunction of sensitive civil equipment: Computers, Pacemakers, Medical equipment (MRI, XRays, Hospitals, Laboratories, Dentists, Veterinary etc.) Audio equipment (Recording/broadcasting studios, theatres) Television/film equipment (Television/film studios) Exposure to Electromagnetic radiations of sensitive people (e.g. young children, nurseries, schools)	Reputational issues	Third-party neighbours	Safety / Reputation	4	4	8	Check that the EMC good practices recommended within the EMC Control Plan have been applied during the design (IDC meetings) and installation phases. Use PADS approved equipment. Detailed HAZID workshop to be undertaken at GRIP 5 (currently assumed by others). Measurements may be required at some specific locations, pending upon the results of the HAZID analysis.	3	2	5						
12	EMC	AC Traction System	Radiated and conducted disturbances may cause malfunction of sensitive military/aviation equipment: Telecommunication systems; Radars and Geo-localisation systems Others	Reputational issues	Military and aviation neighbours	Safety / Reputation	4	3	7	Check that the EMC good practices recommended within the EMC Control Plan have been applied during the design (IDC meetings) and installation phases. Use PADS approved equipment. Detailed HAZID workshop to be undertaken at GRIP 5 (currently assumed by others).	3	2	5						

RISK DEFINITION							RATING			MITIGATION	RATING			CSM Approach			RISK MANAGEMENT		
ID No	Hazard Type	Source of Hazard	Cause or Description of Hazard	Consequence	Immediate Victim (system or people)	Primary Business Objectives	Severity	Frequency	Combined	Safety Measures (Mitigations)	Severity	Frequency	Combined	Code of Practice	Reference System	Evaluation	Standard to Apply and/or comments	Validation/ Verification	Implementation Hazard Open / Close / Transferred
										Measurements may be required at some specific locations, pending upon the results of the HAZID analysis.									
13	EMC	Handheld Radios	Radiated RF interference, particularly when used close to vulnerable devices.	Maloperation of Equipment and train's delays	Railway Systems	Performance	3	3	6	Determine distance from handheld radios where field levels of NR/L2/TEL/30066 are met. Compliance of NR TDS & signalling systems with EN 50121-4. Provide warnings or prohibition notes if required. Measurements and tests, or alternatively, documentary evidence to be provided (EMC Project File) from other UK projects.	2	2	4	Yes	No	No	NR/L2/TEL/30066 BS EN 50121-4		
14	EMC	Handheld Radios	Radiated RF interference, particularly when used close to vulnerable devices.	Maloperation of Equipment	Station Equipment	Performance	3	3	6	Determine distance from handheld radios where field levels of NR/L2/TEL/30066 are met. Provide warnings or prohibition notes if required. Measurements and tests, or alternatively, documentary evidence to be provided (EMC Project File) from other UK projects.	2	2	4	Yes	No	No	NR/L2/TEL/30066		
15	EMC	Handheld Radios	Radiated RF interference, particularly when used close to vulnerable devices.	Reputational issues	Third-party neighbours	Reputation	3	3	6	Determine distance from handheld radios where field levels of NR/L2/TEL/30066 are met. Provide warnings or prohibition notes if required. Measurements and tests, or alternatively, documentary evidence to be provided (EMC Project File) from other UK projects.	2	2	4	Yes	No	No	NR/L2/TEL/30066		

RISK DEFINITION							RATING			MITIGATION	RATING			CSM Approach			RISK MANAGEMENT		
ID No	Hazard Type	Source of Hazard	Cause or Description of Hazard	Consequence	Immediate Victim (system or people)	Primary Business Objectives	Severity	Frequency	Combined	Safety Measures (Mitigations)	Severity	Frequency	Combined	Code of Practice	Reference System	Evaluation	Standard to Apply and/or comments	Validation/ Verification	Implementation Hazard Open / Close / Transferred
16	EMC	Handheld Radios	Radiated RF interference, particularly when used close to vulnerable devices.	Reputational issues	Military and aviation neighbours	Reputation	3	3	6	Determine distance from handheld radios where field levels of NR/L2/TEL/30066 are met. Provide warnings or prohibition notes if required. Measurements and tests, or alternatively, documentary evidence to be provided (EMC Project File) from other UK projects.	2	2	4	Yes	No	No	NR/L2/TEL/30066		
17	EMC	Third Party Handheld Radios	Radiated RF interference can cause maloperation of Railway Handheld Radios, which can impact on safety communications.	Safety	Railway Handheld Radios	Safety	3	3	6	Provide warnings or prohibition notes if required.	2	2	4						
18	EMC	Trainborne Radio transmitters	Radiated RF interference can cause maloperation of Railway Handheld Radios, which can impact on railway systems such as Signalling, Train Detection etc.	Maloperation of Equipment and train's delays	Railway Systems	Performance	3	3	6	Use radio transmitters within their licence requirements.	2	2	4						
19	EMC	Trainborne Radio transmitters	Radiated RF interference can cause maloperation of Railway Handheld Radios, which can impact on station equipment.	Maloperation of Equipment and train's delays	Station Equipment	Performance	3	3	6	Use radio transmitters within their licence requirements. Measurements and tests, or alternatively, documentary evidence to be provided (EMC Project File) from other UK projects.	2	2	4						
20	EMC	Trainborne Radio transmitters	Interference to neighbours' radio receivers or other equipment.	Reputational issues	Third-party neighbours	Reputation	3	3	6	Use radio transmitters within their licence requirements. Measurements and tests, or alternatively, documentary evidence to be provided (EMC Project File) from other UK projects.	2	2	4						
21	EMC	Trainborne Radio transmitters	Interference to neighbours' radio receivers or other equipment.	Reputational issues	Military and aviation neighbours	Reputation	3	3	6	Use radio transmitters within their licence requirements. Measurements and tests, or alternatively, documentary evidence to be provided (EMC Project File) from other UK projects.	2	2	4						

RISK DEFINITION							RATING			MITIGATION	RATING			CSM Approach			RISK MANAGEMENT		
ID No	Hazard Type	Source of Hazard	Cause or Description of Hazard	Consequence	Immediate Victim (system or people)	Primary Business Objectives	Severity	Frequency	Combined	Safety Measures (Mitigations)	Severity	Frequency	Combined	Code of Practice	Reference System	Evaluation	Standard to Apply and/or comments	Validation/ Verification	Implementation Hazard Open / Close / Transferred
22	EMC	Rolling Stock	Train interference induced onto S&T cables cause Right Side Failure of lineside systems Inrush current into rolling stock traction transformers causes large/long DC component which may operate Train Detection System (particularly AC immune DC track circuits),.e.g. passing neutral section. WSF	Train Delays	Signalling Equipment	Performance	3	3	6	Check compliance with NR/L2/SIG/11201. Use Optic Fibres for telecoms and apply EMC Good Practices.	2	2	4	Yes	No	No	NR/L2/SIG/11201		
23	EMC	Rolling Stock	Train interference induced onto S&T cables cause Wrong Side Failure of lineside systems Inrush current into rolling stock traction transformers causes large/long DC component which may operate Train Detection System (particularly AC immune DC track circuits),.e.g. passing neutral section. WSF	Fatalities	Signalling Equipment and Train Detection Systems	Safety	5	3	8	Check compliance with NR/L2/SIG/11201. Use Optic Fibres for telecoms and apply EMC Good Practices. Measurements and tests (Rolling Stock vs. lineside equipment), or alternatively, documentary evidence to be provided (EMC Project File) from other UK projects.	3	3	6	Yes	No	No	NR/L2/SIG/11201		
24	EMC	Rolling Stock	Train harmonics on feed current (including transients due to pantograph contact fluctuation).	Maloperation of Equipment and train's delays	Lineside Equipment	Performance	3	3	6	Compliance with EN 50121-3-1 and immunity below 150 kHz. Design to be performed as per BS EN 50388 section 10 (harmonics criteria) and BS EN 50317 (interaction between pantograph and overhead contact line). Apply EMC Good Practices, follow the applicable standards.	2	2	4	Yes	No	No	EN 50121-3-1 BS EN 50388 section 10 BS EN 50317		
25	EMC	Rolling Stock	Train harmonics on feed current (including transients due to pantograph contact fluctuation).	Maloperation of Equipment and train's delays	Station Equipment	Performance	3	3	6	Compliance with EN 50121-3-1 and immunity below 150 kHz. Design to be performed as per BS EN 50388 section 10 (harmonics criteria) and BS EN 50317 (interaction between pantograph and overhead contact line).	2	2	4	Yes	No	No	EN 50121-3-1 BS EN 50388 section 10 BS EN 50317		

RISK DEFINITION							RATING			MITIGATION	RATING			CSM Approach			RISK MANAGEMENT		
ID No	Hazard Type	Source of Hazard	Cause or Description of Hazard	Consequence	Immediate Victim (system or people)	Primary Business Objectives	Severity	Frequency	Combined	Safety Measures (Mitigations)	Severity	Frequency	Combined	Code of Practice	Reference System	Evaluation	Standard to Apply and/or comments	Validation/ Verification	Implementation Hazard Open / Close / Transferred
										Apply EMC Good Practices, follow the applicable standards.									
26	EMC	DNO Supplies	Excessive interference on DNO supplies causes equipment malfunction.	Maloperation of Equipment and train's delays	Signalling power supplies, telecoms, radio base stations, Train Detection System (TDS) & other signalling systems	Performance	3	3	6	Provide power supply back-up to most critical systems. Implement adequate maintenance processes to ensure that back-up power sources will operate as required on demand (e.g. that diesel is always available for diesel generators). Ensure adequate bonding to prevent high fault current and voltages.	2	2	4						
27	EMC	Third-Party Equipment and operations	Malfunction of the Railway equipment due to excessive interference from Third party Equipment, e.g.: Laboratory equipment; Power equipment; Local Electricity generating facilities;	Maloperation of Railway Equipment and train's delays	Railways Systems	Performance	3	3	6	Understand the activities, equipment and operations of the neighbouring sites. Coordinate with the asset owners. Apply EMC Good Practices, follow the applicable standards.	2	2	4						
28	EMC	Third-Party HV and EHV lines	Induced voltages leading to Right Side Failure or even Wrong Side Failure in extreme cases.	Maloperation of Equipment and train's delays. fatalities	Train detection systems or other signalling systems	Safety	5	2	7	Determine compliance with NR/L2/TEL/31107. Assumption is made that the existing neighbouring HV lines will not change, and no issue has been reported so far. National Grid (and other parties who might be concerned) to be contacted in case the GRIP5 HAZID analysis shows any potential impact.	3	2	5	Yes	No	No	NR/L2/TEL/31107		
29	EMC	Third-Party HV and EHV lines	Induced voltages from third party lines can generate dangerous voltages for NR OLE maintenance staff.	Fatalities	NR Staff	Safety	5	3	8	Strict operational procedures to be implemented. OLE to be earthed during maintenance. Test before touch.	3	2	5						

RISK DEFINITION							RATING			MITIGATION	RATING			CSM Approach			RISK MANAGEMENT		
ID No	Hazard Type	Source of Hazard	Cause or Description of Hazard	Consequence	Immediate Victim (system or people)	Primary Business Objectives	Severity	Frequency	Combined	Safety Measures (Mitigations)	Severity	Frequency	Combined	Code of Practice	Reference System	Evaluation	Standard to Apply and/or comments	Validation/ Verification	Implementation Hazard Open / Close / Transferred
30	EMC	Lightning	Equipment damages due to lightning strikes.	Delays	Railway Systems	Financial	3	2	5	Risk assessment to be performed at GRIP 5 stage. Surge arrestors to be installed for the most sensitive items if needed.	2	2	4						

Table 24 - EMC Hazard Matrix

Page 1 of 7	Document Review Notice (DRN)					
	Form Ref	NR/L2/INI/02009/F0044	Issue Date	05/09/2015	Issue	8.0

Project Number:	158454	**Project Name:**	Cambridge South Infrastructure Enhancements		
Project Manager:	Kevin Sullivan		**Principal Contractor:**	J Murphy & Son	
Engineering Deliverable Owner:	J Murphy & Son		**CEM Name:**	James Drury	
Submission Discipline:	Multi-Discipline		**CRE Name:**	Andrew Ratcliffe	
Document Number:	158454-Jms-Zz-Zzz-Pln-Eds-000003			**Revision No:**	1.0
Document Title:	Cambridge South Station - Electromagnetic Compatibility (Emc) Control Plan (Grip 4)			**GRIP:**	4
NR DPE Name: Steve Jones				**CSM Significant:**	Yes
Document Transmittal/Submission No:	158454-JMS-00-ZZZ-TRN-PDC-000142/001				
Date Received:	29/10/2021		**Date Return Required:**	29/11/2021	
REVIEWERS:-	**DRN No:**	158454-NRS-ZZ-ZZZ-DRN-EDS-000002 Rev 01		**DRN Date:**	16/11/2021

Name	Position	Discipline	Signature
Steve Jones	DPE	Buildings Civils - (Lead)	S.P.J
Simon Lane	PE MEP	Building Services	S.L
Alexandros Gavrilakis	SPE EMC	EMC	A.G

DISTRIBUTION LIST (of completed review):-

Name	Position	Action Required
Pierre Fayet	CRE-EMC	Response
James Drury	CEM	Response
Andrew Ratcliffe	CRE-C	Response
Niamh Leonard	Project Development Manager	Information
Kevin Sullivan	Senior Programme Manager	Information

Document Details:	**PDF** ☒	**Source Data** ☐	**Two Dimensional** ☐	**Model** ☐
Number: 158454-Jms-Zz-Zzz-Pln-Eds-000003	**Document Title:** Cambridge South Station - Electromagnetic Compatibility (Emc) Control Plan (Grip 4)			
Document URL: 158454-Jms-Zz-Zzz-Pln-Eds-000003				**Revision:** A01
DOCUMENT REVIEW:-			**Risk Review Level:**	Basic

Overall DRN Category	Rejected Non-compliant to contract	Accepted	Accepted with Amendments	Not Accepted Revise & Resubmit
2	**0**	**1**	**2**	**3**

- Acceptance of these documents by Network Rail is not be deemed as validation of the submission, nor does it infer fitness for purpose. Network Rail does not accept any liability for the submission.
- Any changes to the documents should be undertaken in accordance with change control procedures adopted by individual contracting organisations. Such variations are required to be formally recorded and evidence should accompany any resubmission.
- Without relieving the originating organisation of their contractual responsibilities my comments are as follows:
  - Overall DRN Category 0 rejected and a category 3 non acceptance requires the whole document(s) to be revised and resubmitted to address the comments. Prior to any re-work a way forward shall be agreed between supplier and the Designated Project Engineer
  - Overall DRN Category 2 acceptance with amendments requires the appropriate responses with additional information to be submitted to address the comments
  - Comment type 0 is used to capture comments if the submission is an overall DRN Category 0
  - Comment types 2A, 2B, 3A and 3B require a written response & Comment type 4 is for information only
  - Comment type 5 is used to identify an aspect of a submission which shows a 'Safe by Design' feature
- For comments types 2 or 3 a suffix is added to the comment type: **A**) Quality of Supplier's submission or **B**) Client preference/changes.

****Issued By:**	Steve Jones	**Signature:**	S.P.J	**Date:**	29/11/2021

DRN ACCEPTANCE AND/OR CLOSED OUT (including Supplier's responses)**:-**

****Closed By:**		**Signature:**		**Date:**	

Page 2 of 7	Document Review Notice (DRN)					
	Form Ref	NR/L2/INI/02009/F0044	Issue Date	05/09/2015	Issue	8.0

**Only to be signed by the Project Designated Project Engineer or person with such formally recorded delegated authority. Review comments to be returned to Supplier via control process agreed between the Project Manager and Supplier.

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*
1	5.5 LV systems – Section 5.2.4 states there are no REB's, this is conflicting.	SL	2A	Yes	Yes	We understand this comment applies to the EMC strategy rather than the EMC Control Plan. We confirm there is no REB. Therefore section 5.2.4 is correct and section 5.5 has been amended to be consistent. The EMC strategy document reference 158454-JMS-ZZ-ZZZ-STR-EPT-000003 has been amended accordingly.	Fayet		
2	5.6 Interfacing Projects – Do the proposed medical laboratories or the upgrades to the signalling systems not constitute 'major interfacing projects'?	SL	2A	Yes	Yes	We understand this comment applies to the EMC strategy rather than the EMC Control Plan. Section 5.6 of the EMC Strategy reference 158454-JMS-ZZ-ZZZ-STR-EPT-000003 has been amended accordingly.	Fayet		
3	6.1 EMC assessment – Section 5.6 states no major interfacing projects, this is conflicting.	SL	2A	Yes	Yes	We understand this comment applies to the EMC strategy rather than the EMC Control Plan. See above, both sections are now consistent with each other due to the changes that have been brought to section 5.6.	Fayet		
4	7.3.5.1 – Title refers to BS 7571 this should be 7671 as per following paragraphs.	SL	2A	Yes	Yes	We understand this comment applies to the EMC strategy rather than the EMC Control Plan, section 7.3.1.5. The EMC Strategy reference 158454-JMS-ZZ-ZZZ-STR-EPT-000003 has been amended accordingly.	Fayet		
5	General – Needs spelling and grammar checking	SL	2A	Yes	Yes	Both the EMC Strategy reference 158454-JMS-ZZ-ZZZ-STR-EPT-000003 and the EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 have been amended accordingly.	Fayet		
6	Section 4.1 : The latest EMC SI 2016 No. 1091	AG	2A	Yes	Yes	This comment applies to both the EMC	Fayet		

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*
	shall be referenced					strategy and EMC Control plan. The SI 2006 No. 3418 has been revoked and SI 2016 No. 1091 is now the correct regulation to use. Both the EMC Strategy reference 158454-JMS-ZZ-ZZZ-STR-EPT-000003 and the EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 have been amended accordingly.			
7	Page 21: EN 50122-2 referenced, is there a DC traction system nearby?	AG	2A	Yes	Yes	This comment applies to both the EMC strategy and EMC Control plan. The SI 2006 No. 3418 has been revoked and SI 2016 No. 1091 is now the correct regulation to use. Both the EMC Strategy reference 158454-JMS-ZZ-ZZZ-STR-EPT-000003 and the EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 have been amended accordingly.	Fayet		
8	Section 5.2.1.1: What is the mechanism of interference. Is it only towards or only from 3rd party HV? Can the risk be closed at this stage due to separations etc.?	AG	2A	Yes	Yes	The mechanism of interference is mostly by inductive coupling. We confirm the risk can be closed at this stage considering the separation distance is enough, which minimises the risk. The EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 has been amended accordingly.	Fayet		
9	Table 13: If all the mobile basestation transmitters are more than 100 m away from the site, why the risk is moderate and not low?	AG	2A	Yes	Yes	The evaluation of the risk depends of the the value of the electric and magnetic fields, that are related to the power of the GSM antennas, which is not known at this stage. Therefore, our recommendation is to keep those risks open for the antennas that are located at 370 and 420 m from the track. At GRIP5, electromagnetic field	Fayet		

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*
						calculations will be undertaken to fully assess the risk against BS EN 50121-4 criteria and close them if possible. The limit of 100 m in the document is indicative only since the appropriate criteria for GSM antennas is not the distance, but the value of the electromagnetic field that will be calculated at GRIP5. Note some examples from previous projects are available upon request if needed. The EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 has been amended accordingly, also incorporating the explanations above.			
10	Table 15: What is the risk to the bridge? What is the risk to/from the Astra Zeneca site (i.e. low frequency/high frequency, induction/radiation)?	AG	2A	Yes	Yes	The bridge itself as a civil structure is not impacted by EMC issues as long as it doesn't include any sensitive equipment, which is the case. It has been included for information purpose only, also considering that the bridge will be retained, hence it can be considered as a good reference location for EMC measurements. The risk to Astra Zeneca is essentially that the proposed changes (i.e. 4-tracking of the area) may disturb some sensitive laboratory equipment. We are adding one "nature of risk" column to this table to make it more explicit. Note this project is a specific project regarding EMC due to the presence of sensitive third parties in the area. Some discussions about third parties are currently ongoing that are not fully reflected in our EMC deliverables yet. More details about third parties will follow. The EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 has been	Fayet		

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*
						amended accordingly.			
11	Generic: Apart from the station area, is there a risk to 3rd parties to/from the new 4-tracking areas? (i.e. reduced distances etc.)	AG	2A	Yes	Yes	The risks from/to the new 4-tracking areas has not been fully quantified yet at this stage, however, it should be noted that the EMC interface with third parties will require a specific care on this project, more than any other project. Therefore, we have recommended that EMC background noise measurements are undertaken before and after construction, plus some specific studies and assessments to help NR in building a robust EMC file that will be based on evidence rather than high-level assessments to show the impact of the proposed changes. This is currently being discussed separately from those EMC Strategy and Control Plan documents. Our recommendation is that those documents shall be updated at GRIP5 once the discussions are more mature to reflect the latest status of the input from third parties.	Fayet		
12	Section 6.1.2, Note that for new Rolling Stock the TOC rather than the infrastructure owner is responsible for the its introduction assurance (incl EMC)	AG	2A	Yes	Yes	The EMC Control Plan reference 158454-JMS-ZZ-ZZZ-STR-EDS-000003 has been amended accordingly.	Fayet		
13	Hazard Log: As there is any existing hazard log, why a preliminary hazard workshop has not been performed to verify existing hazards and is moved to GRIP 5	AG	4	Yes	Yes	The EMC Hazard log is presented in appendix A of this EMC Control Plan. It is a revised version of the EMC Hazard log that has been delivered at GRIP3. We usually chair the EMC workshops at GRIP5 once the design is more mature with subcontractors on board.	Fayet		

To Perform Spelling Check on the Protected Form Click Here:

* Click in the last Cell (Column) to add a new row after the selected cell or to delete the selected row

Document Review Notice (DRN)				DRN No: 158454-NRS-ZZ-ZZZ-DRN-EDS-000002 Rev 01	
Form Reference	NR/L2/INI/02009/F0044	Issue Date	05/09/2015	Issue	8.0

Network Rail (NR)					Supplier			NR	
No	Comments	By	Type	Integration Activity	Comment Accepted	Responses	By	Response Accepted	*

END

Proof of Evidence – Electromagnetic Compatibility (Mr Rasheed R. Hameed) Appendix 04 Load Demand Assessment [158454-JMS-ZZ-ZZZ-ASS-EDS-000001]

(Inquiries Procedure (England & Wales) Rules 2004

January 2022

[This page is left intentionally blank]

Client	Network Rail
Project Title	Cambridge South Infrastructure Enhancements – Traction Power Loading Assessment (GRIP 4)
Project Number	158454
Operating Unit	M2 - CP6

REPORT

CAMBRIDGE SOUTH INFRASTRUCTURE ENHANCEMENT

TRACTION POWER LOADING ASSESSMENT

(GRIP 4)

MAIN AUTHOR	REVIEWER	APPROVER
		
Ahmed Bachoo	**Abubakar Tariq**	**Pierre Fayet**
E&P (HV) Senior Engineer	E&P (HV) Principal Design Engineer	E&P (HV) Associate Technical Director
07/12/2021	07/12/2021	07/12/2021

ISSUE CONTROL

DOCUMENT No.	158454-JMS-ZZ-ZZZ-ASS-EDS-000001

CURRENT REVISION	CURRENT STATUS CODE	SECURITY CLASSIFICATION
P02	S3 – Suitable for Review and Comments	Internal

REVISION HISTORY

REVISION	STATUS CODE	DATE	REVISION DESCRIPTION
P01	Draft Issue	14/10/2021	Draft Issue for client inputs review
P02	First Issue	07/12/2021	First Submission

Distribution List

NAME	JOB TITLE / COMPANY
Chetan Chikkanaswammy	Arcadis PM
Rob Humphries	Arcadis Design Manager
James Drury	Murphy CEM
Will Ross	Murphy Design Manager
	Network Rail DPE
Sophy Aldridge Neil	Network Rail PM
Lewis Wingford	Network Rail Project Sponsor

Contents

1 Abbreviations and Definitions 9
1.1 Abbreviations 9
1.2 Definitions 10
2 Introduction 12
2.1 Project Background 12
2.2 Purpose 12
2.3 Reference Documents 13
2.4 Scope of Traction Power Loading Assessment 13
2.5 Geographical Scope of the Loading Assessment 13
3 Methodology 16
3.1 Feeding Arrangement 16
3.1.1 Normal Feeding Arrangement (N-0) 16
3.1.2 Emergency Feeding Arrangement (N-1) at Milton FS 17
3.1.3 Emergency Feeding Arrangement (N-1) at Ugley FS 18
3.1.4 Emergency Feeding Arrangement (N-1) at Kings Lynn FS 19
4 Input Data, Assumptions, Exclusions and Risks 20
4.1 Input Data 20
4.1.1 Timetable 20
4.1.2 Rolling Stock 24
4.1.2.1 Mechanical Parameters: Class 375 4 - Car 24
4.1.2.2 Mechanical Parameters – Class 375 12 - Car 26
4.1.2.3 Mechanical Parameters – Class 710 5 - Car 28
4.1.2.4 Mechanical Parameters - Class 700 8 – Car 30
4.1.2.5 Mechanical Parameters - Class 700 12 – Car 32
4.1.3 Infrastructure and Electrical Data 34
4.1.3.1 Infrastructure Data 34
4.1.3.2 Electrical Data 37
4.1.3.3 Feeding Arrangement 38
4.1.4 Assumptions 39
4.1.4.1 Type of OLE 39
4.1.4.2 Track 41
4.1.4.3 Timetable 41
4.1.4.4 Existing Feeder 41
4.1.5 Exclusions 42

4.1.6 Risks 43
5 Traction Power Loading – Output 44
5.1 Assessment Criteria 44
5.1.1 Firm Service Capacity 44
5.1.2 Voltage Regulation 44
5.1.3 Negative Phase Sequence 44
5.2 Results 45
5.2.1 Summary of Results 46
5.2.1.1 30-Minute Load r.m.s Calculation 47
6 Recommendations 50
7 Conclusion 51

Tables

Table 1: List of Abbreviations 10
Table 2: List of Definitions 11
Table 3. Reference documents 13
Table 4 Timetable for Traction Power Loading Assessment Model 20
Table 5 Routes Schedule obtained from iTSS Version 1.4 and WTT 21
Table 6. Aerodynamic Resistance Coefficients for Class 375 25
Table 7. Aerodynamic Resistance Coefficients for Class 375 - 12car 27
Table 8. Aerodynamic Resistance Coefficients for Class 710 29
Table 9. Aerodynamic Resistance Coefficients for Class 700 31
Table 10. Aerodynamic Resistance Coefficients for Class 700 – 12 car 33
Table 11 Specific Details of Five Mile Diagram Per Route 36
Table 12 Specific Details of the Bonding Diagram Per Route 37
Table 13 Specific Details of the Isolation Diagram Per Route 37
Table 14 OLE Data 39
Table 15. Input Assumptions on Power Supply Incoming Feeder 41
Table 16 Maximum and Minimum Voltage Limits 44
Table 17 Summary of Results 46
Table 18 Normal Feeding Arrangement with Regen On – Train Performance Results 54
Table 19 Normal Feeding Arrangement with Regen Off – Train Performance Results 62
Table 20 Emergency Feeding Arrangement at Milton FS with Regen On – Train Performance Results 70
Table 21 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train Performance Results 77
Table 22 Emergency Feeding Arrangement at Ugley FS with Regen On – Train Performance Results 84

Figures

Figure 1 Cambridge South Traction Power Loading Model 14
Figure 2 Normal Feeding Arrangement 17
Figure 3 N-1 Feeding Arrangement at Milton FS, Loss of Supply 1 17
Figure 4 N-1 Feeding Arrangement at Milton FS, Loss of Supply F2 18
Figure 5 N-1 Feeding Arrangement at Ugley FS, Loss of Supply F2 18
Figure 6 N-1 Feeding Arrangement at Kings Lynn FS 19
Figure 7 Route 1&2 Train Graph – Kings Lynn to East Coast Main Line 22
Figure 8 Route 5&6 Train Graph – Kings Lynn to Stansted 23
Figure 9 Class 375 4 – Car – Tractive Effort Characteristics 24
Figure 10 Class 375 - 4 Car - Regenerative Effort Characteristics 25
Figure 11 Class 375 12 – Car – Tractive Effort Characteristics 26
Figure 12 Class 375 - 12 Car - Regenerative Effort Characteristics 27
Figure 13 Class 710 5 - Car – Tractive Effort Characteristics 28
Figure 14 Class 710 - 5 Car - Regenerative Effort Characteristics 29
Figure 15 Class 700 8 - Car – Tractive Effort Characteristics 30
Figure 16 Class 700 - 8 Car - Regenerative Effort Characteristics 31
Figure 17 Class 700 12 - Car – Tractive Effort Characteristics 32
Figure 18 Class 700 - 12 Car - Regenerative Effort Characteristics 33
Figure 19 Double Track OLE Configuration 40
Figure 20 Single Track OLE Configuration 40
Figure 21 30-Minute Load r.m.s at Milton FS during Normal Feeding Arrangement with Regen Off 47
Figure 22 30-Minute Load r.m.s at Milton FS during Emergency Feeding Arrangement at Kings Lynn FS with Regen On 48
Figure 23 30-Minute Load r.m.s at Milton FS during Emergency Feeding Arrangement at Ugley FS with Regen On 49
Figure 24 Total MVA (Generated & Consumed) For Normal Feeding Arrangement with Regen On 55
Figure 25 MVA Load at Milton FS Tx 1 – Normal Feeding Arrangement with Regen On 56
Figure 26 MVA Load at Milton FS Tx 2 – Normal Feeding Arrangement with Regen On 57
Figure 27 MVA Load at Kings Lynn FS – Normal Feeding Arrangement with Regen On 58
Figure 28 MVA Load at Ugley FS – Normal Feeding Arrangement with Regen On 59
Figure 29 Total MVA (Generated & Consumed) For Normal Feeding Arrangement with Regen Off 63
Figure 30 MVA Load at Milton FS Tx 1 – Normal Feeding Arrangement with Regen Off 64
Figure 31 MVA Load at Milton FS Tx 2 – Normal Feeding Arrangement with Regen Off 65
Figure 32 MVA Load at Kings Lynn FS – Normal Feeding Arrangement with Regen Off 66
Figure 33 MVA Load at Ugley FS – Normal Feeding Arrangement with Regen Off 67
Figure 34 Total MVA (Generated & Consumed) For Emergency Feeding Arrangement at Milton FS with Regen On 71

Figure 35 MVA Load at Milton FS Tx 1 – Emergency Feeding Arrangement at Milton FS with Regen On.... 72
Figure 36 MVA Load at Kings Lynn FS – Emergency Feeding Arrangement at Milton FS with Regen On ... 73
Figure 37 MVA Load at Ugley FS – Emergency Feeding Arrangement at Milton FS with Regen On 74
Figure 38 Total MVA (Generated & Consumed) For Emergency Feeding Arrangement at Kings Lynn FS with Regen On 78
Figure 39 MVA Load at Milton FS Tx 1 – Emergency Feeding Arrangement at Kings Lynn FS with Regen On 79
Figure 40 MVA Load at Milton FS Tx 2 – Emergency Feeding Arrangement at Kings Lynn FS with Regen On 80
Figure 41 MVA Load at Ugley FS – Emergency Feeding Arrangement at Kings Lynn FS with Regen On.... 81
Figure 42 Total MVA (Generated & Consumed) For Emergency Feeding Arrangement at Ugley FS with Regen On 85
Figure 43 MVA Load at Milton FS Tx 1 – Emergency Feeding Arrangement at Ugley FS with Regen On.... 86
Figure 44 MVA Load at Milton FS Tx 2 – Emergency Feeding Arrangement at Ugley FS with Regen On.... 87
Figure 45 MVA Load at Kings Lynn FS – Emergency Feeding Arrangement at Ugley FS with Regen On.... 88
Figure 46 Normal Feeding Arrangement with Regen On – Voltage Profile for Route 1 and 2 for all trains.... 90
Figure 47 Normal Feeding Arrangement with Regen On – Voltage Profile for Route 3 and 4 for all trains.... 90
Figure 48 Normal Feeding Arrangement with Regen On – Voltage Profile for Route 5 and 6 for all trains.... 91
Figure 49 Normal Feeding Arrangement with Regen On - Voltage Profile for Route 7 and 8 for all trains 91
Figure 50 Normal Feeding Arrangement with Regen On – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1 92
Figure 51 Normal Feeding Arrangement with Regen On – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2 93
Figure 52 Normal Feeding Arrangement with Regen On – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3 93
Figure 53 Normal Feeding Arrangement with Regen On – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4 94
Figure 54 Normal Feeding Arrangement with Regen On – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5 94
Figure 55 Normal Feeding Arrangement with Regen On – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6 95
Figure 56 Normal Feeding Arrangement with Regen On – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7 95
Figure 57 Normal Feeding Arrangement with Regen On – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8 96
Figure 58 Normal Feeding Arrangement with Regen Off – Voltage Profile for Route 1 and 2 for all trains.... 97
Figure 59 Normal Feeding Arrangement with Regen Off – Voltage Profile for Route 3 and 4 for all trains.... 97
Figure 60 Normal Feeding Arrangement with Regen Off - Voltage Profile for Route 5 and 6 for all trains 98
Figure 61 Normal Feeding Arrangement with Regen Off – Voltage Profile for Route 7 and 8 for all trains.... 98
Figure 62 Normal Feeding Arrangement with Regen Off – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1 99

Figure 63 Normal Feeding Arrangement with Regen Off – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2 100
Figure 64 Normal Feeding Arrangement with Regen Off – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3 100
Figure 65 Normal Feeding Arrangement with Regen Off – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4 101
Figure 66 Normal Feeding Arrangement with Regen Off – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5 101
Figure 67 Normal Feeding Arrangement with Regen Off – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6 102
Figure 68 Normal Feeding Arrangement with Regen Off – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7 102
Figure 69 Normal Feeding Arrangement with Regen Off – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8 103
Figure 70 Emergency Feeding Arrangement at Milton FS with Regen On - Voltage Profile for Route 1 and 2 for all trains 104
Figure 71 Emergency Feeding Arrangement at Milton FS with Regen On - Voltage Profile for Route 3 and 4 for all trains 104
Figure 72 Emergency Feeding Arrangement at Milton FS with Regen On - Voltage Profile for Route 5 and 6 for all trains 105
Figure 73 Emergency Feeding Arrangement at Milton FS with Regen On - Voltage Profile for Route 7 and 8 for all trains 105
Figure 74 Emergency Feeding Arrangement at Milton FS with Regen On – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1 106
Figure 75 Emergency Feeding Arrangement at Milton FS with Regen On – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2 107
Figure 76 Emergency Feeding Arrangement at Milton FS with Regen On – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3 107
Figure 77 Emergency Feeding Arrangement at Milton FS with Regen On – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4 108
Figure 78 Emergency Feeding Arrangement at Milton FS with Regen On – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5 108
Figure 79 Emergency Feeding Arrangement at Milton FS with Regen On – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6 109
Figure 80 Emergency Feeding Arrangement at Milton FS with Regen On – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7 109
Figure 81 Emergency Feeding Arrangement at Milton FS with Regen On – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8 110
Figure 82 Emergency Feeding Arrangement at Kings Lynn FS with Regen On - Voltage Profile for Route 1 and 2 for all trains 111
Figure 83 Emergency Feeding Arrangement at Kings Lynn FS with Regen On - Voltage Profile for Route 3 and 4 for all trains 111
Figure 84 Emergency Feeding Arrangement at Kings Lynn FS with Regen On - Voltage Profile for Route 5 and 6 for all trains 112

Figure 85 Emergency Feeding Arrangement at Kings Lynn FS with Regen On - Voltage Profile for Route 7 and 8 for all trains 112

Figure 86 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1 113

Figure 87 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2 114

Figure 88 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3 114

Figure 89 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4 115

Figure 90 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5 115

Figure 91 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6 116

Figure 92 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7 116

Figure 93 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8 117

Figure 94 Emergency Feeding Arrangement at Ugley FS with Regen On - Voltage Profile for Route 1 and 2 for all trains 118

Figure 95 Emergency Feeding Arrangement at Ugley FS with Regen On - Voltage Profile for Route 3 and 4 for all trains 118

Figure 96 Emergency Feeding Arrangement at Ugley FS with Regen On - Voltage Profile for Route 5 and 6 for all trains 119

Figure 97 Emergency Feeding Arrangement at Ugley FS with Regen On - Voltage Profile for Route 7 and 8 for all trains 119

Figure 98 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1 120

Figure 99 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2 121

Figure 100 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3 121

Figure 101 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4 122

Figure 102 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5 122

Figure 103 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6 123

Figure 104 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7 123

Figure 105 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8 124

Figure 106 Architecture of the simulation software 127

1 Abbreviations and Definitions

1.1 Abbreviations

Table below outlines a list of Abbreviations applicable to the document.

AC	Alternating Current
AFD	Alternate Feeding Diagram
AiP	Approval in Principle
AT	Auto-Transformer
BS	British Standard
BT	Booster Transformer
Cat	Catenary
CENELEC	Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardization)
CSIE	Cambridge South Infrastructure Enhancements
CTRL	Channel Tunnel Rail Link
Cont	Contact
Drg	Drawing
ELR	Engineer's Line Reference
EN	Euro-Norm (European Standard)
ENA	Energy Networks Association
FBC	Full Business Case
FS	Feeder Station
FSC	Firm Service Capacity
FTN	Fixed Telecom Network
GRIP	Governance for Railway Investment Projects
HS1	High Speed 1 (formerly known as Channel Tunnel Rail Link [CTRL])
HV	High Voltage
iTSS	Indicative Train Service Specification
JMS	J. Murphy & Sons Limited
km	Kilometre
km.h-1	Kilometre per hour
kV	Kilo Volt
LUL	London Underground Limited
MFD	Major Feeding Diagram
MPC	Mid-Point Connection
MVA	Mega Volt-Amperes

MWh	Mega Watt Hour
No.	Number
NPS	Negative Phase Sequence
NR	Network Rail
OLE	Overhead Line Equipment
Ref	Reference
r.m.s	Root Mean Squared
RSC	Return Screening Conductor
tph	Trains Per Hour
TSC	Track Sectioning Cabin
TQ	Technical Query
TWAO	Transport and Works Act Order
UK	United Kingdom
V	Volt
WAML	West Anglia Main Line
WTT	Working Timetable

Table 1: List of Abbreviations

1.2 Definitions

Table below outlines the list of definitions applicable to the document.

N-0	Normal Feeding Arrangement i.e. the feeder station feeds the train sections without any issues to its transformers. Please refer to NR/L2/ELP/27275 Page 14 for further detail.
N-1	Emergency Feeding Arrangement i.e. occurs when one of the transformers at the feeder station stops working. Please refer to NR/L2/ELP/27275 Page 14 for further detail.
N-2	Occurs when two transformers at the Feeder Station are not available and stop working. Please refer to NR/L2/ELP/27275 Page 14 for further detail. Also the requirement from NR/L1/ELP/27000 page 24 must be met for N-2.
Firm Service Capacity (FSC)	The capacity reserved at the point of supply to meet the demand associated with an interruption. For two transformer sites, this is usually 1 of the 2 circuits and for a single transformer site a single interruption on an adjacent supply point.
GRIP 3 – Option Selection & Approval in Outline	Sufficiently developed options which may be supported by survey and analysis showing ability to achieve specification, integration across disciplines, constructability and highlighting land purchases and other long lead items. This would be the stage when Approval of Outline is achieved for each affected discipline.
GRIP 4 – Single Option Development & Approval in Principle	Development of the chosen single option. This is the stage when the assurance activities of the suppliers should enable Network Rail to use a risk-based assurance process.

GRIP 5 – Detailed Design	Drawings and documentation that enable the infrastructure to be constructed, tested and commissioned.
GRIP 6 – Construction, Testing and Commissioning	To enable the works to be brought into service with evidence showing correct construction, testing and commissioning records and results including details of any changes to design and outstanding works/defects.
Hazard	Situation with potential to cause harm or loss.
Risk	Something that may happen in the future with an adverse effect on the Project.
Sponsor	A Network Rail person who acts as the single point of contact between the Client and the Project or Development Manager.
Supplier	Any provider (internal or external to Network Rail) of engineering deliverables or functions.

Table 2: List of Definitions

2 Introduction

The Cambridge South Infrastructure Enhancements (CSIE) Project is a multi-disciplinary project being undertaken by Arcadis for the client, J. Murphy & Sons Limited (JMS). The aim of the Cambridge South Infrastructure Enhancement Project is to develop infrastructure options to improve connectivity in the Cambridgeshire region. As outlined by Network Rail, the objective of GRIP 4 is to complete deliverables and surveys to an Approval in Principle (AiP) Design for all disciplines (including provision of agreed surveys) that will enable the project to proceed to GRIP 5 and achieve a successful decision to deliver following Full Business Case (FBC) submission. Alongside this the project needs to secure the necessary consents to proceed, namely Network Change Approval and a Transport and Works Act Order (TWAO).

2.1 Project Background

Cambridge is a successful and fast-growing city and by 2020, the Cambridge Biomedical Campus is expected to house the largest concentration of biomedical expertise in Europe. Over the next four years many new jobs are expected to be created and the Cambridge Southern Fringe will be further developed. This is expected to place significant pressures on an already close to capacity transport system. There are local and national stakeholder aspirations for a new station to the south of Cambridge in the vicinity of Addenbrooke's Hospital.

The aim of the Cambridge South Infrastructure Enhancements Project is to develop infrastructure options to improve connectivity and capacity in the Cambridgeshire region meeting rail demand forecast up to 2043. The baseline infrastructure for this work will be based on 2020.

Cambridge is served by both the East Coast Main Line (via the Shepreth Branch) and the West Anglia Main Line. Both routes offer services to and from London. In addition, the city is served by Cross Country services which provide connectivity between Stansted Airport and Birmingham as well as several intermediate locations. Thameslink services on the East Coast Main Line provide direct trains across central London to Maidstone East and Brighton via Gatwick Airport.

Early-stage operational feasibility work and timetable analysis undertaken by Network Rail and train operating companies in 2017, identified the need for several interventions to accommodate long term capacity needs:

- Four-tracking of the West Anglia Main Line between Shepreth Branch Junction and the existing Cambridge Station;
- Reconstruction of the A1134 Long Road overbridge (Structure BGK/1544a) to facilitate Four-tracking;
- A new station at Cambridge South;
- Grade separation at Shepreth Branch Junction to provide for future East West Rail requirements.

2.2 Purpose

The purpose of this report is to summarise the results of the traction power loading assessment undertaken for the Cambridge South Infrastructure Enhancements project. The traction power loading assessment work has been carried out to assess if the existing electrical infrastructure at Milton Feeder Station is capable of supporting the additional load due to an increase in the number of trains in the timetable, running between Shepreth Branch Junction and Cambridge Station and stopping at the new Cambridge South Station.

The results of the traction power loading assessment are presented in this report.

2.3 Reference Documents

Ref No.	Document Title	Document No.
Ref 1	Network Rail Southeast Territory AC Major Feeding Diagram	QH/EP/MFD/01.01 Revision C
Ref 2	Anglia Route Electrification - 25kV Alternate Feeding Diagrams	NR/AFD/RF1/1 Revision C, NR/AFD/RF/1/5 Rev D, NR/AFD/RF/1/6 Rev B, NR/AFD/RF/1/2 Rev C, NR/AFD/RF/1/8 Rev C
Ref 3	2043 iTSS from CRD Version 1.4	eb ref: 158454-NWR-GV_000-ZZ-SPE-MPM-000001
Ref 4	Timetable Confirmation	158454-JMS-00-ZZZ-ETQ-EMG
Ref 5	Cambridge South Infrastructure Enhancements Cambridge South Scheme Plan	20-SO-055 Version 2.0

Table 3. Reference documents

2.4 Scope of Traction Power Loading Assessment

The scope covers the 25 kV traction power loading assessment for the Cambridge South Infrastructure Enhancements Project. The main area of interest in this project is the area between Shepreth Branch Junction and Cambridge Station which operates using a classic 25 kV electrification with booster transformers.

The Anglia Major Feeding Diagram (MFD) Ref 1 is presented in Appendix C.

The traction power loading assessment has been carried out according to the feeding arrangements of Milton Feeder Station and its neighbouring feeder stations.

2.5 Geographical Scope of the Loading Assessment

The area of interest is the electrical section normally fed by Milton Feeder Station. The electrical section for Cambridge South traction power loading assessment will be formed of several electrical sub sections which are described and shown in Figure 1 below.

The extended geographical areas i.e., Stansted and Kings Lynn have been included to incorporate the emergency feeding conditions i.e. N-1.

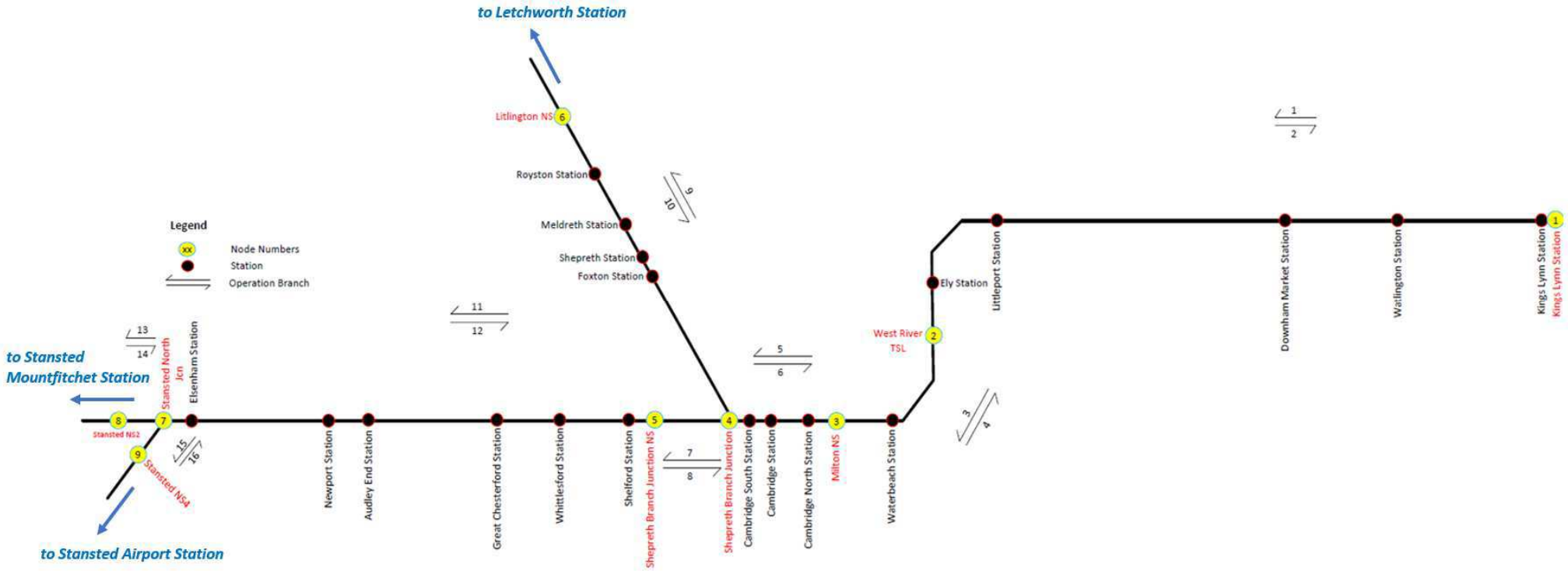


Figure 1 Cambridge South Traction Power Loading Model

As seen from Figure 1, the traction power loading assessment covers the area fed by Milton FS during N-0 (normal) condition i.e. up to the neutral sections at Littlington (Royston Branch) and Littleport (WAML) including all the stations as well as the new Cambridge South Station.

3 Methodology

Assessment of the traction power loading supplies in Normal and N-1 feeding conditions, have been performed using modelling based on establishing the equivalent electrical circuit of the network and running trains according to pre-defined timetables. Detail of the simulator used in this study is given in Appendix B.

Simulation of the network offers the ability to determine the traction power values and levels of voltage at different busbars and nodes, as well as the levels of current flowing in different paths and conductors of the network. This will enable assessment of the levels of traction power at the Feeder Station.

The basic structure of the traction power simulation model for Cambridge South Infrastructure Enhancements project is shown in Figure 1. From Figure 1, the Cambridge South model is built up using nodes and branches which are the core components of any traction power simulation modelling.

A node is a point in the model that defines the location of the area to be modelled. A branch can be found between two nodes and runs in opposite directions. Within the branches, stations can be located and defined.

From the MFD Ref 1 (which can be found in Appendix C), Milton Feeder Station feeds the majority of the network around the Cambridge area. With the introduction of a new station i.e. Cambridge South, there will be an increase in the number of trains in the timetable which will have an impact on the Firm Service Capacity at Milton Feeder Station.

At Milton FS, there are two transformers both rated at 26.5 MVA. For this modelling purposes, four feeding arrangements have been considered due to the normal and emergency feeding arrangement at Milton FS and its neighbouring feeder stations. The four feeding arrangements are described below:

- Normal Feeding Arrangement (N-0);
- Emergency N-1 Feeding Arrangement when one of the transformers at Milton FS is non-operational;
- Emergency N-1 Feeding Arrangement when one transformer at Ugley FS is non-operational;
- Emergency N-1 Feeding Arrangement when one transformer at Kings Lynn FS is non-operational.

It should be noted that the Normal Feeding Arrangement shall be undertaken with Regen On and Off and the Emergency Feeding Arrangements shall be undertaken with Regen On.

3.1 Feeding Arrangement

3.1.1 Normal Feeding Arrangement (N-0)

In the normal feeding arrangement, it is assumed that both the transformers at Milton FS are fully functioning and operate at their normal conditions with the bus coupler open as per AFD Ref 2. Figure 2 below shows an extract from the AFD Ref 2 in normal feeding arrangement.

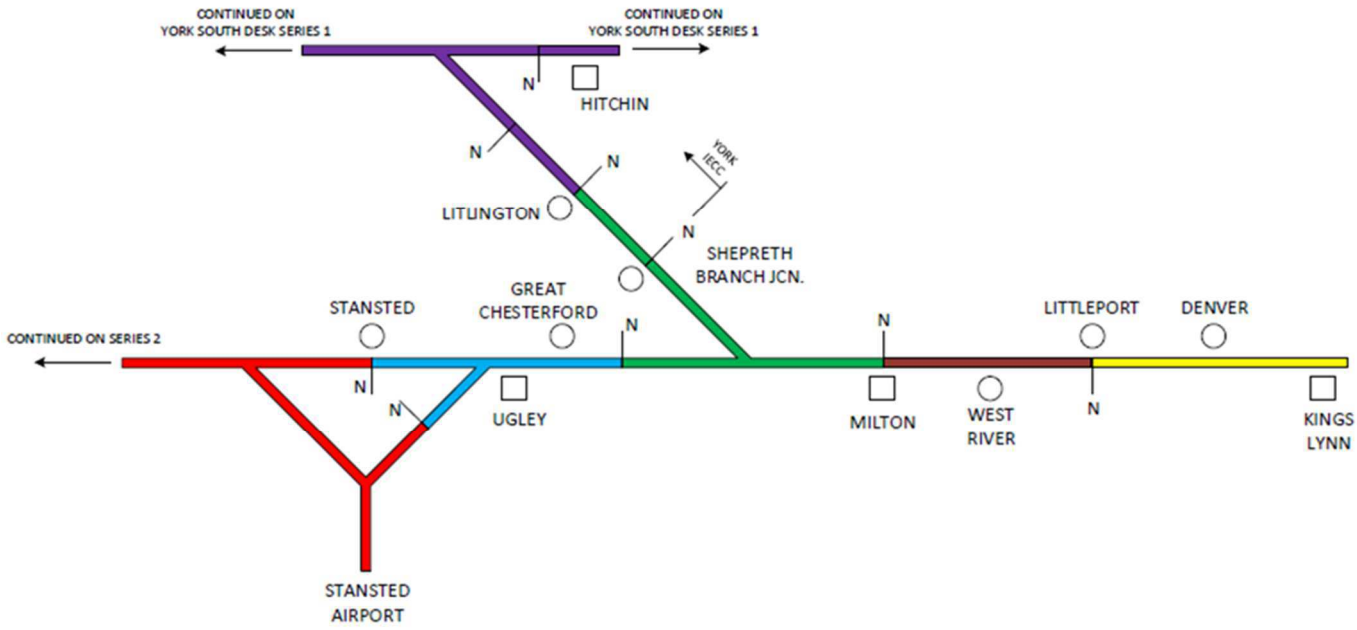


Figure 2 Normal Feeding Arrangement

3.1.2 Emergency Feeding Arrangement (N-1) at Milton FS

During the N-1 feeding arrangement, one of the transformers at Milton FS is out of use & non-operational and the bus coupler is closed as per AFD Ref 2. Figure 3 and Figure 4 below show an extract from the AFD Ref 2 (Drg No. NR/AFD/RF/1/5 Rev D and Drg No. NR/AFD/RF/1/6 Rev B) in N-1 feeding arrangement.

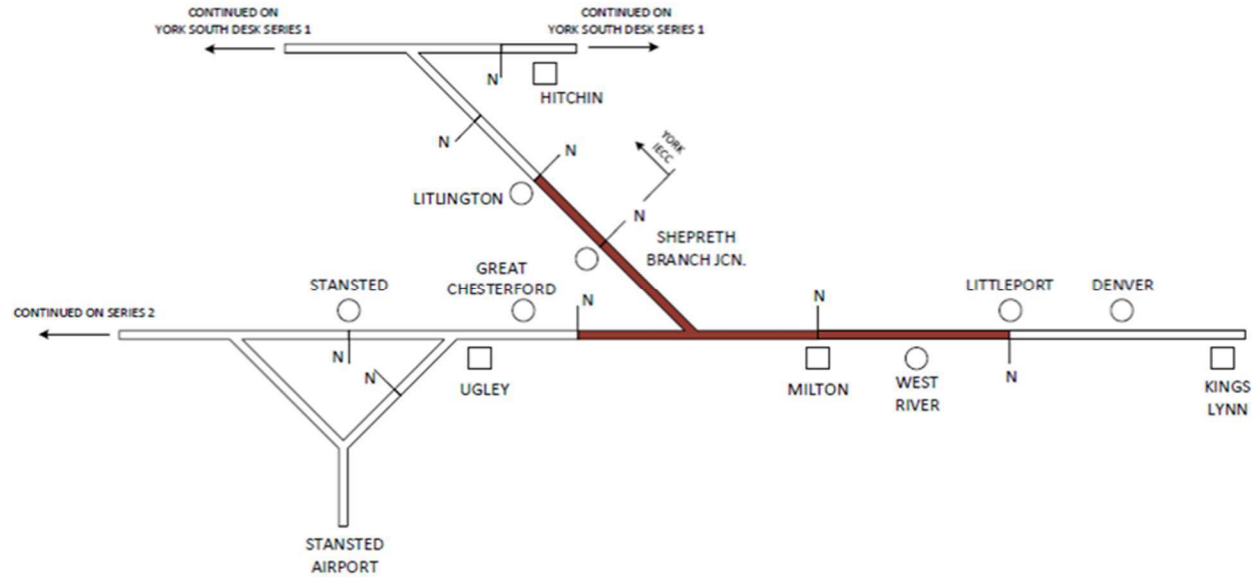


Figure 3 N-1 Feeding Arrangement at Milton FS, Loss of Supply 1

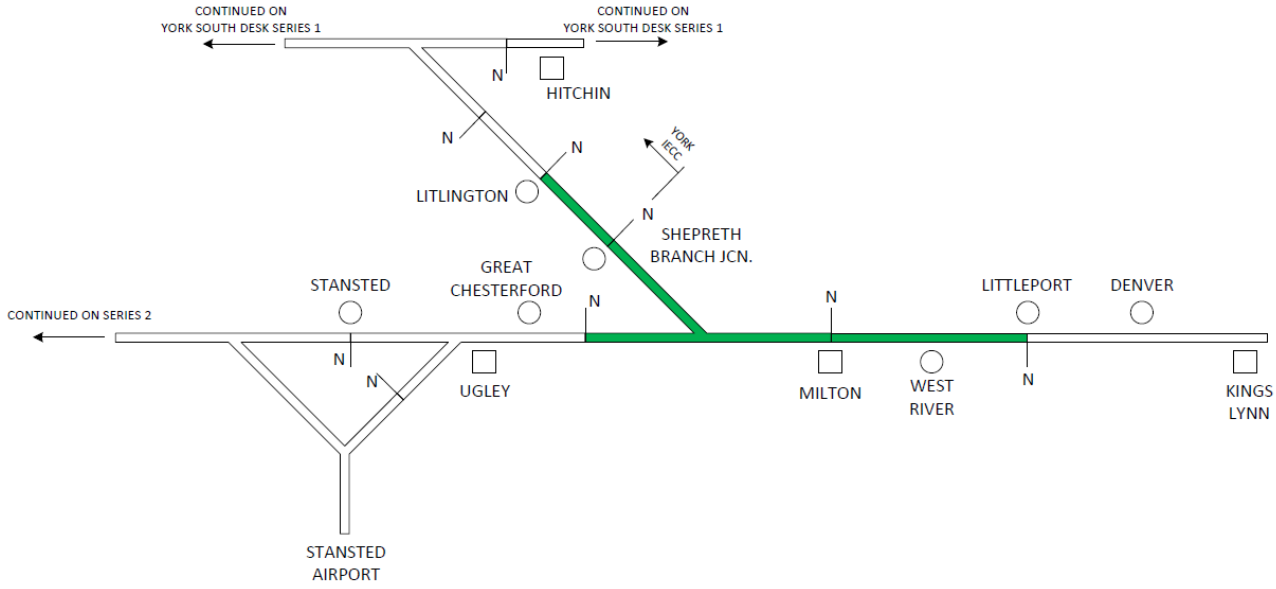


Figure 4 N-1 Feeding Arrangement at Milton FS, Loss of Supply F2

3.1.3 Emergency Feeding Arrangement (N-1) at Ugley FS

During the N-1 feeding arrangement, the transformer at Ugley FS is out of use & non-operational and the bus coupler is open as per AFD Ref 2. Figure 5 below shows an extract from the AFD Ref 2 (Drg No. NR/AFD/RF/1/2 Rev C) in N-1 feeding arrangement.

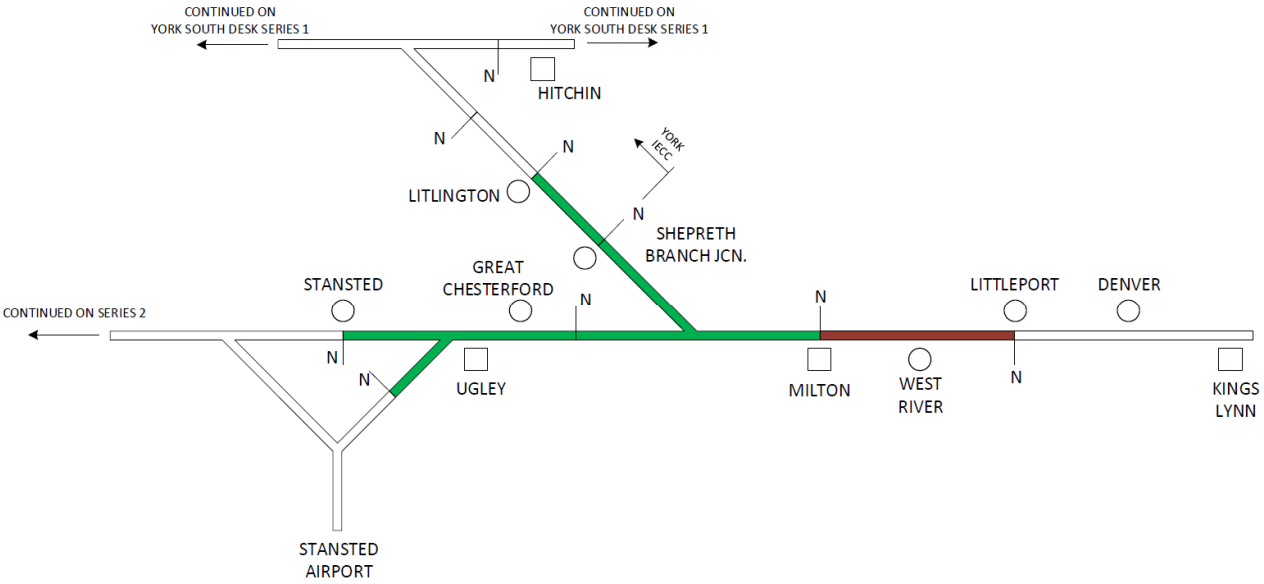


Figure 5 N-1 Feeding Arrangement at Ugley FS, Loss of Supply F2

3.1.4 Emergency Feeding Arrangement (N-1) at Kings Lynn FS

During the N-1 feeding arrangement, the transformer at Kings Lynn FS is out of use & non-operational and the bus coupler at Littleport TSC is open as per AFD Ref 2. Figure 6 below shows an extract from the AFD Ref 2 (Drg No. NR/AFD/RF/1/8 Rev C) in N-1 feeding arrangement.

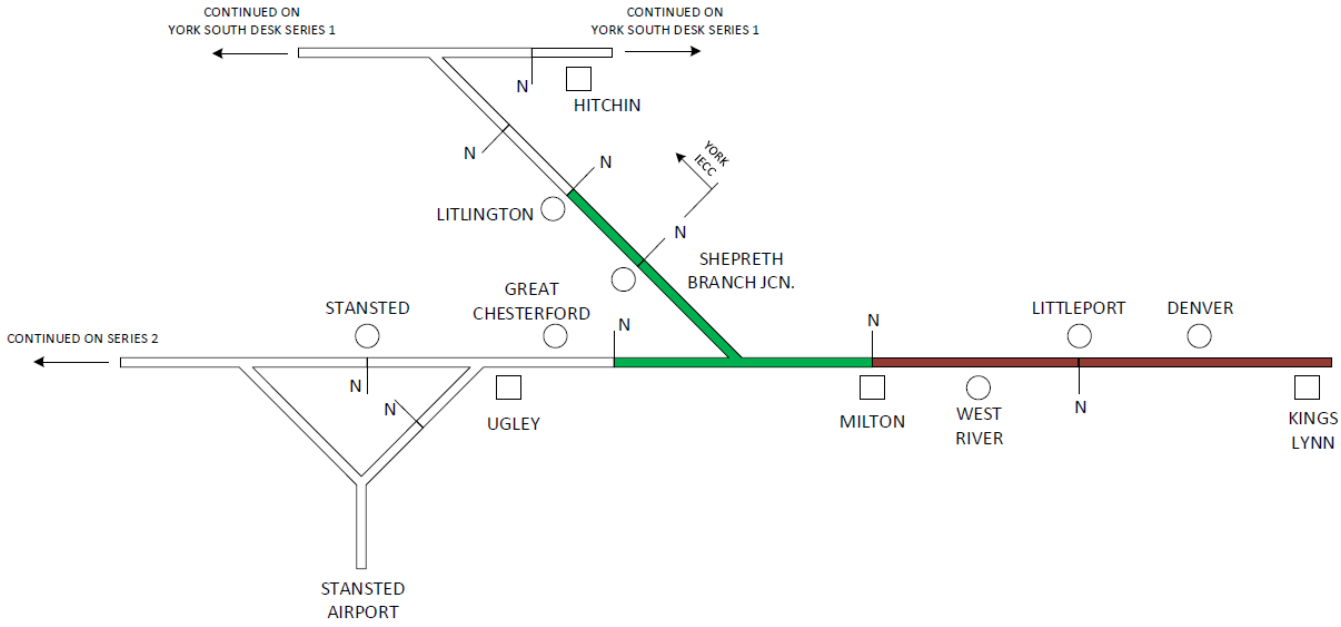


Figure 6 N-1 Feeding Arrangement at Kings Lynn FS

4 Input Data, Assumptions, Exclusions and Risks

The following section gives an overview of the modelling assumptions made and data references used in the modelling.

4.1 Input Data

4.1.1 Timetable

The data for the timetable, types of rolling stock used and the routes schedule in this study have been obtained from iTSS Version 1.4 Ref 3 via eB reference number: 158454-NWR-GV_000-ZZ-SPE-MPM-000001 and WTT. The WTT was used to create the stopping patterns for the trains.

Table 4 below shows the timetable used in the traction power loading assessment model from the iTSS Version 1.4 Ref 3.

Route	ID from iTSS	From	To	Rolling Stock Type	TPH	Speed	Train Formation
1	GT1, GT3	Kings Lynn	Kings Cross	Class 387	1	145 km.h-1	12 car
	GT2	Kings Lynn	Cambridge	Class 387	1	145 km.h-1	4 car
2	GT1	Kings Cross	Kings Lynn	Class 387	1	145 km.h-1	12 car
	GT3	Kings Cross	Ely	Class 387	1	145 km.h-1	12 car
3	GT5, GT6, GT9	Cambridge	Kings Cross	Class 700, Class 365/387	2 & 3	145 km.h-1	Class 700 8 car, Class 365/387 12 car
	GT7, GT8	Cambridge	Brighton	Class 700	2	145 km.h-1	12 car
4	GT5, GT6, GT7, GT8	Kings Cross	Cambridge	Class 700	2	145 km.h-1	Mix of 8 and 12 car
	GT7, GT8	Brighton	Cambridge	Class 700	2	145 km.h-1	12 car
5	GA3	Cambridge	Stansted Airport	Class 755	1	145 km.h-1	4 car
	GA3	Birmingham New Street	Stansted Airport	Class 755	1	145 km.h-1	4 car
6	GA3	Stansted Airport	Birmingham New Street	Class 755	1	145 km.h-1	4 car
7	GA4, GA6	Cambridge	Liverpool Street	Class 720	2	145 km.h-1	10 car
	GA5, GA7	Kings Lynn	Liverpool Street	Class 720	1	145 km.h-1	10 car
	GA4, GA6	Ely	Liverpool Street	Class 720	1	145 km.h-1	10 car
8	GA4	Bishops Stortford	Cambridge	Class 720	1	145 km.h-1	10 car
	GA4, GA6	Liverpool Street	Cambridge	Class 720	1 & 2	145 km.h-1	10 car

Table 4 Timetable for Traction Power Loading Assessment Model

The routes schedule is shown in Table 5 below. The routes modelled in the traction power study are extensive i.e. from Kings Lynn to East Coast Main Line and from Kings Lynn to Stansted.

Route	Description
Route 1	From Kings Lynn Station to Royston Station
Route 2	From Royston Station to Kings Lynn Station
Route 3	From Cambridge North Station to Royston Station
Route 4	From Royston Station to Cambridge North Station
Route 5	From Kings Lynn Station to Elsenham Station towards Stansted Airport Station
Route 6	From Elsenham Station via Stansted Airport Station to Kings Lynn Station
Route 7	From Kings Lynn Station to Elsenham Station towards Stansted Mountfitchet Station
Route 8	From Elsenham Station via Stansted Mountfitchet Station to Kings Lynn Station

Table 5 Routes Schedule obtained from iTSS Version 1.4 and WTT

The timetable used incorporates trains operating between Kings Lynn Station in the North, Royston Station and Elsenham Station in the South. The simulations for the traction power loading assessment were run over the morning peak timetable from 0546 to 1033.

Train graphs of the routes modelled are shown in Figure 7 and Figure 8 below, demonstrating the number of trains per hour, and stopping stations.

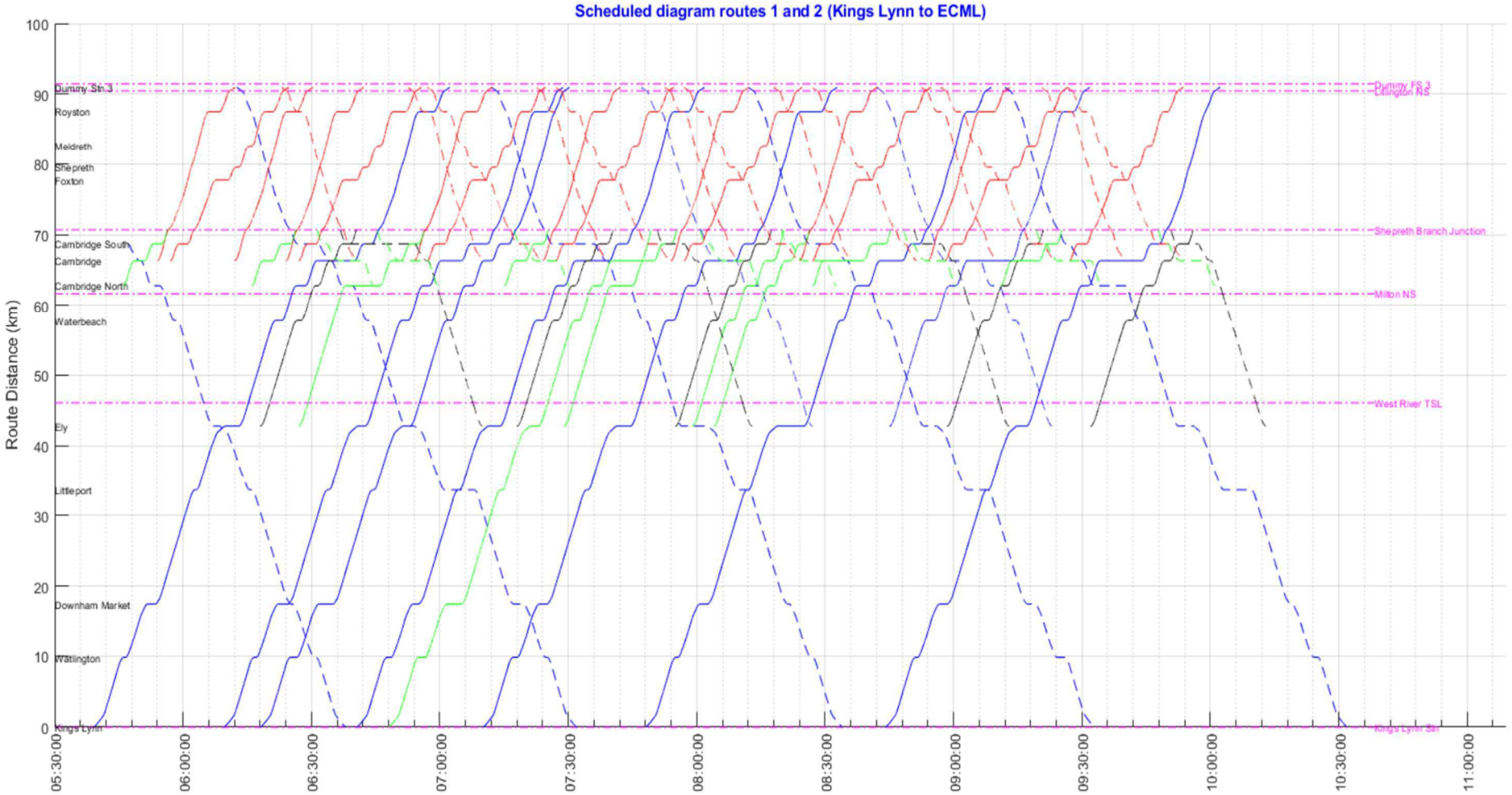


Figure 7 Route 1&2 Train Graph – Kings Lynn to East Coast Main Line

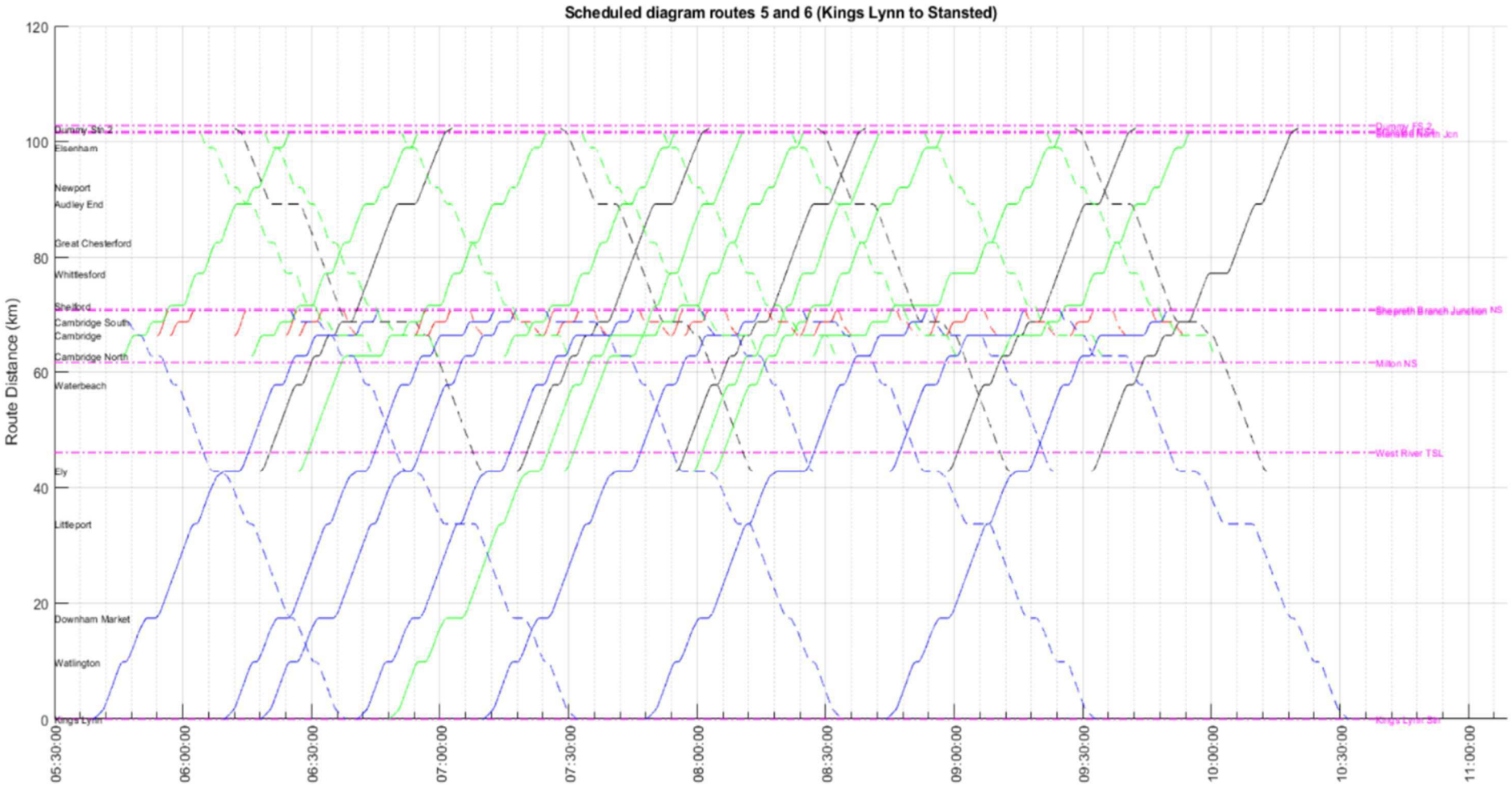


Figure 8 Route 5&6 Train Graph – Kings Lynn to Stansted

4.1.2 Rolling Stock

The traction characteristics of the rolling stock have been modelled considering their tractive/braking effort characteristics as well as their aerodynamic resistance that were available in Arcadis's internal library of rolling stock. In some cases (Class 375), the Arcadis simulator has defined those characteristics using basic parameters such as the maximum power, based on similar 5 or 12 car formations, assuming typical formation e.g., 4 or 10 or 12 car would consume similar traction load.

4.1.2.1 Mechanical Parameters: Class 375 4 - Car

A. Tractive Effort

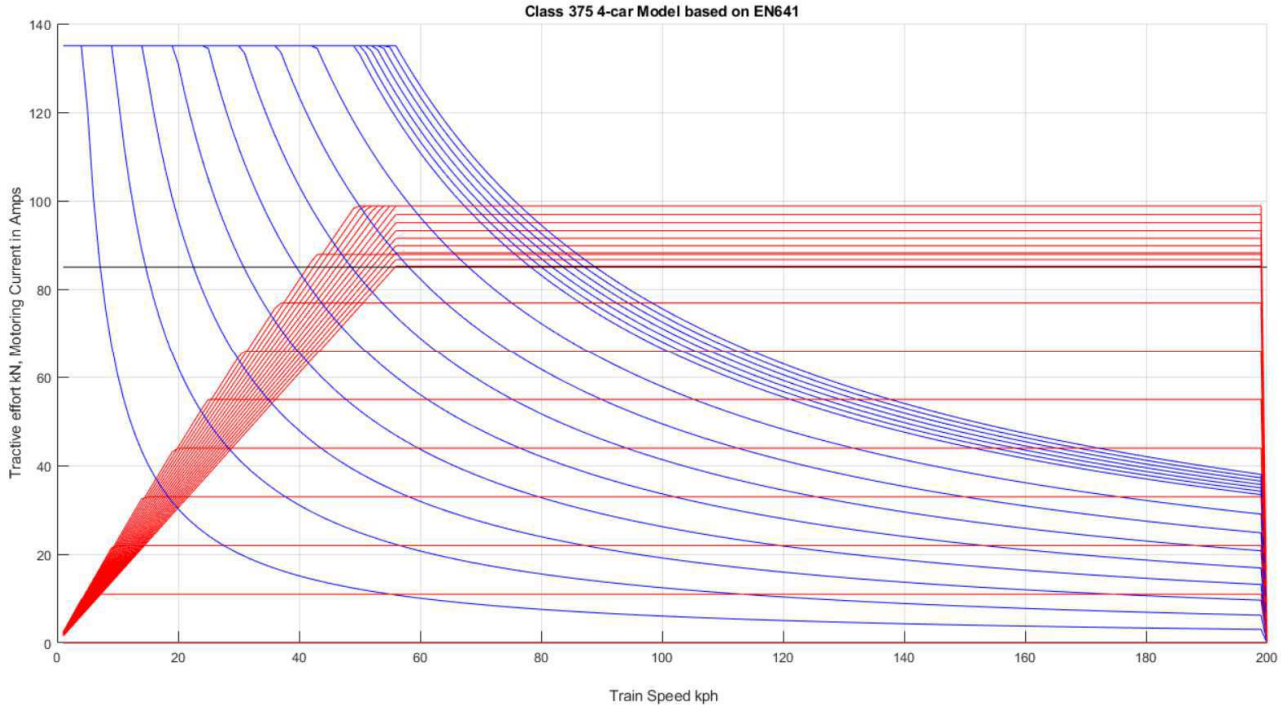


Figure 9 Class 375 4 – Car – Tractive Effort Characteristics

Note: Multiple curves of tractive effort and motoring current for line voltages between 17.5 kV to 29 kV in 0.5 kV steps are shown in Figure 9 above.

B. Braking Effort

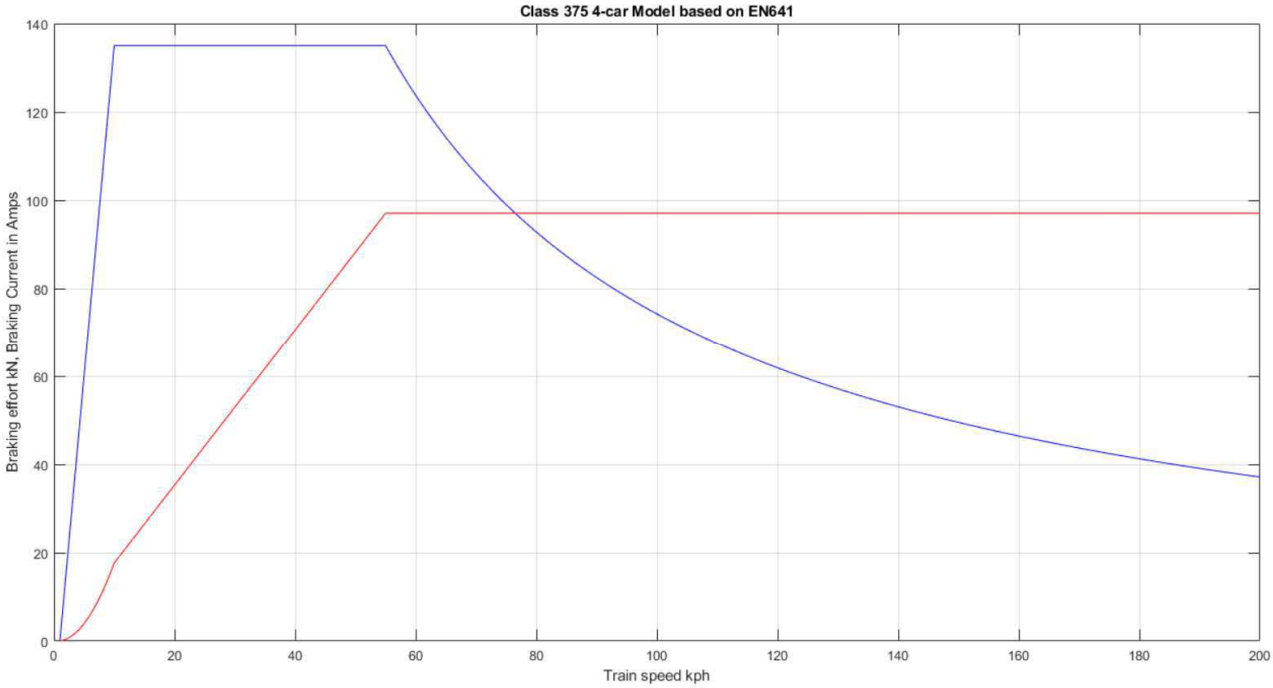


Figure 10 Class 375 - 4 Car - Regenerative Effort Characteristics

C. Tractive Resistance

The tractive resistance is calculated using the following formula:

$$(A + Bv)x\ W + Cv^2$$

where, v = train speed (km/h) and W = weight (tonnes)

Formula Coefficients:

Coefficient	Coefficient	Unit
A	6.225	kN
B	0.02433	(kN.h)/(km)
C	0.002126	$kN.h^2km^2$

Table 6. Aerodynamic Resistance Coefficients for Class 375

4.1.2.2 Mechanical Parameters – Class 375 12 - Car

A. Tractive Effort

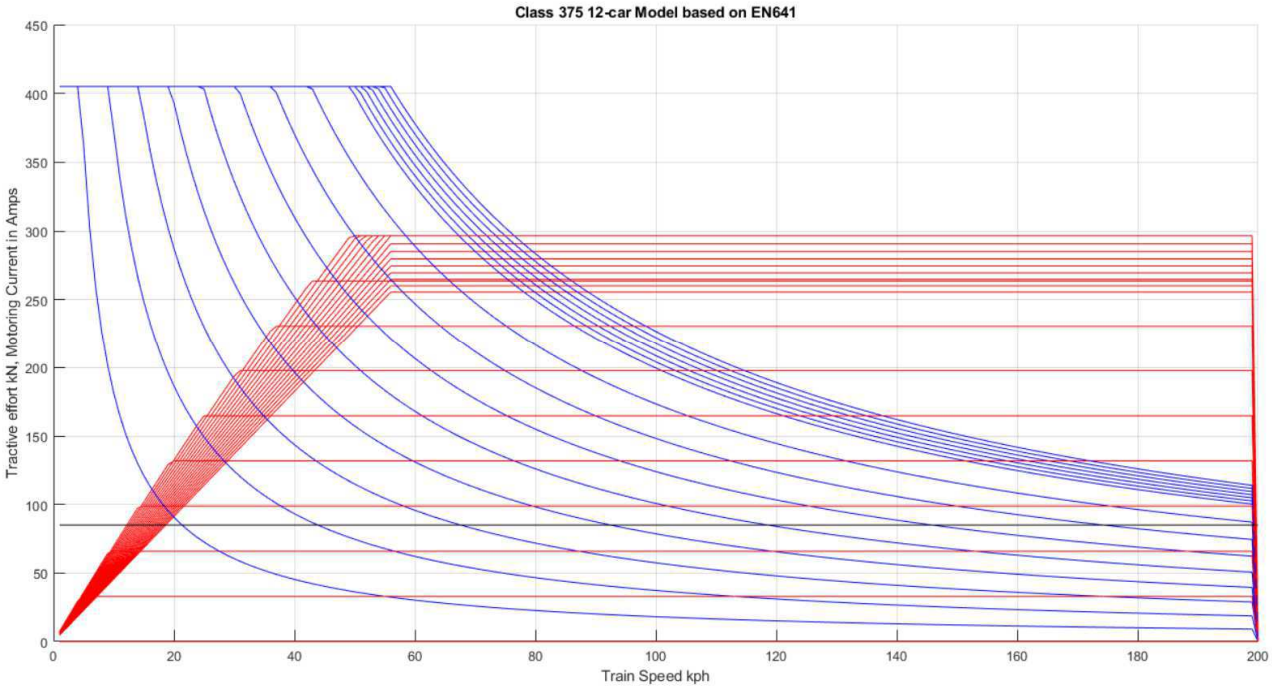


Figure 11 Class 375 12 – Car – Tractive Effort Characteristics

Note: Multiple curves of tractive effort and motoring current for line voltages between 17.5 kV to 29 kV in 0.5 kV steps are shown in Figure 11 above.

B. Braking Effort

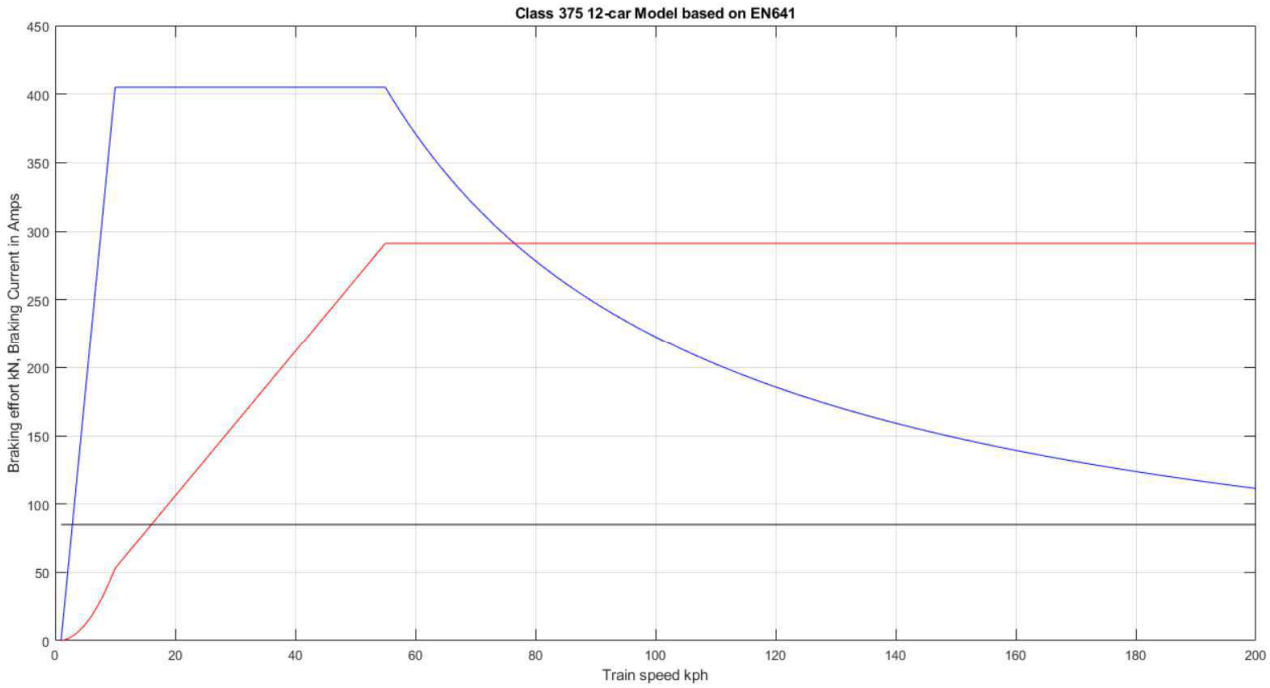


Figure 12 Class 375 - 12 Car - Regenerative Effort Characteristics

C. Tractive Resistance

The tractive resistance is calculated using the following formula:

$(A + B)x\ W + Cv^2$

where, v = train speed (km/h) and W = weight (tonnes)

Formula Coefficients:

Coefficient	Coefficient	Unit
A	18.675	kN
B	0.073	(kN.h)/(km)
C	0.0021	$kN.h^2km^2$

Table 7. Aerodynamic Resistance Coefficients for Class 375 - 12car

4.1.2.3 Mechanical Parameters – Class 710 5 - Car

A. Tractive Effort

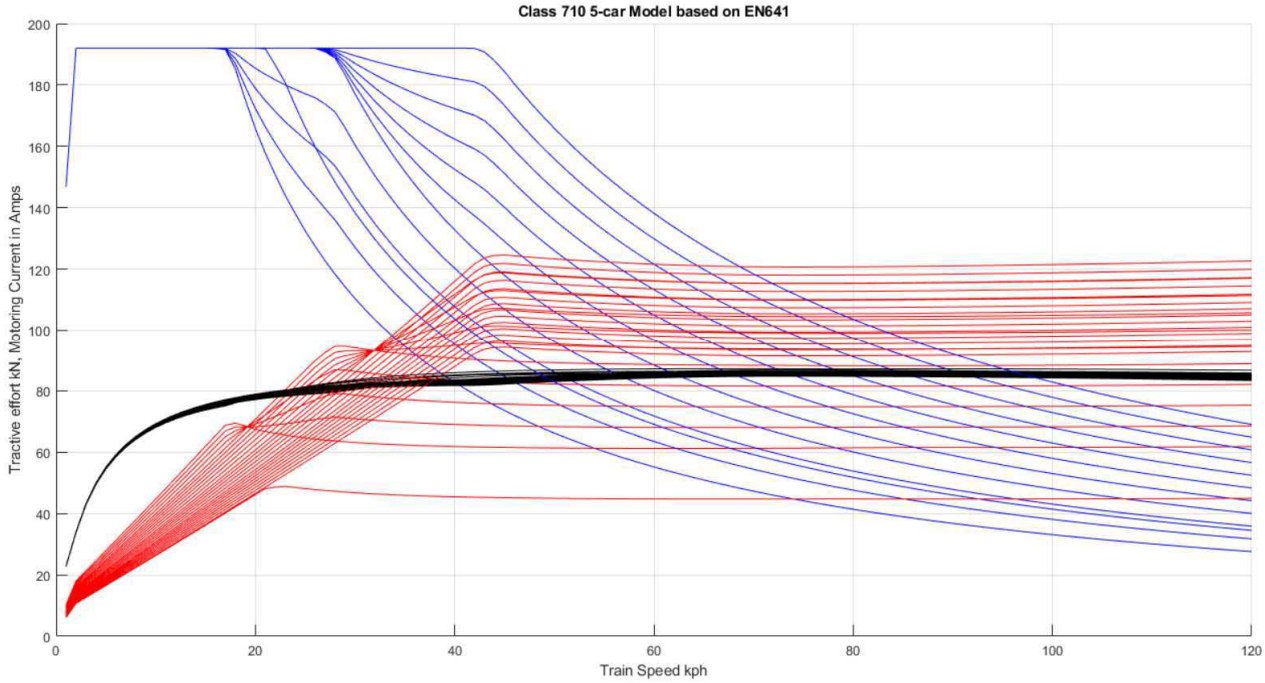


Figure 13 Class 710 5 - Car – Tractive Effort Characteristics

Note: Multiple curves of tractive effort and motoring current for line voltages between 17.5 kV to 29 kV in 0.5 kV steps are shown in Figure 13 above.

B. Braking Effort

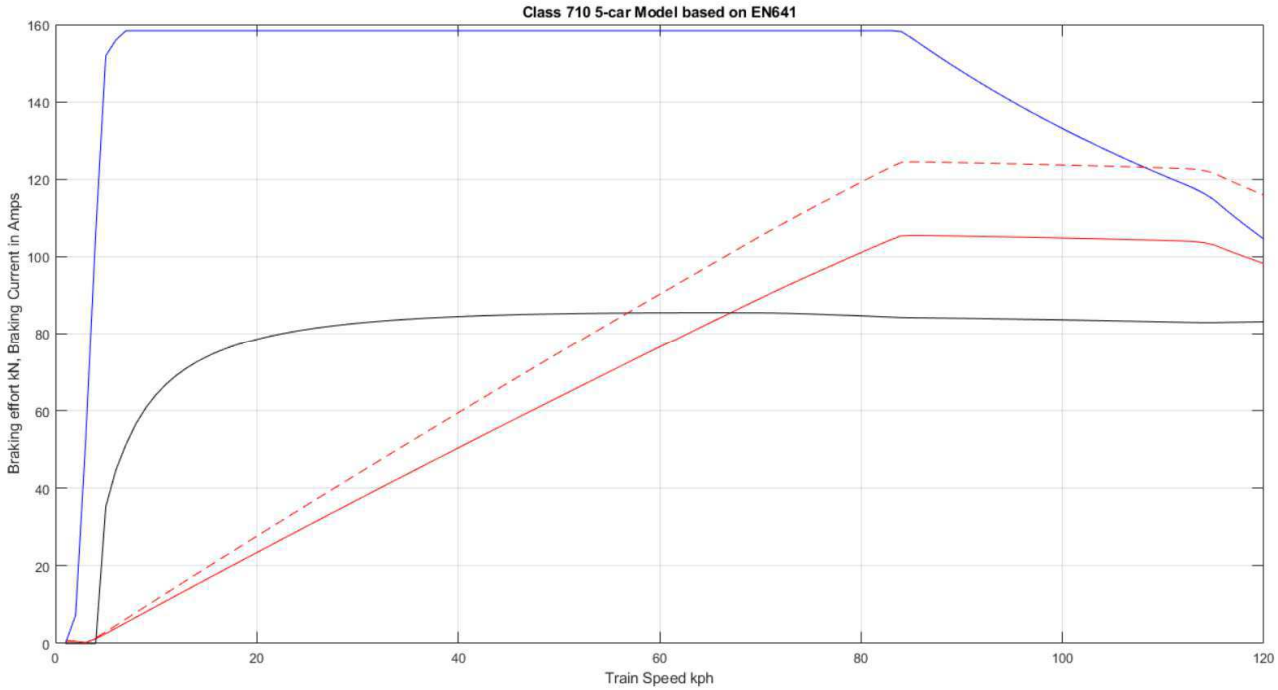


Figure 14 Class 710 - 5 Car - Regenerative Effort Characteristics

C. Tractive Resistance

The tractive resistance is calculated using the following formula:

$$(A + Bv)x\ W + Cv^2$$

where, v = train speed (km/h) and W = weight (tonnes)

Formula Coefficients:

Coefficient	Coefficient	Unit
A	8.34	kN
B	0.0123	(kN.h)/(km)
C	0.00132	$kN.h^2km^2$

Table 8. Aerodynamic Resistance Coefficients for Class 710

4.1.2.4 Mechanical Parameters - Class 700 8 – Car

A. Tractive Effort

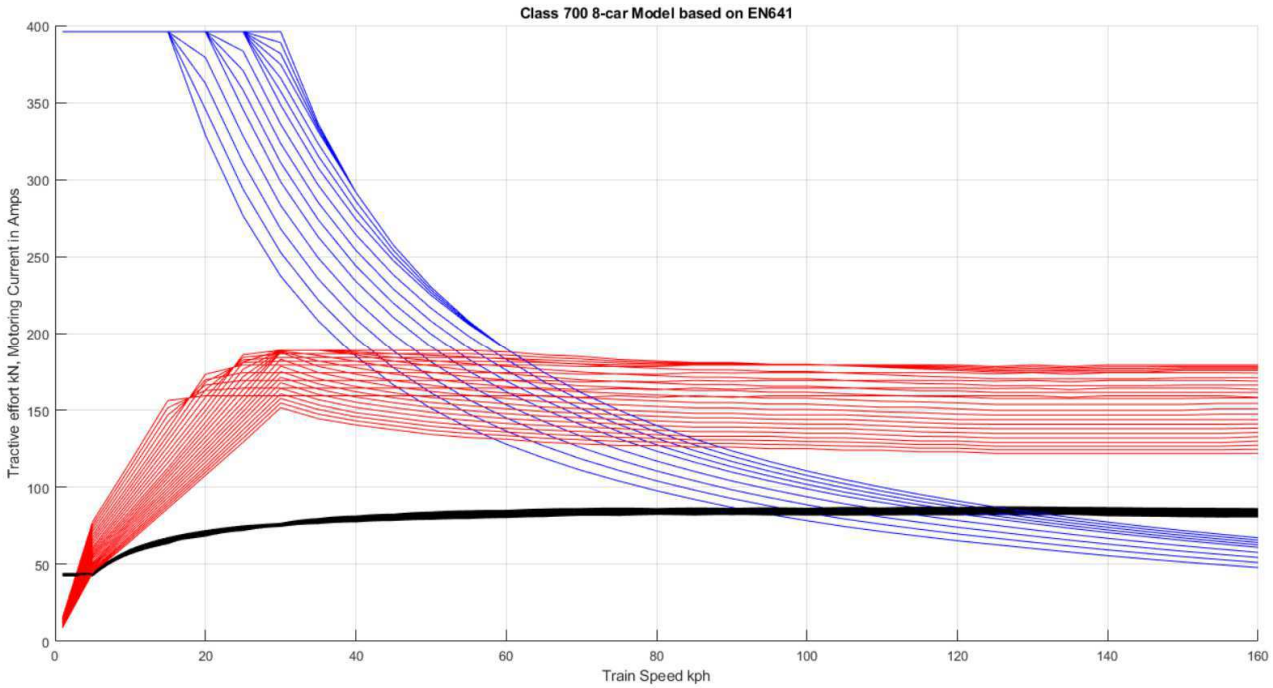


Figure 15 Class 700 8 - Car – Tractive Effort Characteristics

Note: Multiple curves of tractive effort and motoring current for line voltages between 17.5 kV to 29 kV in 0.5 kV steps are shown in Figure 15 above.

B. Braking Effort

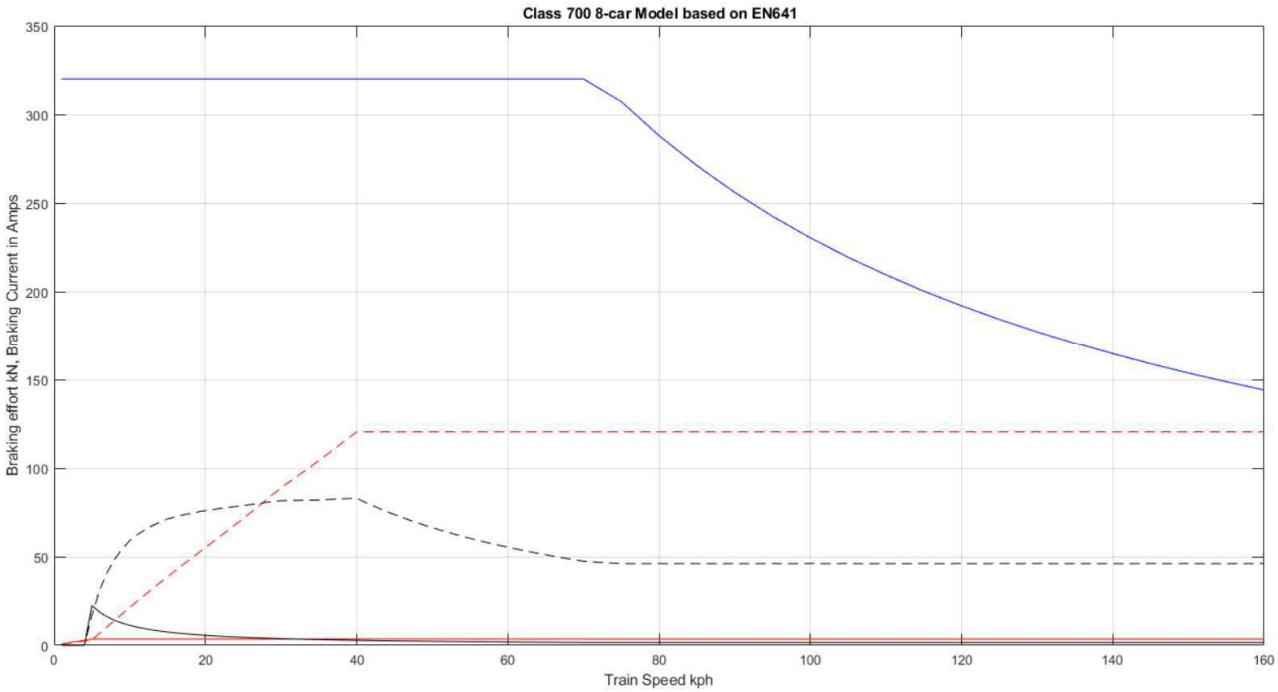


Figure 16 Class 700 - 8 Car - Regenerative Effort Characteristics

C. Tractive Resistance

The tractive resistance is calculated using the following formula:

$$(A + Bv)x\ W + Cv^2$$

where, v = train speed (km/h) and W = weight (tonnes)

Formula Coefficients:

Coefficient	Coefficient	Unit
A	3.9686	kN
B	0.0202	(kN.h)/(km)
C	0.0007	$kN.h^2km^2$

Table 9. Aerodynamic Resistance Coefficients for Class 700

4.1.2.5 Mechanical Parameters - Class 700 12 – Car

A. Tractive Effort

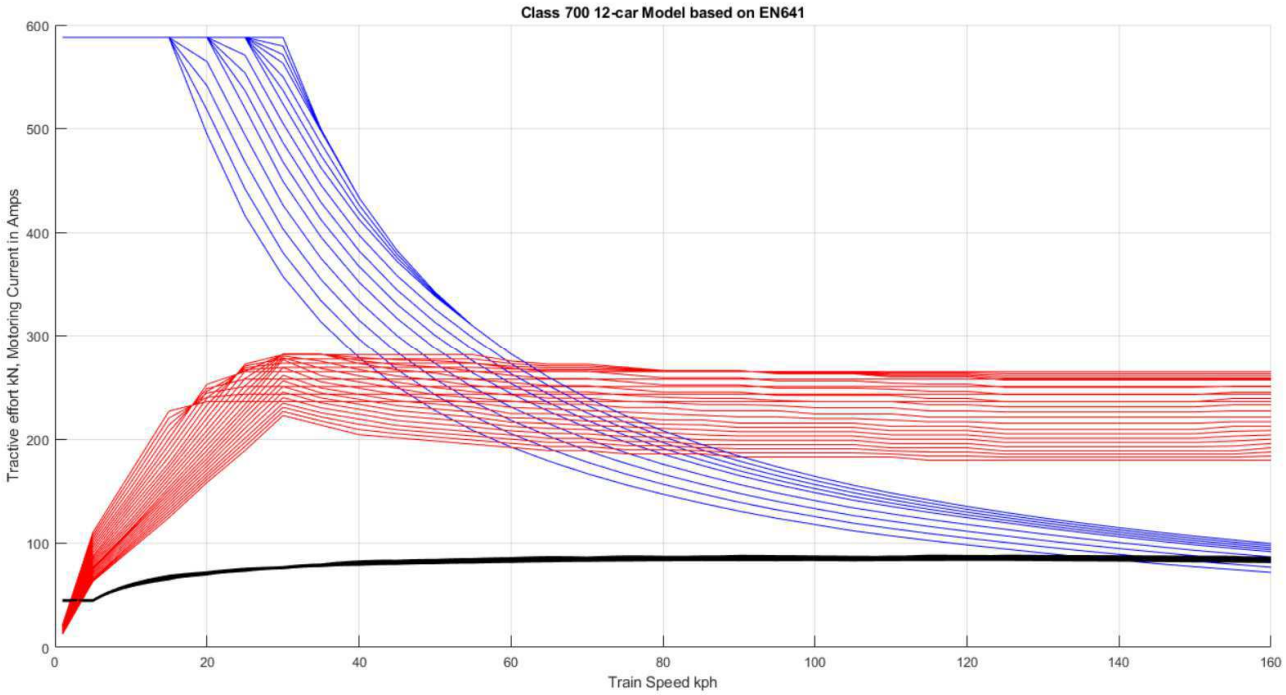


Figure 17 Class 700 12 - Car – Tractive Effort Characteristics

Note: Multiple curves of tractive effort and motoring current for line voltages between 17.5 kV to 29 kV in 0.5 kV steps are shown in Figure 17 above.

B. Braking Effort

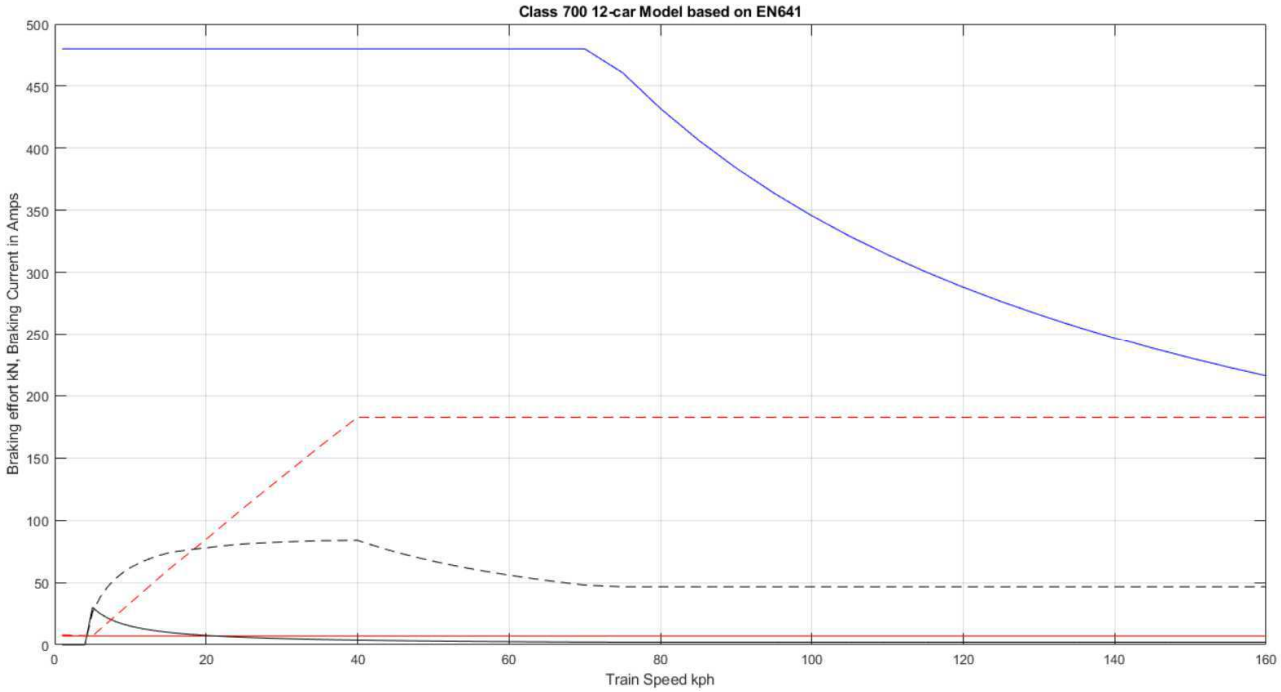


Figure 18 Class 700 - 12 Car - Regenerative Effort Characteristics

C. Tractive Resistance

The tractive resistance is calculated using the following formula:

$$(A + Bv)x\ W + Cv^2$$

where, v = train speed (km/h) and W = weight (tonnes)

Formula Coefficients:

Coefficient	Coefficient	Unit
A	5.9193	kN
B	0.0299	(kN.h)/(km)
C	0.0009	$kN.h^2km^2$

Table 10. Aerodynamic Resistance Coefficients for Class 700 – 12 car

4.1.3 Infrastructure and Electrical Data

4.1.3.1 Infrastructure Data

The infrastructure data used in the traction power loading assessment model include:

- Gradient
- Speed Limit
- Stations

The above data was taken from the five-mile diagram. Table 11 below shows specific details of the five-mile diagram i.e., Diagram No, ELR etc. Furthermore, the details presented in Table 11 below are as per the routes modelled.

It should be noted that the train maximum line speeds were taken from the five-mile line diagram for the existing routes and the proposed Signalling Scheme Plan Ref 5 where any line speeds are due to take place.

Routes 1 & 2:					
Route	**Drawing No.**	**Diagram No.**	**Title**	**ELR**	**Mileage**
1 & 2	7023120-	BGK-20	Kings Lynn	BGK	92 mile to 96 mile 75 chains
1 & 2	7023119-	BGK-19	Watlington	BGK	87 mile to 92 mile
1 & 2	7023118-	BGK-18	Downham Market	BGK	82 mile to 87 mile
1 & 2	7023117-	BGK-17	Hilgay	BGK	77 mile to 82 mile
1 & 2	7023116-	BGK-16	Littleport	BGK	72 mile to 77 mile
1 & 2	7023115-	BGK-15	Ely	BGK	67 mile to 72 mile
1 & 2	7023114-	BGK-14	Waterbeach - Ely	BGK	62 mile to 67 mile
1 & 2	7023113-	BGK-13	Chesterton Jn - Waterbeach	BGK	57 mile to 62 mile
1 & 2	7023112-	BGK-12	Shelford – Cambridge	BGK	53 mile to 57 mile
1 & 2	7039275	SBR-05	Shepreth Jn	SBR	52 mile to 55 mile 27 chains
1 & 2	7039274-	SBR-04	Meldreth - Foxton	SBR	47 mile to 52 mile
1 & 2	7039273-	SBR-03	Royston	SBR	43 mile to 47 mile
Routes 3 & 4:					
3 & 4	7023112-	BGK-12	Shelford – Cambridge	BGK	53 mile to 55 mile 52 chains

3 & 4	7039275	SBR-05	Shepreth Jn	SBR	52 mile to 55 mile 27 chains
3 & 4	7039274-	SBR-04	Meldreth - Foxton	SBR	47 mile to 52 mile
3 & 4	7039273-	SBR-03	Royston	SBR	43 mile to 47 mile
Routes 5 & 6:					
5 & 6	7023120-	BGK-20	Kings Lynn	BGK	92 mile to 96 mile 75 chains
5 & 6	7023119-	BGK-19	Watlington	BGK	87 mile to 92 mile
5 & 6	7023118-	BGK-18	Downham Market	BGK	82 mile to 87 mile
5 & 6	7023117-	BGK-17	Hilgay	BGK	77 mile to 82 mile
5 & 6	7023116-	BGK-16	Littleport	BGK	72 mile to 77 mile
5 & 6	7023115-	BGK-15	Ely	BGK	67 mile to 72 mile
5 & 6	7023114-	BGK-14	Waterbeach - Ely	BGK	62 mile to 67 mile
5 & 6	7023113-	BGK-13	Chesterton Jn - Waterbeach	BGK	57 mile to 62 mile
5 & 6	7023112-	BGK-12	Shelford – Cambridge	BGK	52 mile to 57 mile
5 & 6	7023111-	BGK-11	Whittlesford	BGK	47 mile to 52 mile
5 & 6	7023110-	BGK-10	Great Chesterford	BGK	42 mile to 47 mile
5 & 6	7023109-	BGK-09	Newport – Audley End	BGK	37 mile to 42 mile
5 & 6	7023108-	BFK-08	Stansted Mountfitchet - Elsenham	BGK	34 mile 25 chains to 37 mile
5 & 6	7023156-	TEN-01	Stansted North Jn – Stansted South Jn	TEN	0 mile to 0 mile 49 chains
5 & 6	7023159-	TLA-01	Stansted Airport Branch	TLA	33 mile 54 chains to 36 mile 67 chains
Routes 7 & 8:					
7 & 8	7023120-	BGK-20	Kings Lynn	BGK	92 mile to 96 mile 75 chains

7 & 8	7023119-	BGK-19	Watlington	BGK	87 mile to 92 mile
7 & 8	7023118-	BGK-18	Downham Market	BGK	82 mile to 87 mile
7 & 8	7023117-	BGK-17	Hilgay	BGK	77 mile to 82 mile
7 & 8	7023116-	BGK-16	Littleport	BGK	72 mile to 77 mile
7 & 8	7023115-	BGK-15	Ely	BGK	67 mile to 72 mile
7 & 8	7023114-	BGK-14	Waterbeach - Ely	BGK	62 mile to 67 mile
7 & 8	7023113-	BGK-13	Chesterton Jn - Waterbeach	BGK	57 mile to 62 mile
7 & 8	7023112-	BGK-12	Shelford – Cambridge	BGK	52 mile to 57 mile
7 & 8	7023111-	BGK-11	Whittlesford	BGK	47 mile to 52 mile
7 & 8	7023110-	BGK-10	Great Chesterford	BGK	42 mile to 47 mile
7 & 8	7023109-	BGK-09	Newport – Audley End	BGK	37 mile to 42 mile
7 & 8	7023108-	BFK-08	Stansted Mountfitchet - Elsenham	BGK	33 mile 28 chains to 37 mile

Table 11 Specific Details of Five Mile Diagram Per Route

4.1.3.2 Electrical Data

The electrical data used in the traction power loading assessment model include:

- Cross Bond
- Booster Transformer
- Mid-Point Connection (MPC)
- Track Sectioning Cabin (TSC)
- Feeder Station (FS)

The above data was taken from the Bonding diagram and Isolation diagram. Bonding diagrams were used to obtain data for cross bonds, booster transformers, and mid-point connections. Isolation diagrams were used to obtain data for track sectioning cabins and feeder stations.

Table 12 and Table 13 below show the specific details of the Bonding diagram and the Isolation Diagram i.e., Drawing No, Mileage etc. It should be noted that the details presented in Table 6 below are as per the routes modelled.

Route	Drawings	ELR	Mileage
1 & 2	B/A/C 155.3 – 156.0 Sheet 2 to B/E/EC 65 – 69	BGK & SBR	96.93 mile to 43.11 mile
3 & 4	B/A/C 91.2 – 92.9 to B/E/EC 65 – 69	BGK & SBR	57.93 mile to 43.11 mile
5 & 6	B/A/C 155.3 – 156.0 Sheet 2 to A30-LIV-SSD-TC-506	BGK & TLA	96.93 mile to 36.84 mile
7 & 8	B/A/C 155.3 – 156.0 Sheet 2 to B/E 53.1 – 54.3	BGK	96.93 mile to 33.31 mile

Table 12 Specific Details of the Bonding Diagram Per Route

Route	Drawings	ELR	Mileage
1 & 2	NSE/WA/R/40 to NSE/WA/H/61	BGK & SBR	96.93 mile to 43.11 mile
3 & 4	NSE/WA/R/36.00 to NSE/WA/H/61	BGK & SBR	57.93 mile to 43.11 mile
5 & 6	NSE/WA/R/40 to EA/WA/R/23	BGK & TLA	96.93 mile to 36.84 mile
7 & 8	NSE/WA/R/40 to EA/WA/R/22	BGK	96.93 mile to 33.31 mile

Table 13 Specific Details of the Isolation Diagram Per Route

4.1.3.3 Feeding Arrangement

As described in Section 3.1 above, four feeding arrangements have been considered in this traction power loading assessment (with Regen On and Off) due to the normal and emergency feeding arrangement at Milton FS and its neighbouring feeder stations. The four feeding arrangements include:

- Normal Feeding Arrangement (N-0);
- Emergency N-1 Feeding Arrangement when one of the transformers at Milton FS is non-operational;
- Emergency N-1 Feeding Arrangement when one transformer at Kings Lynn FS is non-operational;
- Emergency N-1 Feeding Arrangement when one transformer at Ugley FS is non-operational.

4.1.4 Assumptions

4.1.4.1 Type of OLE

The OLE type is Mark3B with single rail return. It has also been assumed that the existing electrification is Booster Transformers OLE with return conductors. Table 14 below shows the OLE data which has been used in the traction power loading assessment for double and single track. Figure 19 and Figure 20 below shows the OLE configuration for a double track and single track respectively.

ID	Description	X	Y	Diameter	Normal Condition	
		m	m	mm	Self-Resistance	Self-Reactance
Open Route Double Track						
R1_up	Running Rail	-2.452	0	95.600	0.1551	0.7682
Cont_up	Contact 1 Copper	-1.702	4.88	11.672	0.1649	0.7684
Cat_up	Cat 1 Copper	-1.702	5.88	7/3.95	0.2051	0.7674
RC_up	RC1 Aluminium	-3.452	5.455	19/4.22	0.1063	0.7312
R4_dn	Running Rail	2.452	0	95.600	0.1551	0.7682
Cont_dn	Contact 2 Copper	1.702	4.88	11.672	0.1649	0.7684
Cat_dn	Cat 2 Copper	1.702	5.88	7/3.95	0.2051	0.7674
RC_dn	RC2 Aluminium	3.452	5.455	19/4.22	0.1063	0.7312
Open Route Single Track						
R1_up	Running Rail	-2.452	0	95.600	0.1551	0.7682
Cont_up	Contact 1 Copper	-1.702	4.88	11.672	0.1649	0.7684
Cat_up	Cat 1 Copper	-1.702	5.88	7/3.95	0.2051	0.7674
RC_up	RC1 Aluminium	-3.452	5.455	19.422	0.1063	0.7312

Table 14 OLE Data

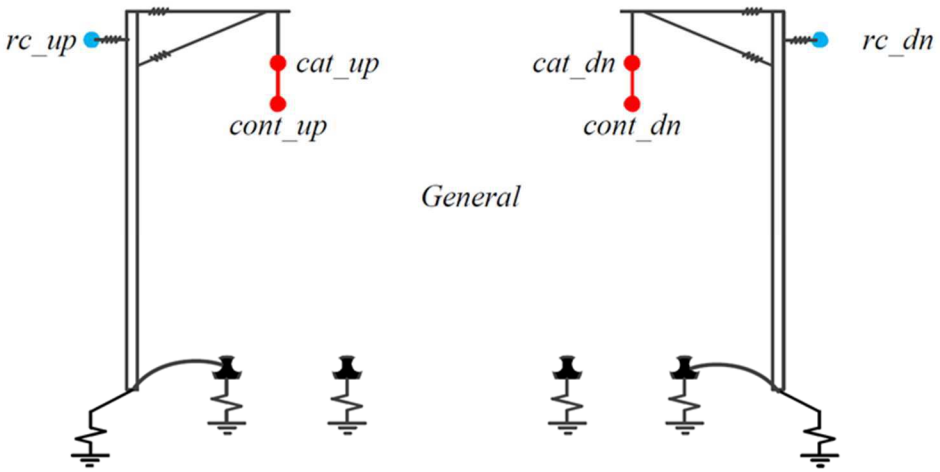


Figure 19 Double Track OLE Configuration

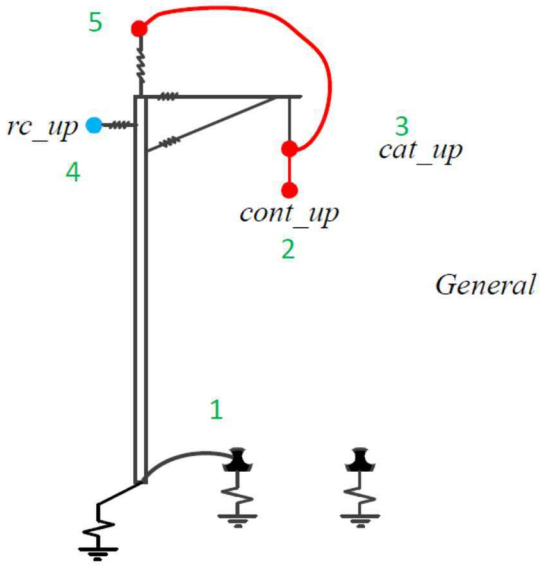


Figure 20 Single Track OLE Configuration

4.1.4.2 Track

The area of interest in which the traction power loading assessment is made, it is assumed that the configuration of tracks is single and double.

Single Track:

Starts from BGK 96 mile and 54 chains right after Kings Lynn Station and ends at BGK 91 mile and 20 chains before Watlington Station.

It then starts from BGK 86 mile and 04 chains after Downham Market Station and ends at BGK 76 mile and 36 chains before Littleport Station.

The type of rail is 60kg/meter, and the relative magnetic permeability is assumed to be 50 for the rails.

Double Track:

It is assumed that the area of interest in which the traction power loading assessment is conducted is all double track except for the areas identified above.

All track circuits in the traction power loading assessment are single rail track circuit. This has been considered to model the traction return circuit.

4.1.4.3 Timetable

Passenger loading is assumed to be AW3 for all high speed and long-distance services and AW1 for all other services as per NR/L2/ELP/27275. Passenger Loading is as follows:

- AW0, Weight of empty, ready-to-run vehicle.
- AW1, AW0 plus full seated load, including crew.
- AW3, AW1 plus standees at 6 passengers m^2.

4.1.4.4 Existing Feeder

For existing supply points, the following parameters are assumed:

Site Information						
Supply Point	**Incoming Voltage (kV)**	**Configuration**	**Transformer (MVA)**	**FSC (MVA)**	**No – Load Voltage (kV)**	**Transformer Impedance [Ω]**
Milton FS	132	6 kA	26.5	20	26.5	0.4175 + j4.36 Ω

Table 15. Input Assumptions on Power Supply Incoming Feeder

4.1.5 Exclusions

The following items have been excluded from the assessment at this stage:

- No freight trains are modelled;
- Assessment of reduced train service levels for alternate feeding scenarios;
- Timetable permutations;
- Depot loading assessments;
- Traction power harmonics assessment (G5/5 compliance);
- Thermal rating assessment on feeders and cables;
- Diversionary routing;
- Telecoms / FTN cable length assessment;
- Induced voltage study (ELSSA);
- N-2 outage scenarios (Including N-1 feeding arrangements with Regen Off);
- Mean useful voltage as defined in BS EN 50388;
- ENA Engineering Recommendation P24 (2020) for % NPS voltage unbalance limits.

4.1.6 Risks

- The rolling stock is based on the iTSS. Should the final rolling stock be different or change, then further analysis would be required;
- N-2 outage scenarios (Including N-1 feeding arrangements with Regen Off) are outside the scope of the project. Certain N-2 scenarios can result in the requirement of more supply points and increased capacity or additional electrical infrastructure (e.g. Neutral Sections, TSC, and paralleling conductors).

5 Traction Power Loading – Output

5.1 Assessment Criteria

The acceptance criteria for the traction power modelling work are based on the following:

5.1.1 Firm Service Capacity

Firm Service Capacity (FSC) as a contractual limit has been agreed with the supplier for the existing electrification. It must not be exceeded for a 30-minute average load at each supply point.

Firm Service Capacity (FSC) limits for Milton FS are verified against contractually available capacity of 20 MVA and shall not be exceeded for a 30-minute average load.

5.1.2 Voltage Regulation

In order to ensure effective operation of the rolling stock, the lowest permanent voltage on the infrastructure is required to remain above 19 kV under Normal or N-1 timetable operation, defined as U_{min1} in BS EN 50163. While lower special national conditions exist for legacy infrastructure, Section 4.3.2 of the Network Rail Asset Policy NR/L1/ELP/27000 requires new designs to be compatible with voltage limits set in BS EN 50163 without GB special conditions.

As such, minimum voltage compliance for this modelling study was assessed against U_{min1} (19 kV).

Pass / fail criteria for voltage are defined in BS EN 50388 clause 8.3 and BS EN 50163 Clause 4.1.

The mean-useful voltage must be greater than 22 kV, and the maximum and minimum voltages are defined in Table 16 below.

	Lowest Non-Permanent Voltage (V)	Lowest Permanent Voltage (V)	Nominal Voltage (V)	Highest Permanent Voltage (V)	Highest Non-Permanent Voltage (V)
	U_{min2}	U_{min1}	U_n	U_{max1}	U_{max2}
a.c. (r.m.s values)	17500	19000	25000	27500	29000

Table 16 Maximum and Minimum Voltage Limits

The duration of voltages between U_{min1} and U_{min2} shall not exceed 2 minutes.

5.1.3 Negative Phase Sequence

Negative Phase Sequence (NPS) is an unbalance generated between voltage phases on the primary side of the supply transformer due to the single-phase railway load.

Strict limits are placed on the railway to control the amount of unbalance that a supply transformer is allowed to generate.

Substation load pass / fail criteria are set by the Negative Phase Sequence limits in ENA/ER/P24 as follows:

- 1 minute load < 2% NPS and preferably <1% NPS;
- 30 min load < 1% NPS;
- Feeder station capacity of the supply.

5.2 Results

The traction power loading study has been undertaken for Normal Feeding Arrangement with Regen On and Off and for the Emergency Feeding Arrangements with Regen On. Table 17 below shows the results of the five simulation runs that have been undertaken against the assessment criteria discussed in Section 5.1 above.

Simulation Results		Normal Feeding Arrangement with Regen On	Normal Feeding Arrangement with Regen Off	Emergency Feeding Arrangement at Milton FS with Regen On	Emergency Feeding Arrangement at Kings Lynn FS with Regen On	Emergency Feeding Arrangement at Ugley FS with Regen On
Umean-useful (kV)	(EN50388 Cl8.3, >22kV)	25.2	25.2	25.0	25.1	24.3
Minimum Voltage (kV)	(EN50163 Cl 4.1)	21.5	21.2	21.3	20.7	18.0 (< 120 seconds as per EN50163 Cl 4.1)
Maximum Voltage (kV)	(EN50163 Cl 4.1)	27.0	26.5	26.9	27.1	26.9
Maximum Instantaneous Load (MVA)	Milton FS Tx1	19.7	19.7	37.3	22.7	19.7
	Milton FS Tx2	32.6	32.6	-	32.6	38.4
	Kings Lynn FS	15.7	15.7	15.7	-	15.7
	Ugley FS	20.0	20.1	20.0	20.0	-
Maximum 1-minute Load r.m.s (MVA)	Milton FS Tx1	13.9	13.9	32.5	18.0	13.9
	Milton FS Tx2	25.1	25.8	-	25.1	35.0
	Kings Lynn FS	12.9	12.9	12.9	-	12.9
	Ugley FS	16.7	17.0	16.7	16.7	-
Maximum 30-minute Load r.m.s (MVA)	Milton FS Tx1	6.3	6.6	16.6	9.5	6.3
	Milton FS Tx2	12.8	14.4	-	12.8	18.0
	Milton FS Tx1 + Milton FS Tx2	19.1	21.0	16.6	22.3	24.3
	Kings Lynn FS	6.0	6.0	6.0	-	6.0

	Ugley FS	7.4	8.0	7.4	7.4	-
Total MWh Generated at tracks		71.1	85.3	70.8	71.4	70.0
Total MWh Consumed by trains		70.1	84.2	69.8	70.0	68.2
Transmission Losses Percentage		1.4	1.3	1.5	2.0	2.2

Table 17 Summary of Results

5.2.1 Summary of Results

This section summarises the results of the simulation runs undertaken for this project and provides explanation to the different colours used in Table 17 above.

The values obtained from the simulation runs are highlighted in green as they meet the assessment criteria described in Section 5.1. Furthermore, the transformers at Kings Lynn FS and Ugley FS are assumed to be Class VI and are therefore compliant with BS EN 50329.

The minimum voltage of the train for the Emergency Feeding Arrangement at Ugley FS with Regen On has been highlighted in amber as its less than 19 kV. However, this value of 18 kV occurs for less than two minutes at 84 km after Great Chesterford Station on Routes 5 & 6 and at 89 km at Audley End Station on Routes 7 & 8.

This is expected to happen as the trains on Routes 5 & 6 and Routes 7 & 8 start from Kings Lynn Station which is a long distance on the routes in the timetable. Furthermore, the minimum voltage of 18 kV occurs for less than two minutes which is acceptable as per BS EN 50163 Clause 4.1.

The values which have been highlighted in red are a sum of the maximum 30-minute load r.m.s of Milton FS Tx1 and Milton FS Tx2. These values are greater than the 20 MVA FSC limit at Milton FS.

However, it should be noted that both the transformer at Milton FS i.e. Milton Tx1 and Milton Tx2 will not be operating at maximum 30-minute load r.m.s at the same time. Therefore, further calculation has been undertaken to show the 30-minute load r.m.s at a single instance at Milton FS.

Note: This calculation has been undertaken for all those simulation runs who's maximum 30-minute load r.m.s is greater than 20 MVA at Milton FS; these include: Normal Feeding Arrangement with Regen Off, Emergency Feeding Arrangement at Kings Lynn FS with Regen On and Emergency Feeding Arrangement at Ugley FS with Regen On.

5.2.1.1 30-Minute Load r.m.s Calculation

Normal Feeding Arrangement with Regen Off

The maximum 30-minute load r.m.s for the Normal Feeding Arrangement with Regen Off is 20.5 MVA. The graph in Figure 21 below shows the 30-minute load r.m.s at Milton Tx1 and Tx2 as well as the sum of the 30-minute load r.m.s.

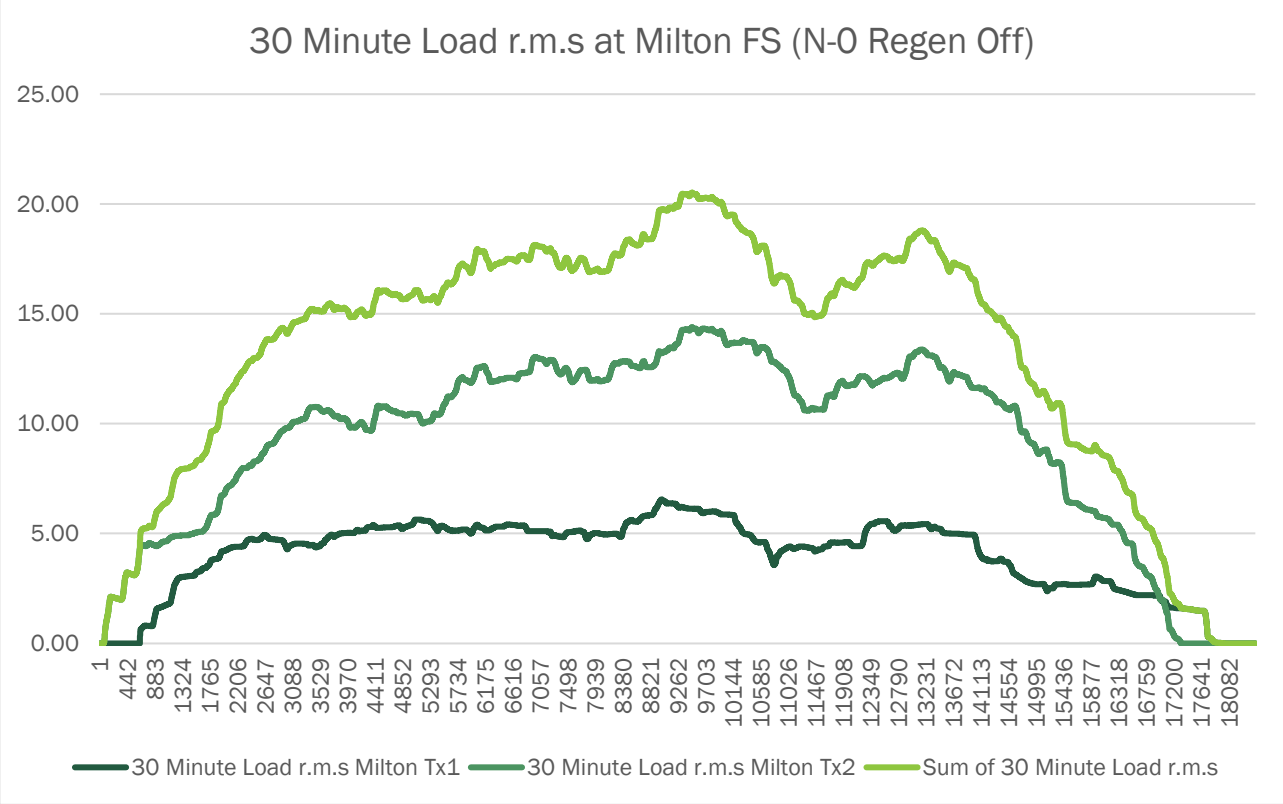


Figure 21 30-Minute Load r.m.s at Milton FS during Normal Feeding Arrangement with Regen Off

Emergency Feeding Arrangement at Kings Lynn FS with Regen On

The maximum 30-minute load r.m.s for the Emergency Feeding Arrangement at Kings Lynn FS with Regen On is 20.9 MVA. The graph in Figure 22 below shows the 30-minute load r.m.s at Milton Tx1 and Tx2 as well as the sum of the 30-minute load r.m.s.

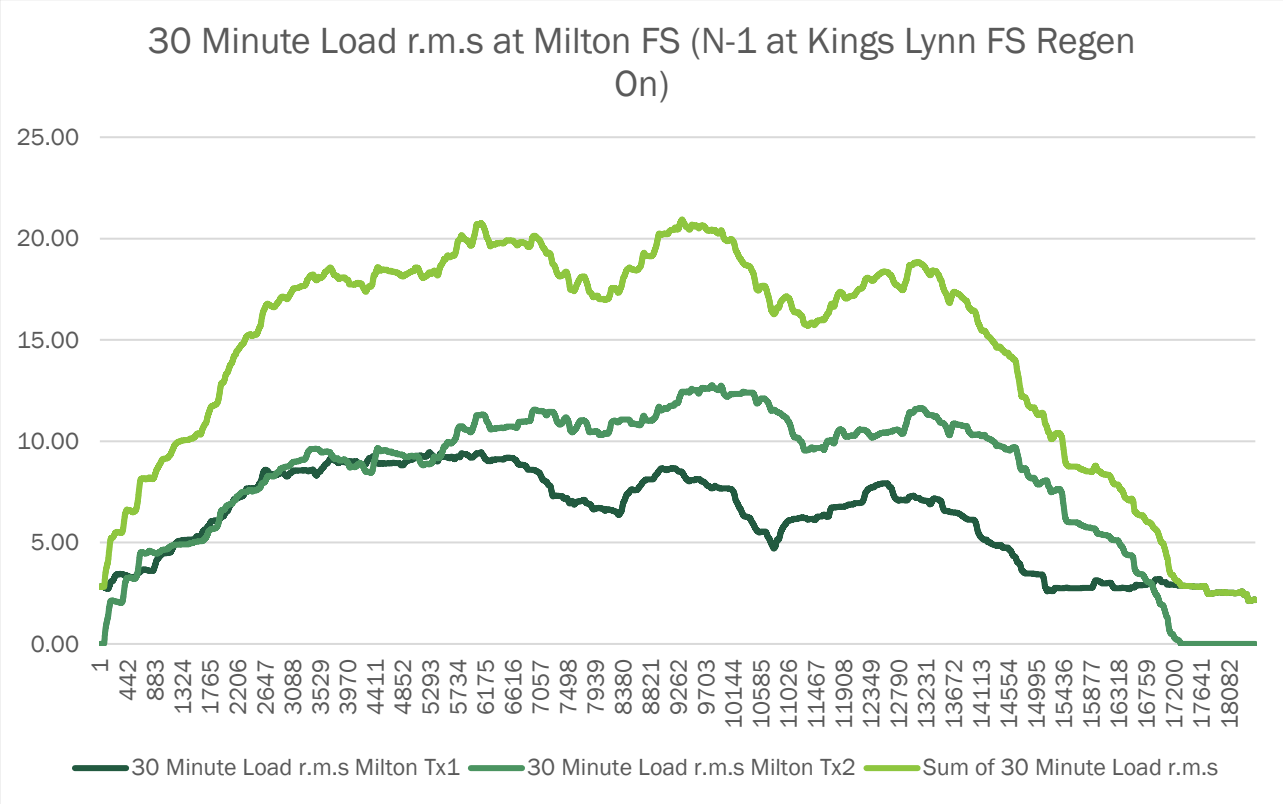


Figure 22 30-Minute Load r.m.s at Milton FS during Emergency Feeding Arrangement at Kings Lynn FS with Regen On

Emergency Feeding Arrangement at Ugley FS with Regen On

The maximum 30-minute load r.m.s for the Emergency Feeding Arrangement at Ugley FS with Regen On is 24.0 MVA. The graph in Figure 23Figure 21 below shows the 30-minute load r.m.s at Milton Tx1 and Tx2 as well as the sum of the 30-minute load r.m.s.

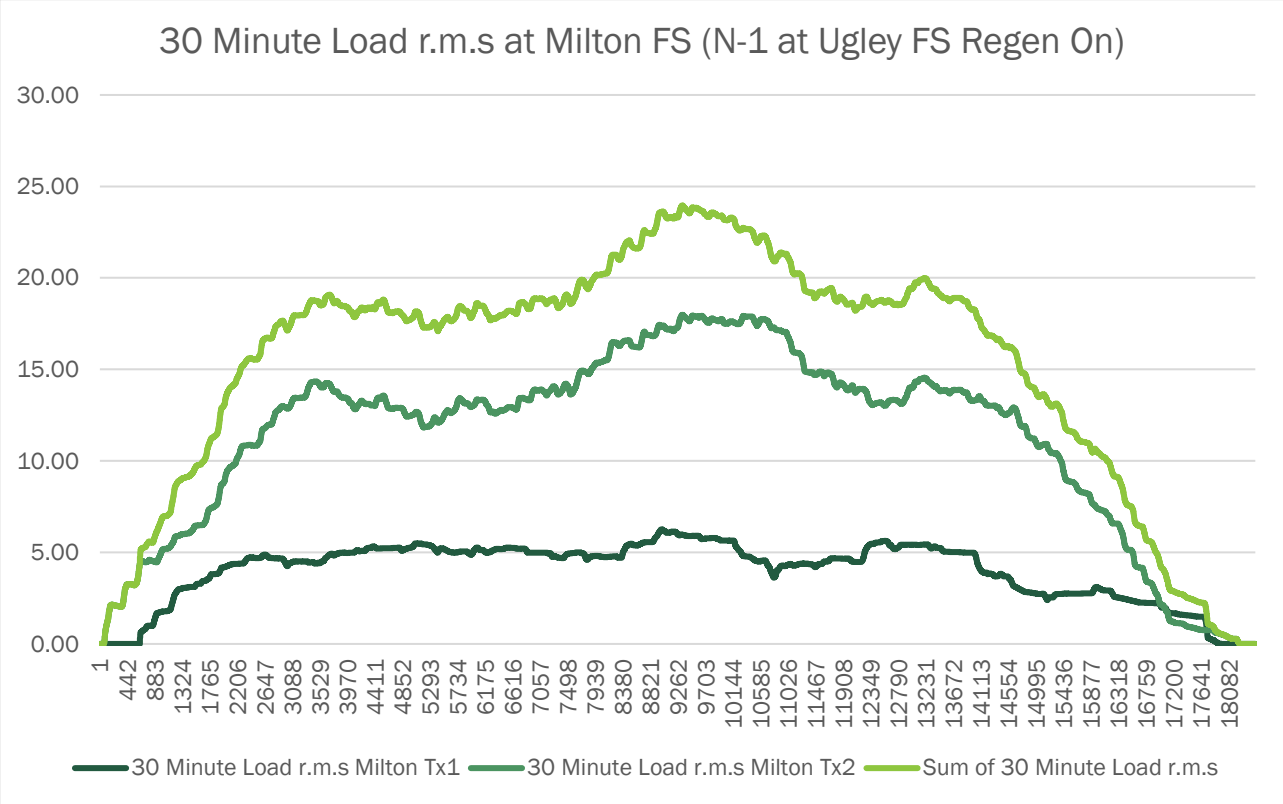


Figure 23 30-Minute Load r.m.s at Milton FS during Emergency Feeding Arrangement at Ugley FS with Regen On

6 Recommendations

This simulation has been undertaken with the traction transformers at Milton FS rated at 26.5 MVA nominal capacity, as shown in the current MFD Ref 1and Appendix C.

From the simulation results, it can be seen that during the Emergency Feeding Arrangement at Ugley FS with Regen On, the minimum voltage of the train is 18 kV which is below the required 19 kV as per BS EN 50163 Clause 4.1.

Furthermore, during the Normal Feeding Arrangement with Regen Off, the maximum 30-minute load r.m.s exceeds the allowed FSC of 20 MVA. Similarly, this is also seen during the Emergency Feeding Arrangement at Kings Lynn FS with Regen On and during the Emergency Feeding Arrangement at Ugley FS with Regen On.

Therefore, some recommendations are presented below based on the results of the traction power loading assessment.

The recommendations are as follows:

- In order to achieve the train minimum voltage of 19 kV and above, reduce the number of trains/services in the timetable during the Emergency Feeding Arrangement at Ugley FS with Regen On.
- The Firm Service Capacity at Milton FS needs to be increased by 25% in order to feed during the Normal Feeding Arrangement with Regen Off and during the Emergency Feeding Arrangements at Kings Lynn FS and Ugley FS with Regen On;
- Alternatively, reduce the number of trains/services in the timetable in order to achieve the 20 MVA FSC at Milton FS.

7 Conclusion

This simulation has been undertaken with the traction transformers at Milton FS rated at 26.5 MVA nominal capacity, as shown in the current MFD Ref 1and Appendix C.

Transformer Rating:

The results from the traction power loading assessment in Normal Feeding Arrangement with Regen On and Off have concluded that Milton FS has sufficient capacity to feed the additional trains on the timetable stopping and passing at the new Cambridge South Station in nominal mode.

In the Emergency Feeding Arrangement at Milton FS i.e., with only one transformer operating, the maximum 30-minute r.m.s loading is still within the permissible capacity of 26.5 MVA.

Furthermore, in the Emergency Feeding Arrangements with Regen On at Kings Lynn FS and Ugley FS, the transformers at Milton FS are still capable of feeding the additional trains on the timetable stopping and passing at the new Cambridge South Station in nominal mode. The maximum 30-minute r.m.s loading under the emergency feeding arrangements is still within the permissible capacity of 26.5 MVA.

Train Minimum Voltage:

The minimum voltage of the trains in Normal Feeding Arrangement with Regen On and Off, in Emergency Feeding Arrangement at Milton FS with Regen On and in Emergency Feeding Arrangement at Kings Lynn with Regen On are all above the required 19 kV limit.

However, during the Emergency Feeding Arrangement at Ugley FS with Regen On, the minimum voltage of the trains are below 19 kV by 5.2%.

Firm Service Capacity:

The Firm Service Capacity at Milton FS is 20 MVA. The results from the traction power loading assessment in Normal Feeding Arrangement with Regen On and in Emergency Feeding Arrangement at Milton FS with Regen On are under the required limit of the FSC.

However, the results in the Normal Feeding Arrangement with Regen Off, Emergency Feeding Arrangement at Kings Lynn FS with Regen On and Emergency Feeding Arrangement at Ugley FS with Regen On are above the required limit of the FSC by 20%.

U-mean useful:

The Umean-useful, minimum, and maximum voltages are within the limits specified in BS EN 50388 for Normal and Emergency Feeding Arrangements and are hence compliant to TSI requirements.

Appendix A – Modelling Results for Normal Feeding and Emergency Feeding Arrangement

Normal Feeding Arrangement with Regen On

a) Train Performance Results:

Train No	Total Energy Consumed (MWh)	Umean-useful (Train) (V)	Minimum Voltage (V)	Minimum Voltage at Distance (km)	Maximum Voltage (V)	Minimum Dwell Time at Station (sec)
10301	2.8	25.7	21.6	87.7	26.9	40 sec at Watlington
10302	2.8	25.5	22.8	84.2	26.9	40 sec at Watlington
10103	1.4	25.8	22.7	89.0	26.9	40 sec at Littleport
10304	2.8	25.5	21.8	87.8	26.8	40 sec at Littleport
10305	2.8	25.4	22.6	78.2	26.8	40 sec at Littleport
10306	2.8	25.6	22.2	78.2	26.9	40 sec at Watlington
10307	2.8	25.8	23.1	33.9	26.8	40 sec at Watlington
10308	1.4	25.1	22.0	87.8	26.7	82 sec at Cambridge North
20301	1.3	25.9	25.2	58.1	26.8	40 sec at Cambridge
20302	1.8	25.5	23.5	15.1	26.8	40 sec at Cambridge
20303	1.8	25.3	22.9	6.2	26.7	40 sec at Cambridge
20304	1.2	25.1	22.6	20.9	26.7	40 sec at Royston
20305	1.8	25.3	22.5	12.1	26.9	40 sec at Cambridge
20306	1.2	25.6	23.3	25.1	26.7	40 sec at Waterbeach
20307	1.8	25.5	22.3	14.0	26.8	40 sec at Cambridge South
31101	0.6	25.5	24.8	20.0	26.5	125 sec at Royston
31002	0.5	25.2	23.0	26.0	26.7	40 sec at Shepreth
30303	0.8	25.2	23.1	20.0	26.8	118 sec at Royston
31104	0.6	25.0	23.8	19.6	26.6	125 sec at Royston
31005	0.5	25.2	24.0	28.6	26.7	40 sec at Shepreth
31106	0.6	24.9	22.4	10.3	26.5	125 sec at Royston
31007	0.5	24.9	22.8	21.1	26.5	40 sec at Shepreth
31108	0.6	24.5	22.4	27.6	26.6	125 sec at Royston
31009	0.5	24.8	22.5	27.2	26.6	40 sec at Shepreth
31110	0.6	24.6	22.3	16.0	26.6	125 sec at Royston
31011	0.5	24.5	22.2	25.7	26.7	40 sec at Shepreth
31112	0.6	24.6	22.7	20.0	26.5	125 sec at Royston
31013	0.5	25.1	23.4	9.5	26.7	40 sec at Shepreth
31114	0.6	24.7	22.7	11.0	26.5	185 sec at Royston
31015	0.5	24.5	22.1	22.6	26.7	40 sec at Shepreth

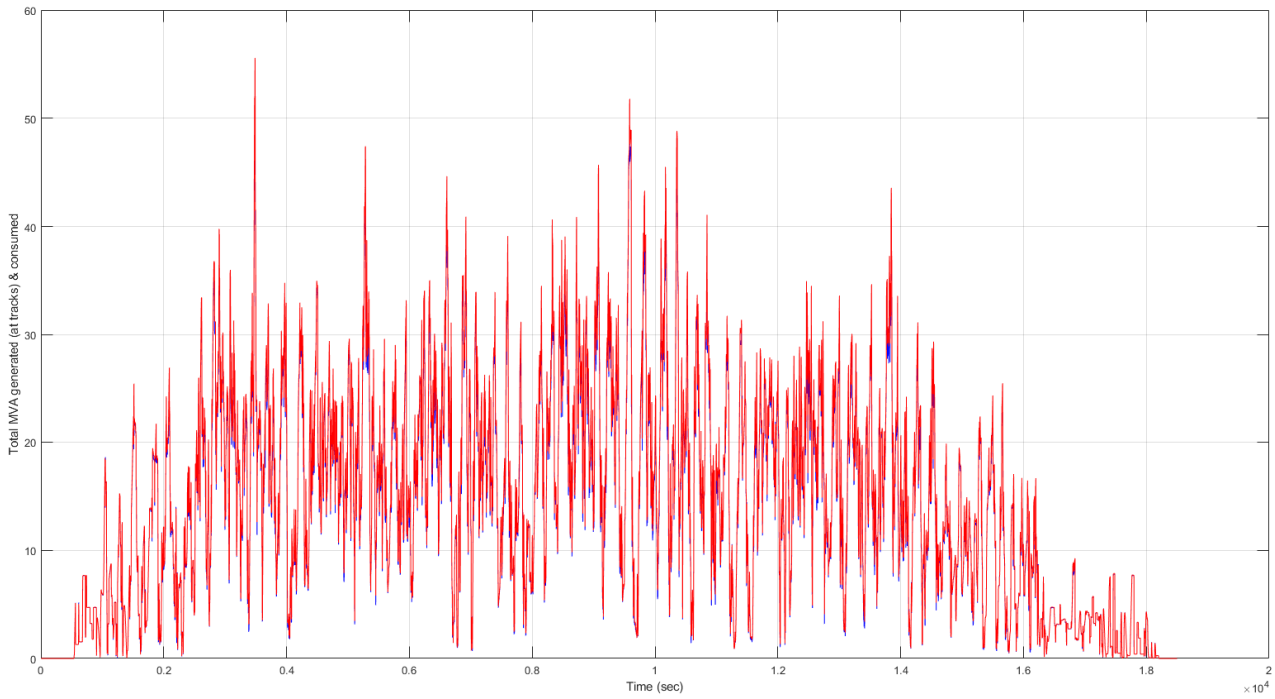
31016	0.5	25.3	23.6	26.0	26.6	40 sec at Shepreth
41101	0.4	25.1	23.8	3.9	26.6	69 sec at Royston
41102	0.4	24.4	21.5	5.9	26.5	69 sec at Royston
41003	0.4	24.7	21.5	1.7	26.5	40 sec at Meldreth
41104	0.4	24.5	22.7	4.9	26.8	40 sec at Royston
41005	0.4	24.7	22.6	1.1	26.6	40 sec at Meldreth
41106	0.4	24.4	21.8	6.1	26.6	40 sec at Royston
41007	0.4	24.6	21.7	1.2	26.5	40 sec at Meldreth
41108	0.4	24.3	22.1	1.2	26.7	99 sec at Royston
41009	0.4	25.1	22.8	5.5	26.6	40 sec at Meldreth
41110	0.4	24.3	21.5	5.0	26.5	69 sec at Royston
41011	0.4	24.7	21.6	1.2	26.5	40 sec at Meldreth
41112	0.4	24.3	22.0	5.0	26.7	189 sec at Royston
41013	0.4	24.8	21.9	1.9	26.7	40 sec at Meldreth
50601	0.7	25.9	24.5	79.3	26.5	40 sec at Cambridge North
50602	0.7	25.7	23.4	69.7	26.5	40 sec at Cambridge North
50603	0.7	25.6	24.0	67.5	26.5	40 sec at Cambridge North
50604	0.7	25.7	23.0	69.4	26.5	40 sec at Cambridge
50605	0.7	26.1	24.3	66.6	26.6	44 sec at Waterbeach
60601	0.6	25.7	22.9	36.7	26.6	40 sec at Cambridge
60602	0.6	25.7	23.3	37.0	26.6	40 sec at Cambridge
60603	0.6	25.8	23.3	35.4	26.7	40 sec at Cambridge
60604	0.6	26.0	24.1	32.4	26.5	40 sec at Cambridge
71101	1.1	25.7	24.9	68.9	26.5	40 sec at Great Chesterford
71102	1.1	25.3	22.8	72.7	26.6	40 sec at Great Chesterford
71103	1.4	25.7	24.7	77.5	26.6	40 sec at Great Chesterford
71104	2.1	25.5	23.6	77.3	26.6	40 sec at Littleport
71105	1.1	25.4	23.5	70.4	26.5	40 sec at Great Chesterford
71106	1.3	25.4	23.1	71.8	26.5	40 sec at Great Chesterford
71107	1.2	25.3	23.5	69.9	26.5	40 sec at Shelford
71108	1.4	25.2	23.8	66.7	26.6	40 sec at Great Chesterford
71109	1.2	25.5	24.0	66.3	26.6	40 sec at Great Chesterford

71110	1.1	25.4	23.2	66.5	26.6	40 sec at Great Chesterford
81101	0.9	25.5	22.8	31.4	26.5	40 sec at Great Chesterford
81102	0.9	25.3	23.1	37.5	26.6	40 sec at Audley End
81103	0.9	25.4	23.6	34.5	26.6	40 sec at Audley End
81104	0.9	25.2	22.6	32.7	26.5	40 sec at Great Chesterford
81105	0.9	25.2	23.4	32.5	26.6	40 sec at Audley End
81106	0.9	25.3	23.3	36.7	26.6	40 sec at Audley End
81107	0.9	25.4	23.1	33.7	26.6	40 sec at Audley End
81108	0.9	25.5	24.2	34.7	26.6	40 sec at Audley End

Table 18 Normal Feeding Arrangement with Regen On – Train Performance Results

b) Total Energy Consumption:

Total MWh Generated = 71.1
Total MWh Consumed = 70.1
Losses Percentage = 1.4

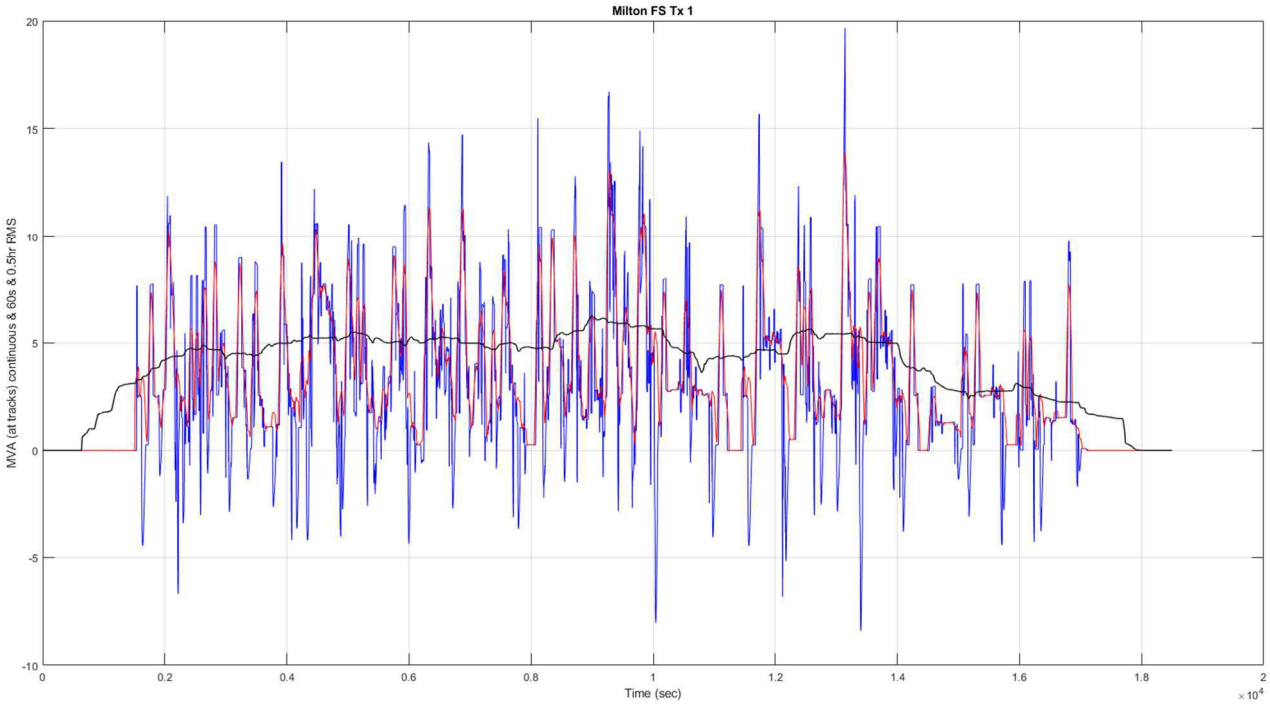


MVA Generated

MVA Consumed

Figure 24 Total MVA (Generated & Consumed) For Normal Feeding Arrangement with Regen On

c) Feeder Station Loading:

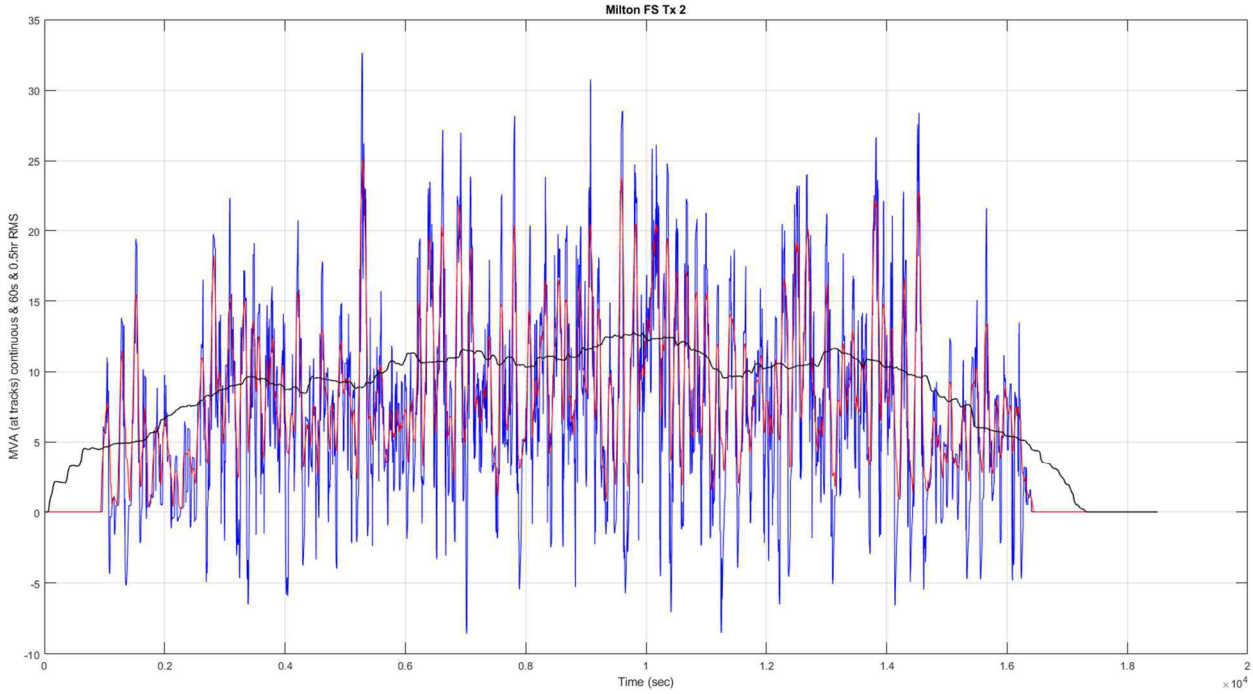


Instantaneous

1 Minute

30 Minute

Figure 25 MVA Load at Milton FS Tx 1 – Normal Feeding Arrangement with Regen On

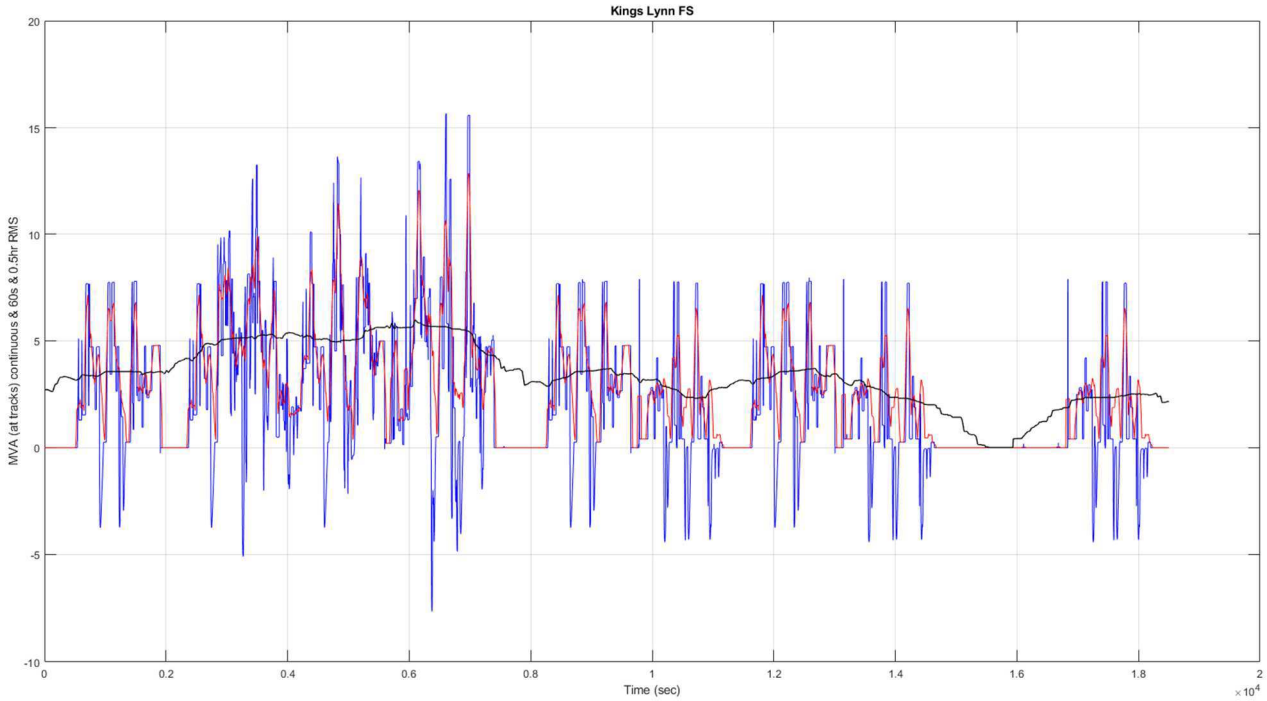


Instantaneous

1 Minute

30 Minute

Figure 26 MVA Load at Milton FS Tx 2 – Normal Feeding Arrangement with Regen On

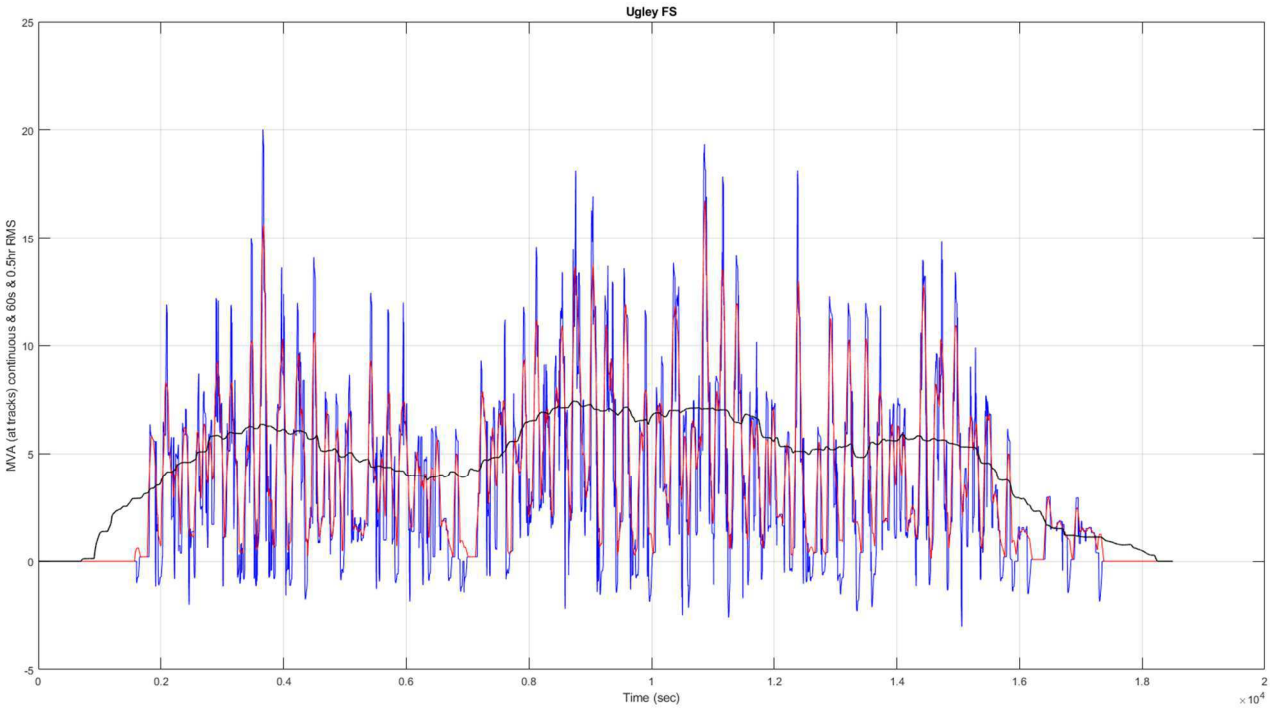


Instantaneous

1 Minute

30 Minute

Figure 27 MVA Load at Kings Lynn FS – Normal Feeding Arrangement with Regen On



Instantaneous

1 Minute

30 Minute

Figure 28 MVA Load at Ugley FS – Normal Feeding Arrangement with Regen On

Normal Feeding Arrangement with Regen Off

a) Train Performance Results:

Train No	Total Energy Consumed (MWh)	Umean-useful (Train) (V)	Minimum Voltage (V)	Minimum Voltage at Distance (km)	Maximum Voltage (V)	Minimum Dwell Time at Station (sec)
10301	3.3	25.7	21.6	87.7	26.5	40 sec at Watlington
10302	3.3	25.5	22.8	77.8	26.5	40 sec at Watlington
10103	1.5	25.8	22.6	89.0	26.5	40 sec at Littleport
10304	3.3	25.4	21.7	87.8	26.5	40 sec at Littleport
10305	3.3	25.4	22.3	79.1	26.5	40 sec at Littleport
10306	3.3	25.6	21.9	78.2	26.5	40 sec at Watlington
10307	3.3	25.8	23.1	33.9	26.5	40 sec at Watlington
10308	1.8	25.1	22.0	87.8	26.5	82 sec at Cambridge North
20301	1.7	25.9	25.2	58.1	26.5	40 sec at Cambridge
20302	2.4	25.5	23.5	15.1	26.5	40 sec at Cambridge
20303	2.4	25.3	22.9	6.2	26.5	40 sec at Cambridge
20304	1.5	25.0	22.6	20.9	26.5	40 sec at Royston
20305	2.4	25.3	22.0	12.9	26.5	40 sec at Cambridge
20306	1.5	25.5	23.0	25.1	26.5	40 sec at Waterbeach
20307	2.4	25.5	22.2	14.0	26.5	40 sec at Cambridge South
31101	0.6	25.5	24.8	20.0	26.5	125 sec at Royston
31002	0.6	25.1	23.0	26.0	26.5	40 sec at Shepreth
30303	0.9	25.2	23.1	20.0	26.5	118 sec at Royston
31104	0.6	25.0	23.8	19.2	26.5	125 sec at Royston
31005	0.6	25.2	23.8	28.6	26.5	40 sec at Shepreth
31106	0.6	24.9	22.4	10.3	26.5	125 sec at Royston
31007	0.6	24.8	22.6	21.7	26.5	40 sec at Shepreth
31108	0.6	24.5	22.2	27.6	26.5	125 sec at Royston
31009	0.6	24.8	22.5	27.2	26.5	40 sec at Shepreth
31110	0.6	24.5	22.3	16.0	26.5	125 sec at Royston
31011	0.6	24.4	21.9	25.8	26.5	40 sec at Shepreth
31112	0.6	24.6	22.7	20.0	26.5	125 sec at Royston
31013	0.6	25.1	23.4	9.5	26.5	40 sec at Shepreth
31114	0.7	24.6	22.4	11.0	26.5	185 sec at Royston
31015	0.6	24.3	21.9	22.6	26.5	40 sec at Shepreth
31016	0.6	25.3	23.6	26.0	26.5	40 sec at Shepreth
41101	0.5	25.0	23.8	3.9	26.5	69 sec at Royston
41102	0.5	24.3	21.5	5.9	26.5	69 sec at Royston

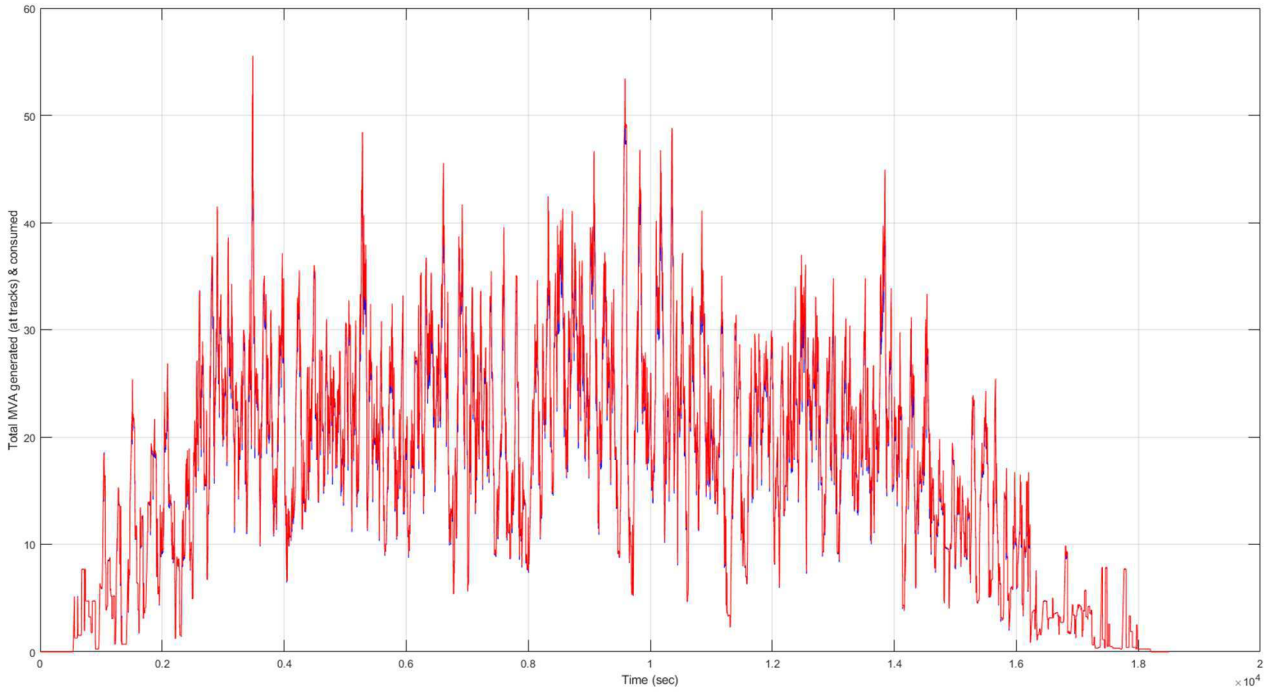
41003	0.5	24.6	21.4	1.7	26.5	40 sec at Meldreth
41104	0.5	24.4	22.6	5.9	26.5	40 sec at Royston
41005	0.5	24.7	22.5	12.5	26.5	40 sec at Meldreth
41106	0.5	24.2	21.7	6.1	26.5	40 sec at Royston
41007	0.5	24.5	21.6	1.2	26.5	40 sec at Meldreth
41108	0.5	24.2	21.7	1.6	26.5	99 sec at Royston
41009	0.5	25.0	22.8	5.5	26.5	40 sec at Meldreth
41110	0.5	24.1	21.2	5.0	26.5	69 sec at Royston
41011	0.5	24.5	21.2	1.2	26.5	40 sec at Meldreth
41112	0.5	24.3	21.9	5.0	26.5	189 sec at Royston
41013	0.5	24.8	21.9	1.9	26.5	40 sec at Meldreth
50601	0.8	25.9	24.5	79.3	26.5	40 sec at Cambridge North
50602	0.8	25.7	23.2	69.7	26.5	40 sec at Cambridge North
50603	0.8	25.6	23.9	67.5	26.5	40 sec at Cambridge North
50604	0.8	25.7	22.8	69.4	26.5	40 sec at Cambridge
50605	0.8	26.1	24.3	66.6	26.5	44 sec at Waterbeach
60601	0.7	25.7	22.9	36.7	26.5	40 sec at Cambridge
60602	0.6	25.7	23.3	37.0	26.5	40 sec at Cambridge
60603	0.6	25.8	23.0	35.4	26.5	40 sec at Cambridge
60604	0.6	26.0	24.1	32.4	26.5	40 sec at Cambridge
71101	1.3	25.7	24.9	68.9	26.5	40 sec at Great Chesterford
71102	1.3	25.3	22.8	72.7	26.5	40 sec at Great Chesterford
71103	1.6	25.7	24.7	77.5	26.5	40 sec at Great Chesterford
71104	2.4	25.5	23.5	66.2	26.5	40 sec at Littleport
71105	1.3	25.4	23.5	70.4	26.5	40 sec at Great Chesterford
71106	1.6	25.4	23.1	71.8	26.5	40 sec at Great Chesterford
71107	1.3	25.2	22.8	69.3	26.5	40 sec at Shelford
71108	1.6	25.2	23.6	65.4	26.5	40 sec at Great Chesterford
71109	1.3	25.5	24.0	66.3	26.5	40 sec at Great Chesterford
71110	1.3	25.4	23.1	66.5	26.5	40 sec at Great Chesterford
81101	1.1	25.5	22.8	31.4	26.5	40 sec at Great Chesterford

81102	1.1	25.3	23.1	37.5	26.5	40 sec at Audley End
81103	1.1	25.4	23.4	31.8	26.5	40 sec at Audley End
81104	1.1	25.2	22.6	32.7	26.5	40 sec at Great Chesterford
81105	1.1	25.1	22.8	31.9	26.5	40 sec at Audley End
81106	1.1	25.3	23.0	36.7	26.5	40 sec at Audley End
81107	1.1	25.4	22.9	33.7	26.5	40 sec at Audley End
81108	1.1	25.5	24.2	34.7	26.5	40 sec at Audley End

Table 19 Normal Feeding Arrangement with Regen Off – Train Performance Results

b) Total Energy Consumption:

Total MWh Generated = 85.3
Total MWh Consumed = 84.2
Losses Percentage = 1.3

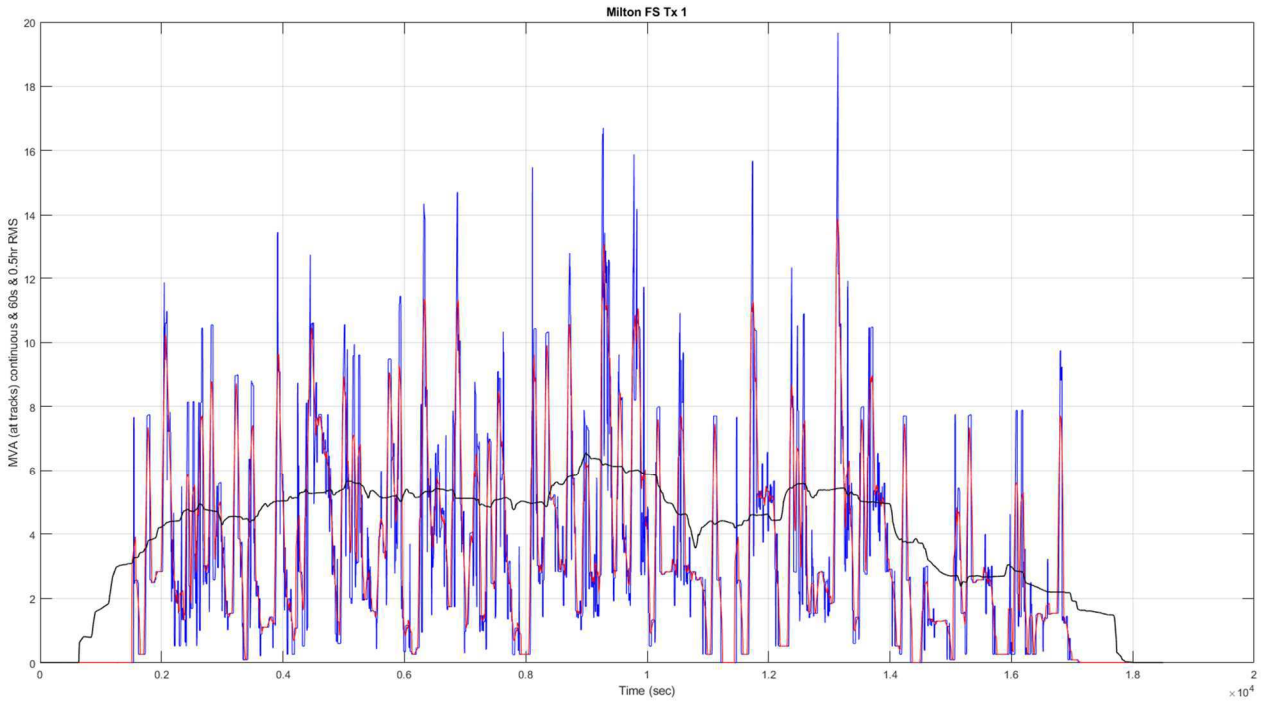


MVA Generated

MVA Consumed

Figure 29 Total MVA (Generated & Consumed) For Normal Feeding Arrangement with Regen Off

c) Feeder Station Loading:

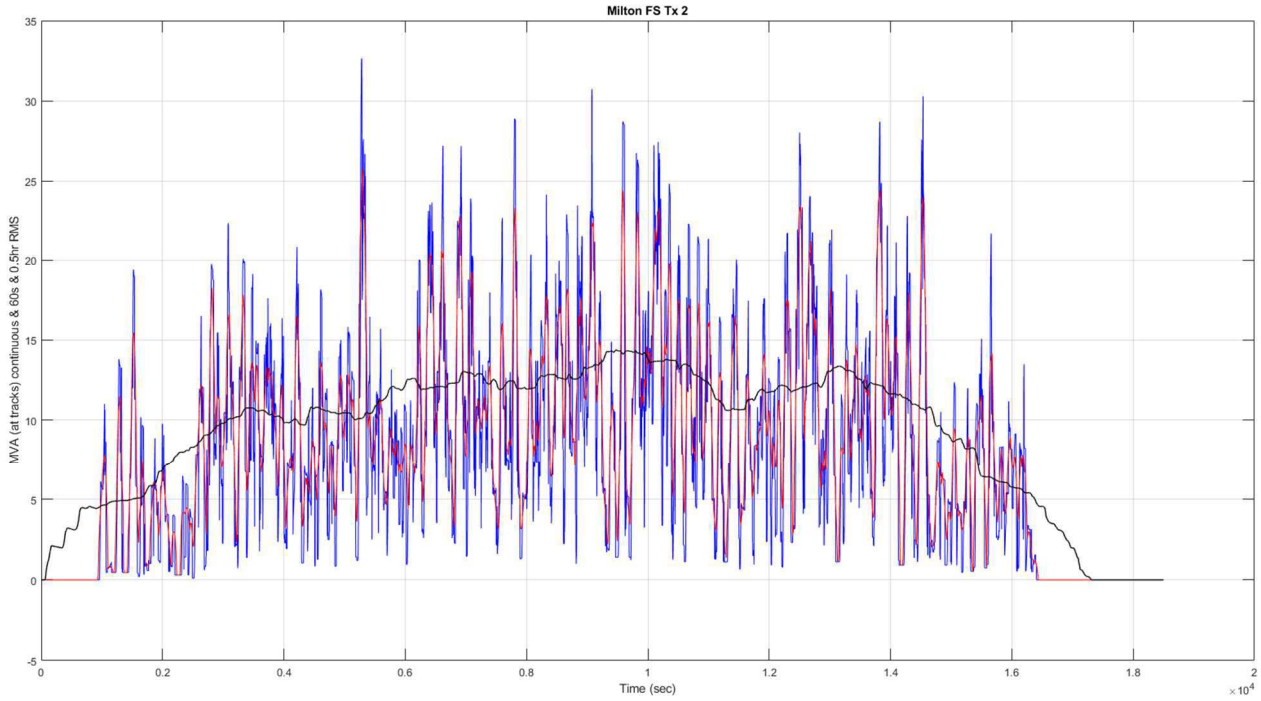


Instantaneous

1 Minute

30 Minute

Figure 30 MVA Load at Milton FS Tx 1 – Normal Feeding Arrangement with Regen Off

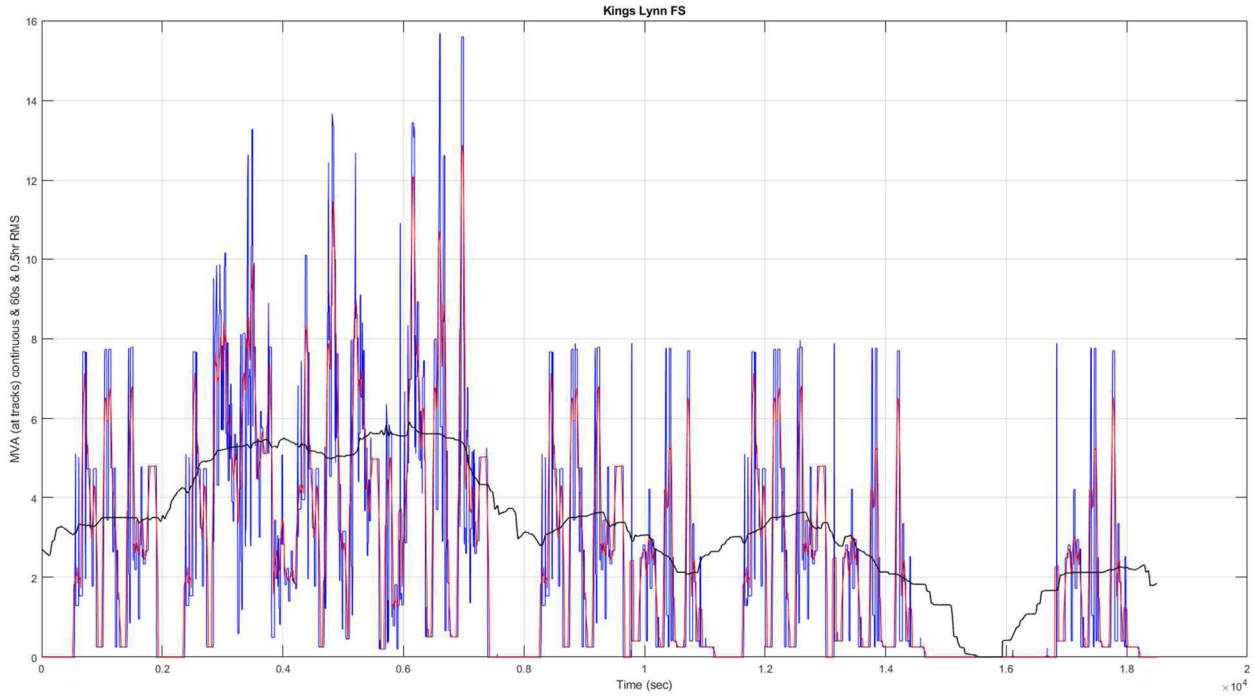


Instantaneous

1 Minute

30 Minute

Figure 31 MVA Load at Milton FS Tx 2 – Normal Feeding Arrangement with Regen Off

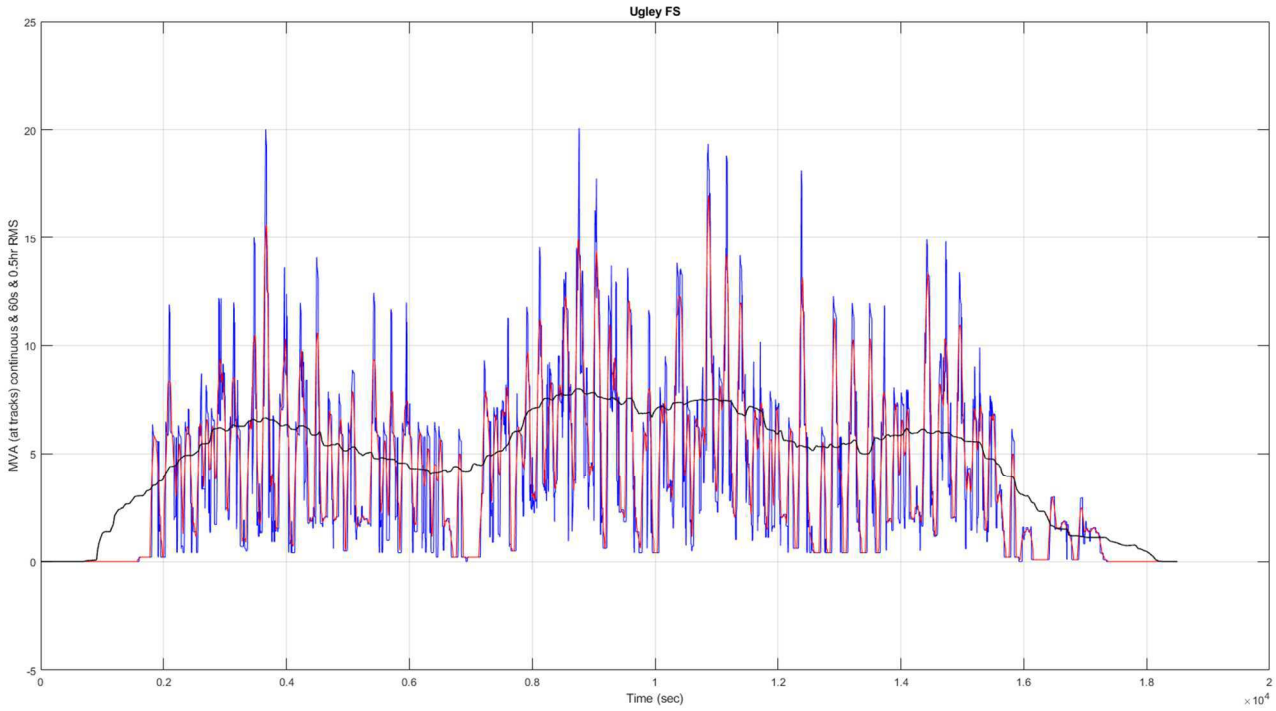


Instantaneous

1 Minute

30 Minute

Figure 32 MVA Load at Kings Lynn FS – Normal Feeding Arrangement with Regen Off



Instantaneous

1 Minute

30 Minute

Figure 33 MVA Load at Ugley FS – Normal Feeding Arrangement with Regen Off

Emergency Feeding Arrangement at Milton FS with Regen On

a) *Train Performance Results:*

Train No	Total Energy Consumed (MWh)	Umean-useful (Train) (V)	Minimum Voltage (V)	Minimum Voltage at Distance (km)	Maximum Voltage (V)	Minimum Dwell Time at Station (sec)
10301	2.8	25.6	21.5	87.5	26.9	40 sec at Watlington
10302	2.8	25.3	21.6	87.5	26.8	40 sec at Watlington
10103	1.4	25.5	21.8	82.0	26.8	40 sec at Littleport
10304	2.8	25.2	21.7	87.8	26.7	40 sec at Littleport
10305	2.8	25.2	22.2	78.2	26.8	40 sec at Littleport
10306	2.8	25.3	22.1	78.2	26.7	40 sec at Watlington
10307	2.8	25.6	23.0	33.9	26.8	40 sec at Watlington
10308	1.4	24.9	22.0	87.8	26.7	82 sec at Cambridge North
20301	1.3	25.7	23.7	58.1	26.8	40 sec at Cambridge
20302	1.8	25.2	23.0	52.7	26.8	40 sec at Cambridge
20303	1.8	24.9	22.4	20.6	26.7	40 sec at Cambridge
20304	1.2	24.7	22.3	20.9	26.6	40 sec at Royston
20305	1.8	25.1	21.9	1.6	26.7	40 sec at Cambridge
20306	1.2	25.3	23.2	25.1	26.7	40 sec at Waterbeach
20307	1.8	25.4	22.0	14.0	26.8	40 sec at Cambridge South
31101	0.6	25.4	24.7	20.0	26.5	125 sec at Royston
31002	0.5	25.0	22.9	26.0	26.7	40 sec at Shepreth
30303	0.8	25.1	22.8	27.6	26.6	118 sec at Royston
31104	0.6	24.9	23.4	10.4	26.5	125 sec at Royston
31005	0.5	25.0	23.7	28.6	26.7	40 sec at Shepreth
31106	0.6	24.8	22.0	10.3	26.5	125 sec at Royston
31007	0.5	24.7	22.4	21.1	26.5	40 sec at Shepreth
31108	0.6	24.2	22.5	5.0	26.6	125 sec at Royston
31009	0.5	24.7	22.4	27.2	26.6	40 sec at Shepreth
31110	0.6	24.2	21.7	27.2	26.5	125 sec at Royston
31011	0.5	24.2	21.8	25.7	26.7	40 sec at Shepreth
31112	0.6	24.6	22.9	20.1	26.5	125 sec at Royston
31013	0.5	25.0	23.6	9.5	26.7	40 sec at Shepreth
31114	0.6	24.5	22.6	11.0	26.5	185 sec at Royston
31015	0.5	24.3	21.7	22.6	26.7	40 sec at Shepreth
31016	0.5	25.2	23.5	26.0	26.6	40 sec at Shepreth
41101	0.4	24.9	22.9	3.9	26.5	69 sec at Royston
41102	0.4	24.2	21.3	4.3	26.5	69 sec at Royston

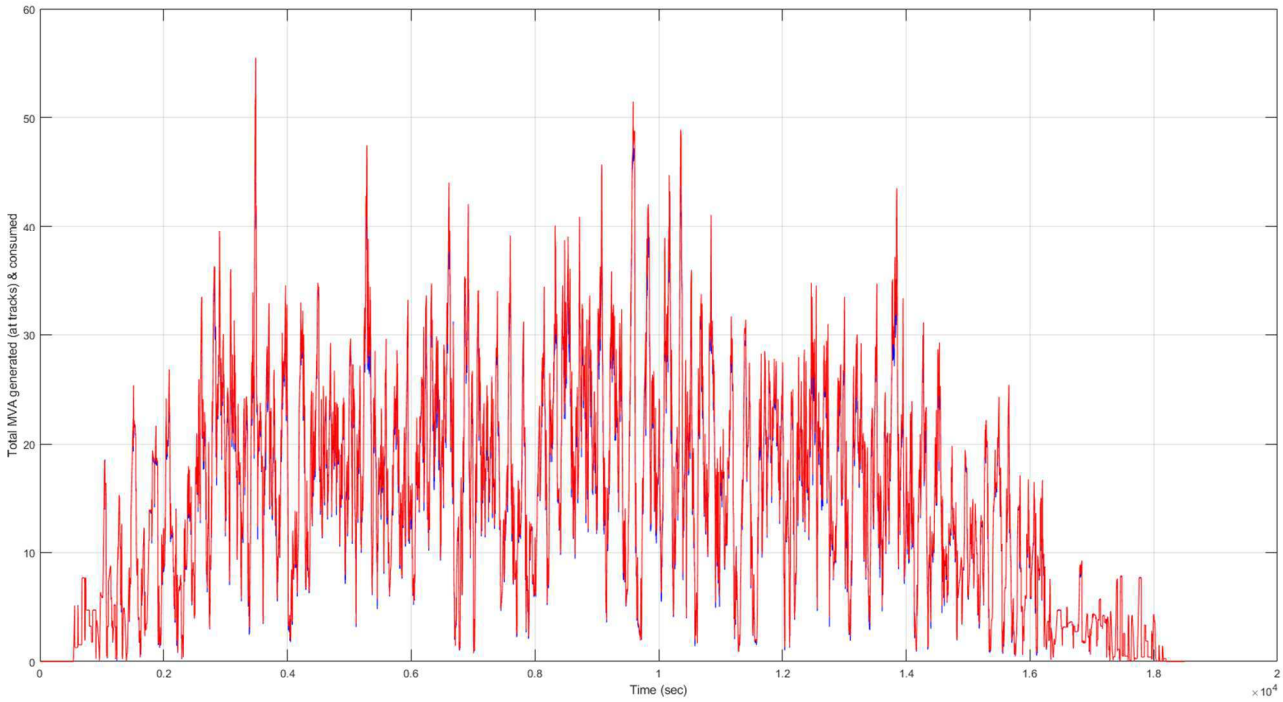
41003	0.4	24.5	21.5	1.7	26.5	40 sec at Meldreth
41104	0.4	24.1	21.4	2.0	26.8	40 sec at Royston
41005	0.4	24.5	22.2	1.1	26.6	40 sec at Meldreth
41106	0.4	24.2	21.7	6.1	26.5	40 sec at Royston
41007	0.4	24.3	21.6	1.2	26.5	40 sec at Meldreth
41108	0.4	24.1	21.7	1.2	26.7	99 sec at Royston
41009	0.4	25.0	22.9	5.6	26.5	40 sec at Meldreth
41110	0.4	24.2	21.4	5.0	26.5	69 sec at Royston
41011	0.4	24.5	21.4	1.2	26.5	40 sec at Meldreth
41112	0.4	24.2	21.9	5.0	26.7	189 sec at Royston
41013	0.4	24.7	21.8	1.9	26.7	40 sec at Meldreth
50601	0.7	25.7	24.1	58.1	26.5	40 sec at Cambridge North
50602	0.7	25.3	22.9	54.4	26.5	40 sec at Cambridge North
50603	0.7	25.3	22.9	68.2	26.5	40 sec at Cambridge North
50604	0.7	25.5	22.6	69.4	26.5	40 sec at Cambridge
50605	0.7	26.0	24.2	42.9	26.5	44 sec at Waterbeach
60601	0.6	25.5	22.5	36.7	26.6	40 sec at Cambridge
60602	0.6	25.5	23.0	37.1	26.5	40 sec at Cambridge
60603	0.6	25.6	23.2	35.4	26.7	40 sec at Cambridge
60604	0.6	26.0	24.0	32.4	26.6	40 sec at Cambridge
71101	1.1	25.7	24.9	68.9	26.5	40 sec at Great Chesterford
71102	1.1	25.2	22.8	72.7	26.5	40 sec at Great Chesterford
71103	1.4	25.5	23.4	43.9	26.5	40 sec at Great Chesterford
71104	2.1	25.3	22.3	44.5	26.6	40 sec at Littleport
71105	1.1	25.1	22.3	69.1	26.5	40 sec at Great Chesterford
71106	1.3	25.3	23.1	71.8	26.5	40 sec at Great Chesterford
71107	1.2	25.0	23.0	69.8	26.5	40 sec at Shelford
71108	1.4	25.0	23.3	57.9	26.5	40 sec at Great Chesterford
71109	1.1	25.4	24.2	66.3	26.6	40 sec at Great Chesterford
71110	1.1	25.3	22.9	66.5	26.6	40 sec at Great Chesterford
81101	0.9	25.5	22.8	31.4	26.5	40 sec at Great Chesterford

81102	0.9	25.2	22.7	37.5	26.5	40 sec at Audley End
81103	0.9	25.3	22.8	36.4	26.5	40 sec at Audley End
81104	0.9	25.1	22.3	32.8	26.5	40 sec at Great Chesterford
81105	0.9	25.1	23.0	32.4	26.5	40 sec at Audley End
81106	0.9	25.2	23.2	36.7	26.6	40 sec at Audley End
81107	0.9	25.3	22.7	33.7	26.6	40 sec at Audley End
81108	0.9	25.5	24.1	34.7	26.5	40 sec at Audley End

Table 20 Emergency Feeding Arrangement at Milton FS with Regen On – Train Performance Results

b) Total Energy Consumption:

Total MWh Generated = 70.8
Total MWh Consumed = 69.8
Losses Percentage = 1.5

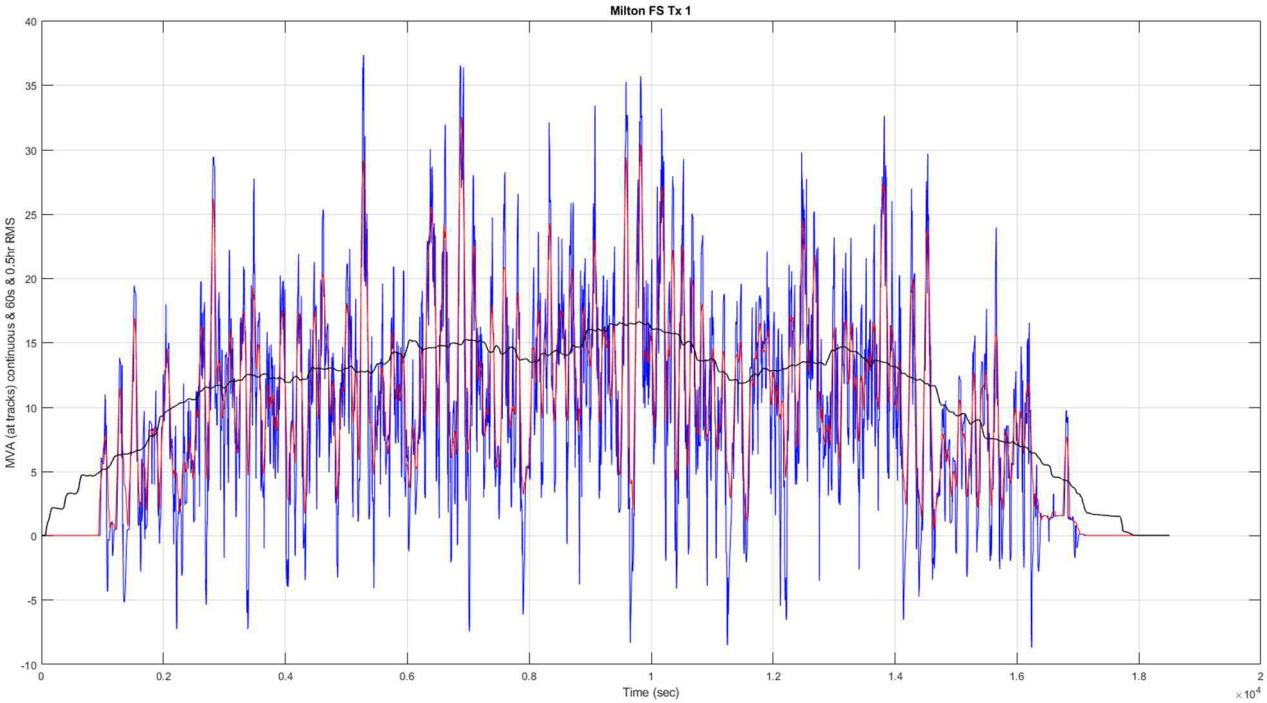


MVA Generated

MVA Consumed

Figure 34 Total MVA (Generated & Consumed) For Emergency Feeding Arrangement at Milton FS with Regen On

c) Feeder Station Loading:

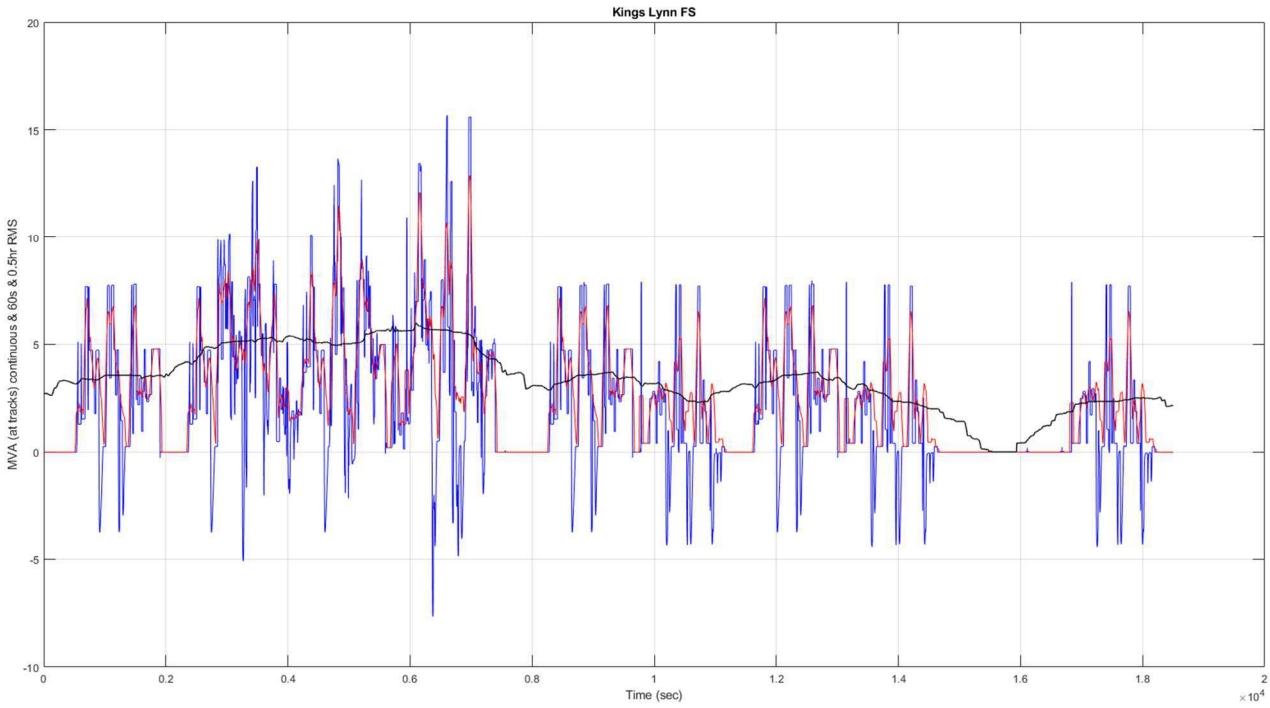


Instantaneous

1 Minute

30 Minute

Figure 35 MVA Load at Milton FS Tx 1 – Emergency Feeding Arrangement at Milton FS with Regen On

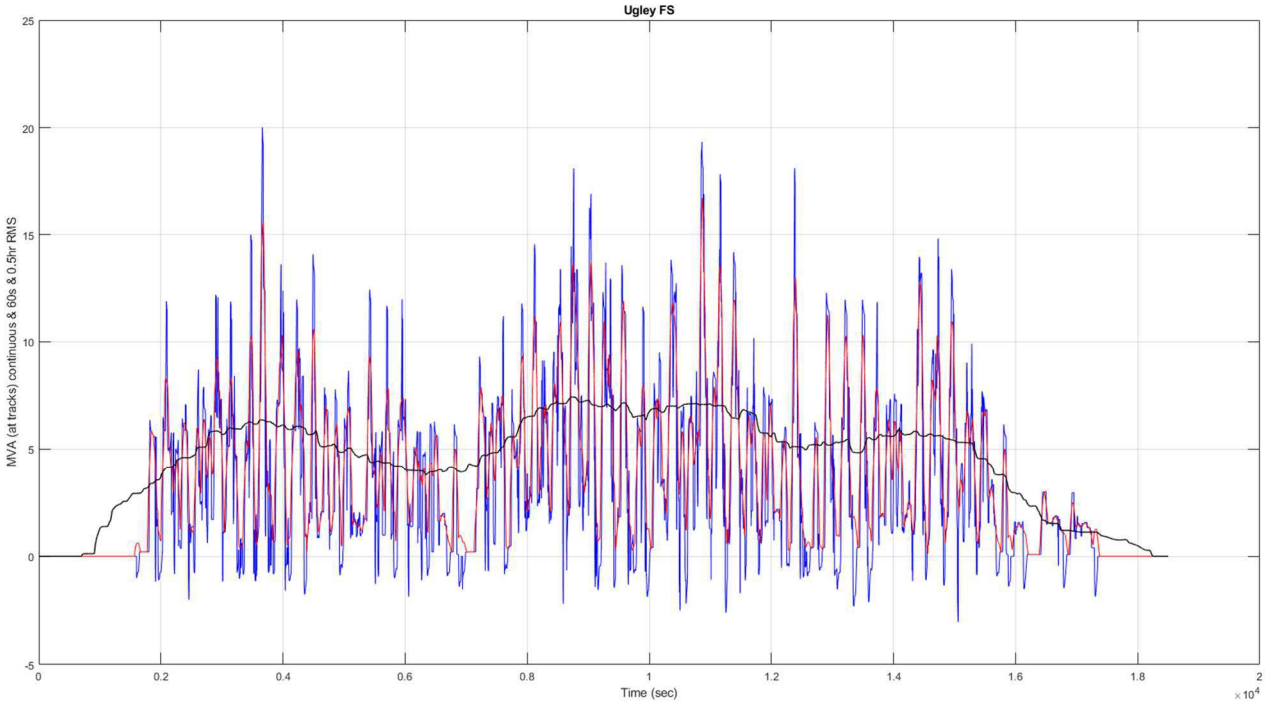


Instantaneous

1 Minute

30 Minute

Figure 36 MVA Load at Kings Lynn FS – Emergency Feeding Arrangement at Milton FS with Regen On



Instantaneous

1 Minute

30 Minute

Figure 37 MVA Load at Ugley FS – Emergency Feeding Arrangement at Milton FS with Regen On

Emergency Feeding Arrangement at Kings Lynn FS with Regen On

a) Train Performance Results:

Train No	Total Energy Consumed (MWh)	Umean-useful (Train) (V)	Minimum Voltage (V)	Minimum Voltage at Distance (km)	Maximum Voltage (V)	Minimum Dwell Time at Station (sec)
10301	2.8	25.3	21.6	87.7	27.0	40 sec at Watlington
10302	2.8	24.8	21.6	23.8	26.9	40 sec at Watlington
10103	1.4	25.2	21.3	12.1	26.9	40 sec at Littleport
10304	2.7	24.6	21.2	12.6	26.7	40 sec at Littleport
10305	2.8	24.6	20.7	7.8	27.1	40 sec at Littleport
10306	2.8	25.1	22.2	78.2	26.8	40 sec at Watlington
10307	2.8	25.2	22.4	18.4	26.9	40 sec at Watlington
10308	1.4	25.0	22.0	87.8	26.7	82 sec at Cambridge North
20301	1.3	25.2	21.3	76.4	26.8	40 sec at Cambridge
20302	1.8	24.7	20.9	72.1	27.0	40 sec at Cambridge
20303	1.8	25.0	22.9	6.2	27.1	40 sec at Cambridge
20304	1.2	25.1	22.6	20.9	26.7	40 sec at Royston
20305	1.8	25.0	22.5	12.1	27.0	40 sec at Cambridge
20306	1.2	25.5	23.3	25.1	26.7	40 sec at Waterbeach
20307	1.8	25.4	22.3	14.0	27.0	40 sec at Cambridge South
31101	0.6	25.5	24.8	20.0	26.5	125 sec at Royston
31002	0.5	25.2	23.0	26.0	26.7	40 sec at Shepreth
30303	0.8	25.2	23.1	20.0	26.8	118 sec at Royston
31104	0.6	25.0	23.8	19.6	26.6	125 sec at Royston
31005	0.5	25.2	24.0	28.6	26.7	40 sec at Shepreth
31106	0.6	24.9	22.4	10.3	26.5	125 sec at Royston
31007	0.5	24.9	22.8	21.1	26.5	40 sec at Shepreth
31108	0.6	24.5	22.4	27.6	26.6	125 sec at Royston
31009	0.5	24.8	22.5	27.2	26.6	40 sec at Shepreth
31110	0.6	24.6	22.3	16.0	26.6	125 sec at Royston
31011	0.5	24.5	22.2	25.7	26.7	40 sec at Shepreth
31112	0.6	24.6	22.7	20.0	26.5	125 sec at Royston
31013	0.5	25.1	23.4	9.5	26.7	40 sec at Shepreth
31114	0.6	24.7	22.7	11.0	26.5	185 sec at Royston
31015	0.5	24.5	22.1	22.6	26.7	40 sec at Shepreth
31016	0.5	25.3	23.6	26.0	26.6	40 sec at Shepreth
41101	0.4	25.1	23.8	3.9	26.6	69 sec at Royston
41102	0.4	24.4	21.5	5.9	26.5	69 sec at Royston

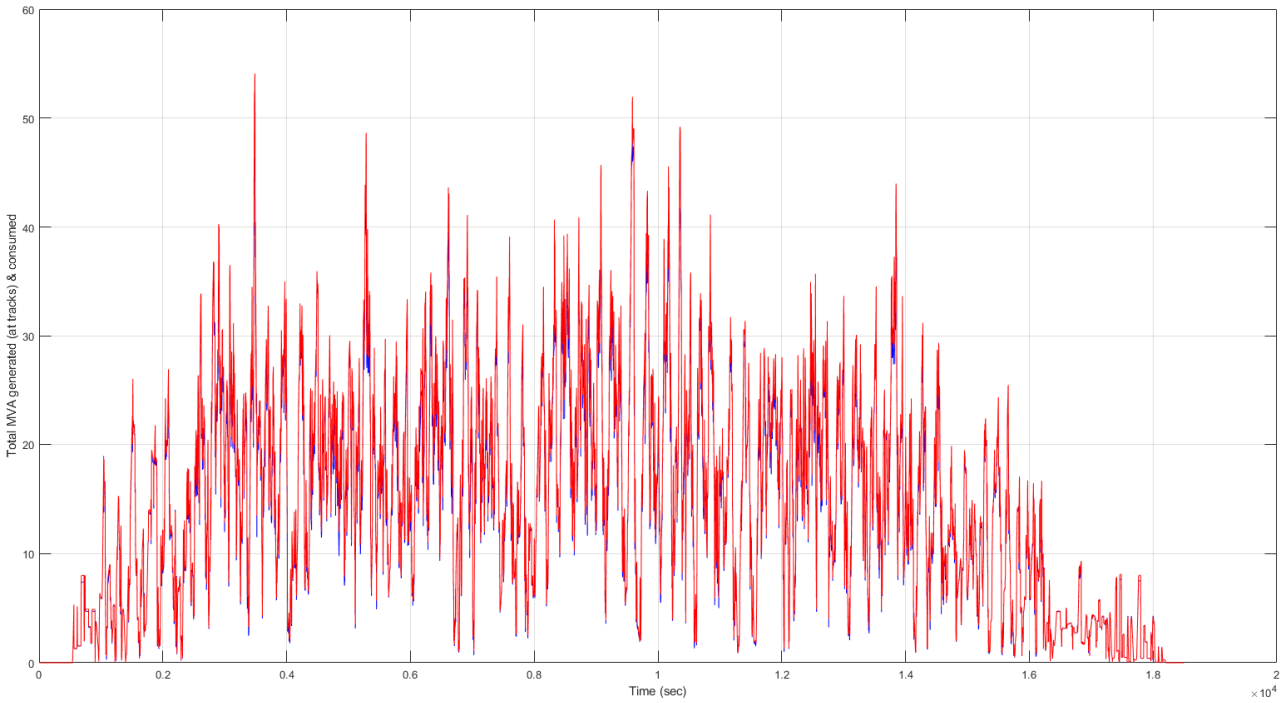
41003	0.4	24.7	21.5	1.7	26.5	40 sec at Meldreth
41104	0.4	24.5	22.7	4.9	26.8	40 sec at Royston
41005	0.4	24.7	22.6	1.1	26.6	40 sec at Meldreth
41106	0.4	24.4	21.8	6.1	26.6	40 sec at Royston
41007	0.4	24.6	21.7	1.2	26.5	40 sec at Meldreth
41108	0.4	24.3	22.1	1.2	26.7	99 sec at Royston
41009	0.4	25.1	22.8	5.5	26.6	40 sec at Meldreth
41110	0.4	24.3	21.5	5.0	26.5	69 sec at Royston
41011	0.4	24.7	21.6	1.2	26.5	40 sec at Meldreth
41112	0.4	24.3	22.0	5.0	26.7	189 sec at Royston
41013	0.4	24.8	21.9	1.9	26.7	40 sec at Meldreth
50601	0.7	25.6	23.8	44.1	26.5	40 sec at Cambridge North
50602	0.7	25.5	23.3	48.3	26.5	40 sec at Cambridge North
50603	0.7	25.5	24.0	67.5	26.5	40 sec at Cambridge North
50604	0.7	25.6	23.0	69.4	26.5	40 sec at Cambridge
50605	0.7	26.1	24.3	66.6	26.6	44 sec at Waterbeach
60601	0.6	25.6	22.9	36.7	26.6	40 sec at Cambridge
60602	0.6	25.7	23.3	37.0	26.6	40 sec at Cambridge
60603	0.6	25.7	23.3	35.4	26.7	40 sec at Cambridge
60604	0.6	26.0	24.1	32.4	26.5	40 sec at Cambridge
71101	1.1	25.7	24.9	68.9	26.5	40 sec at Great Chesterford
71102	1.1	25.3	22.8	72.7	26.6	40 sec at Great Chesterford
71103	1.4	25.5	22.3	44.5	26.6	40 sec at Great Chesterford
71104	2.1	24.5	20.8	1.6	26.6	40 sec at Littleport
71105	1.1	25.4	23.5	70.4	26.5	40 sec at Great Chesterford
71106	1.3	25.4	23.1	71.8	26.5	40 sec at Great Chesterford
71107	1.2	25.2	23.5	69.9	26.5	40 sec at Shelford
71108	1.4	25.2	23.0	42.9	26.6	40 sec at Great Chesterford
71109	1.2	25.5	24.0	66.3	26.6	40 sec at Great Chesterford
71110	1.1	25.4	23.2	66.5	26.6	40 sec at Great Chesterford
81101	0.9	25.5	22.8	31.4	26.5	40 sec at Great Chesterford

81102	0.9	25.3	23.1	37.5	26.6	40 sec at Audley End
81103	0.9	25.4	23.6	34.5	26.6	40 sec at Audley End
81104	0.9	25.2	22.6	32.7	26.5	40 sec at Great Chesterford
81105	0.9	25.2	23.4	32.5	26.6	40 sec at Audley End
81106	0.9	25.3	23.3	36.7	26.6	40 sec at Audley End
81107	0.9	25.4	23.1	33.7	26.6	40 sec at Audley End
81108	0.9	25.5	24.2	34.7	26.6	40 sec at Audley End

Table 21 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train Performance Results

b) Total Energy Consumption:

Total MWh Generated = 71.4
Total MWh Consumed = 70.0
Losses Percentage = 2.0

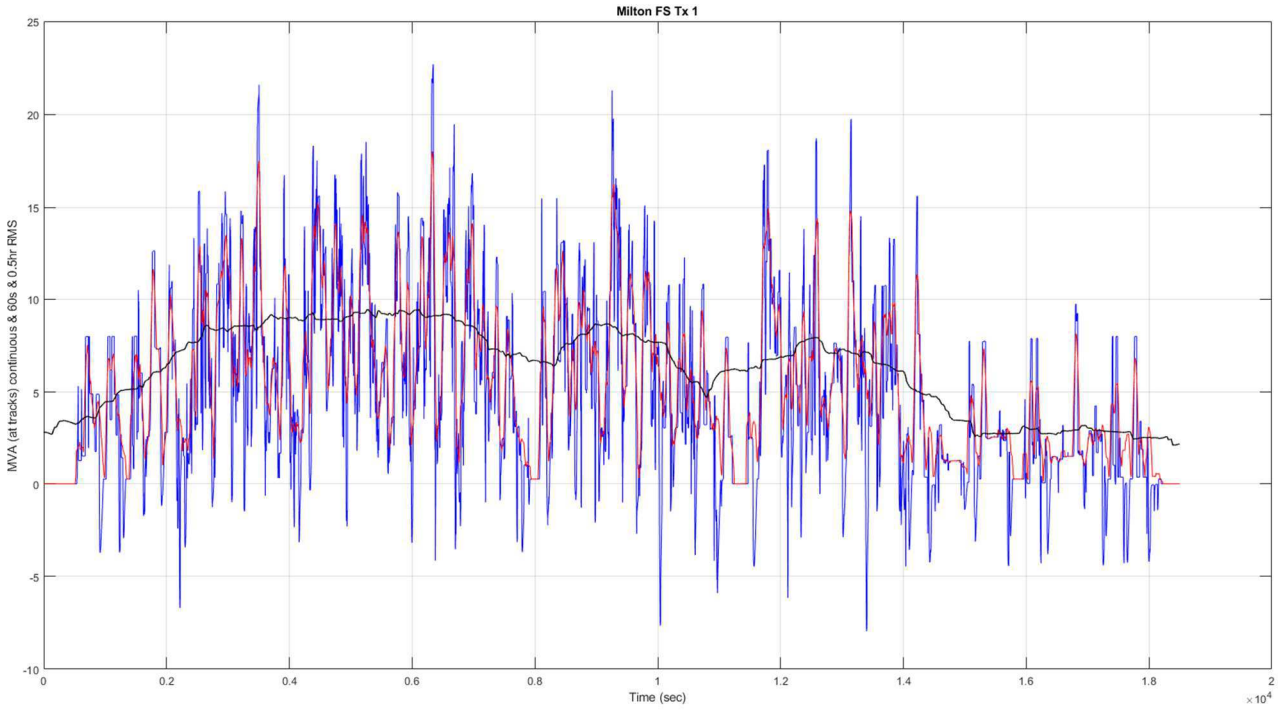


MVA Generated

MVA Consumed

Figure 38 Total MVA (Generated & Consumed) For Emergency Feeding Arrangement at Kings Lynn FS with Regen On

c) Feeder Station Loading:

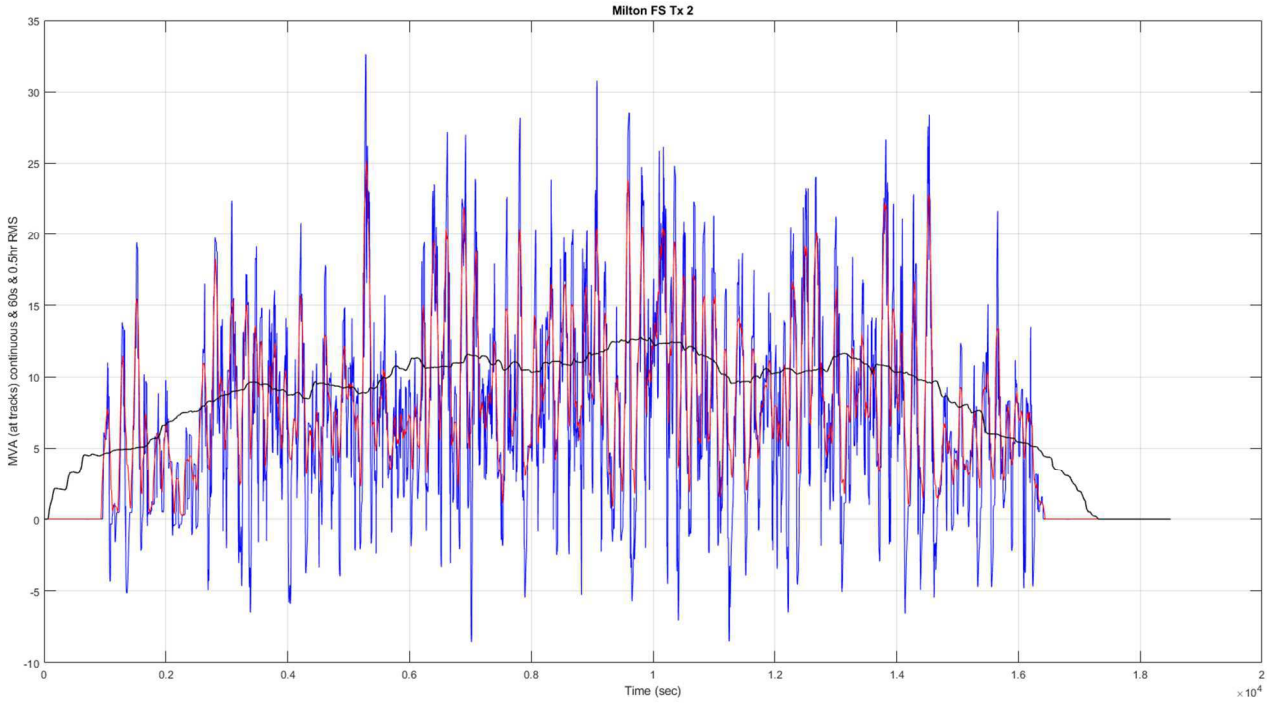


Instantaneous

1 Minute

30 Minute

Figure 39 MVA Load at Milton FS Tx 1 – Emergency Feeding Arrangement at Kings Lynn FS with Regen On

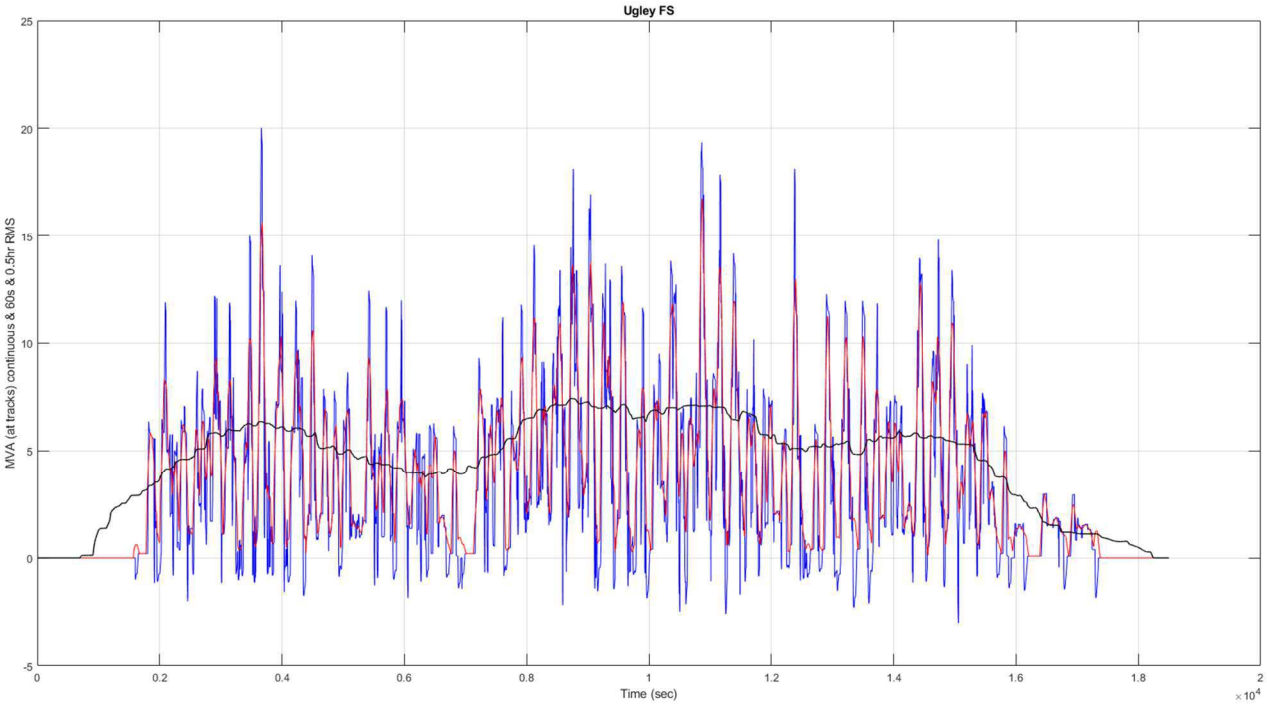


Instantaneous

1 Minute

30 Minute

Figure 40 MVA Load at Milton FS Tx 2 – Emergency Feeding Arrangement at Kings Lynn FS with Regen On



Instantaneous

1 Minute

30 Minute

Figure 41 MVA Load at Ugley FS – Emergency Feeding Arrangement at Kings Lynn FS with Regen On

Emergency Feeding Arrangement at Ugley FS with Regen On

a) Train Performance Results:

Train No	Total Energy Consumed (MWh)	Umean-useful (Train) (V)	Minimum Voltage (V)	Minimum Voltage at Distance (km)	Maximum Voltage (V)	Minimum Dwell Time at Station (sec)
10301	2.8	25.5	21.3	87.6	26.9	40 sec at Watlington
10302	2.8	25.4	22.0	76.7	26.9	40 sec at Watlington
10103	1.4	25.7	22.7	89.0	26.8	40 sec at Littleport
10304	2.8	25.1	20.5	83.0	26.8	40 sec at Littleport
10305	2.7	24.9	19.4	89.5	26.8	40 sec at Littleport
10306	2.8	25.4	21.6	78.2	26.9	40 sec at Watlington
10307	2.8	25.7	23.1	33.9	26.8	40 sec at Watlington
10308	1.4	24.7	21.1	80.8	26.7	82 sec at Cambridge North
20301	1.3	25.9	25.2	58.1	26.8	40 sec at Cambridge
20302	1.8	25.2	21.5	9.0	26.8	40 sec at Cambridge
20303	1.8	25.0	21.7	23.2	26.7	40 sec at Cambridge
20304	1.2	24.1	19.7	20.8	26.7	40 sec at Royston
20305	1.8	24.9	20.2	18.3	26.9	40 sec at Cambridge
20306	1.2	25.1	22.4	2.2	26.7	40 sec at Waterbeach
20307	1.8	25.3	21.8	17.8	26.8	40 sec at Cambridge South
31101	0.6	25.1	23.7	23.8	26.5	125 sec at Royston
31002	0.5	24.3	21.2	24.0	26.5	40 sec at Shepreth
30303	0.7	24.1	20.5	27.6	26.6	116 sec at Royston
31104	0.5	24.0	21.0	10.4	26.5	125 sec at Royston
31005	0.5	24.2	21.7	5.9	26.5	40 sec at Shepreth
31106	0.5	24.1	22.0	13.9	26.5	125 sec at Royston
31007	0.5	24.4	21.7	21.1	26.5	40 sec at Shepreth
31108	0.5	23.9	20.8	25.8	26.6	125 sec at Royston
31009	0.4	23.8	20.3	27.2	26.6	40 sec at Shepreth
31110	0.5	22.9	19.3	16.0	26.5	124 sec at Royston
31011	0.5	23.4	19.6	28.0	26.5	40 sec at Shepreth
31112	0.5	23.1	19.4	14.9	26.5	125 sec at Royston
31013	0.5	24.0	20.2	16.1	26.5	40 sec at Shepreth
31114	0.5	24.2	21.6	26.3	26.5	185 sec at Royston
31015	0.5	24.0	21.0	25.8	26.5	40 sec at Shepreth
31016	0.5	24.7	23.2	23.7	26.5	40 sec at Shepreth
41101	0.4	24.5	20.6	3.9	26.5	69 sec at Royston
41102	0.4	23.8	21.2	5.8	26.5	69 sec at Royston

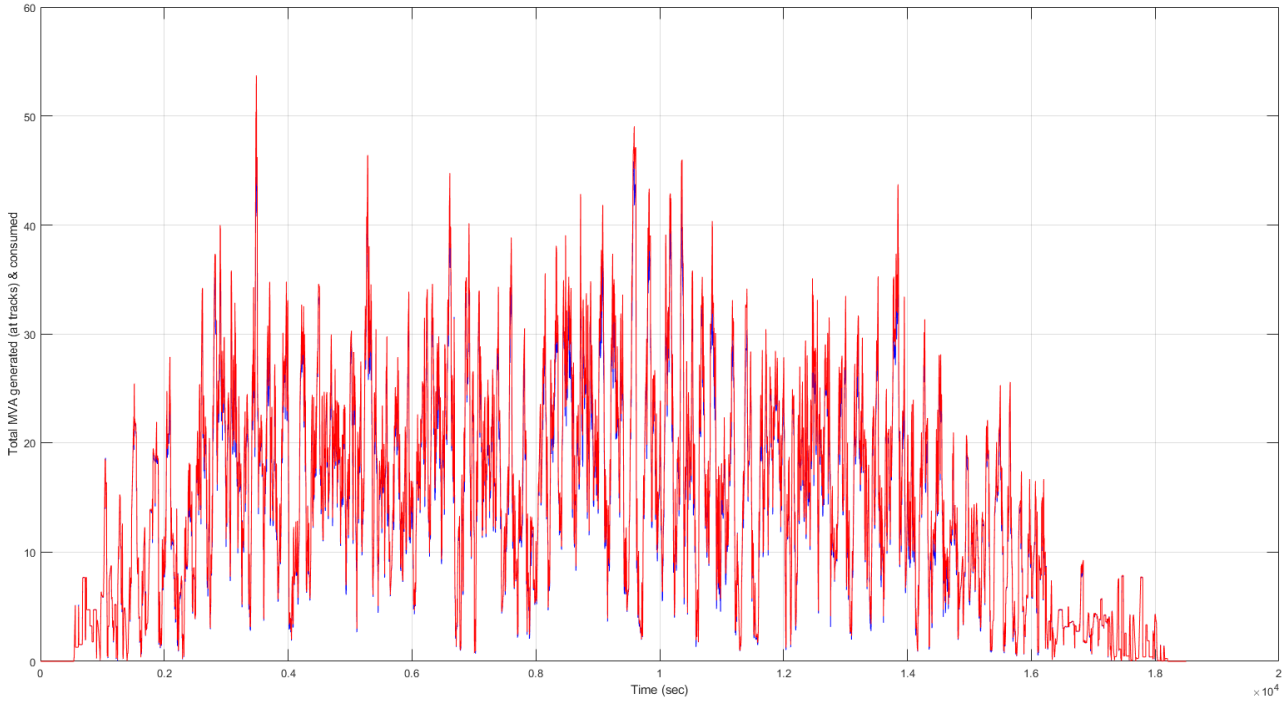
41003	0.4	24.1	21.2	1.7	26.5	40 sec at Meldreth
41104	0.4	24.0	21.2	20.9	26.8	40 sec at Royston
41005	0.4	23.7	20.7	9.3	26.5	40 sec at Meldreth
41106	0.4	23.3	19.0	12.2	26.5	40 sec at Royston
41007	0.4	23.8	19.1	3.9	26.5	40 sec at Meldreth
41108	0.4	23.2	19.7	3.9	26.5	99 sec at Royston
41009	0.4	23.9	19.4	3.9	26.5	40 sec at Meldreth
41110	0.4	23.9	20.9	5.0	26.5	69 sec at Royston
41011	0.4	24.2	21.0	1.2	26.5	40 sec at Meldreth
41112	0.4	23.7	20.9	1.8	26.5	189 sec at Royston
41013	0.4	24.3	21.7	1.8	26.5	40 sec at Meldreth
50601	0.7	25.0	21.7	100.0	26.5	40 sec at Cambridge North
50602	0.7	24.5	18.5	101.6	26.5	40 sec at Cambridge North
50603	0.7	24.0	18.3	89.2	26.5	40 sec at Cambridge North
50604	0.7	25.0	21.8	73.6	26.5	40 sec at Cambridge
50605	0.7	25.9	24.1	66.6	26.6	44 sec at Waterbeach
60601	0.6	24.5	19.6	14.8	26.6	40 sec at Cambridge
60602	0.6	24.6	20.1	13.6	26.5	40 sec at Cambridge
60603	0.6	24.7	18.0	3.1	26.7	40 sec at Cambridge
60604	0.6	25.3	22.3	12.4	26.5	40 sec at Cambridge
71101	1.0	24.8	20.3	92.6	26.6	40 sec at Great Chesterford
71102	1.0	23.9	21.1	71.6	26.5	40 sec at Great Chesterford
71103	1.3	24.8	22.2	71.6	26.5	40 sec at Great Chesterford
71104	2.1	24.7	18.7	87.8	26.5	40 sec at Littleport
71105	1.0	23.9	20.1	98.9	26.6	40 sec at Great Chesterford
71106	1.2	23.6	19.1	98.9	26.5	40 sec at Great Chesterford
71107	1.1	23.6	18.6	84.2	26.5	40 sec at Shelford
71108	1.3	23.6	19.4	83.1	26.5	40 sec at Great Chesterford
71109	1.1	23.9	20.8	66.3	26.5	40 sec at Great Chesterford
71110	1.1	24.3	22.5	68.7	26.5	40 sec at Great Chesterford
81101	0.8	23.7	20.5	17.5	26.5	40 sec at Great Chesterford

81102	0.8	23.3	19.4	11.2	26.5	40 sec at Audley End
81103	0.8	23.9	21.5	11.5	26.6	40 sec at Audley End
81104	0.8	23.1	19.7	32.8	26.5	40 sec at Great Chesterford
81105	0.8	22.0	18.4	11.5	26.5	40 sec at Audley End
81106	0.8	22.7	18.0	10.9	26.5	40 sec at Audley End
81107	0.8	23.9	20.9	4.0	26.5	40 sec at Audley End
81108	0.8	24.1	20.7	2.5	26.5	40 sec at Audley End

Table 22 Emergency Feeding Arrangement at Ugley FS with Regen On – Train Performance Results

b) Total Energy Consumption:

Total MWh Generated = 70.0
Total MWh Consumed = 68.2
Losses Percentage = 2.2

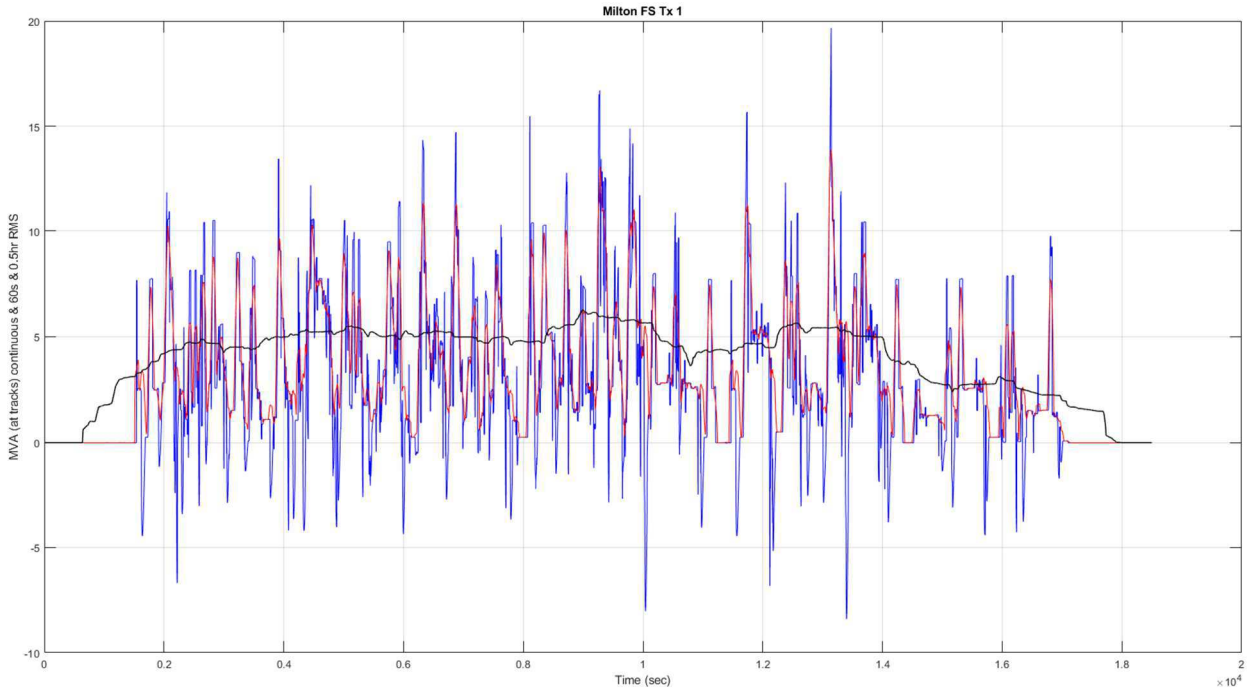


MVA Generated

MVA Consumed

Figure 42 Total MVA (Generated & Consumed) For Emergency Feeding Arrangement at Ugley FS with Regen On

c) Feeder Station Loading:

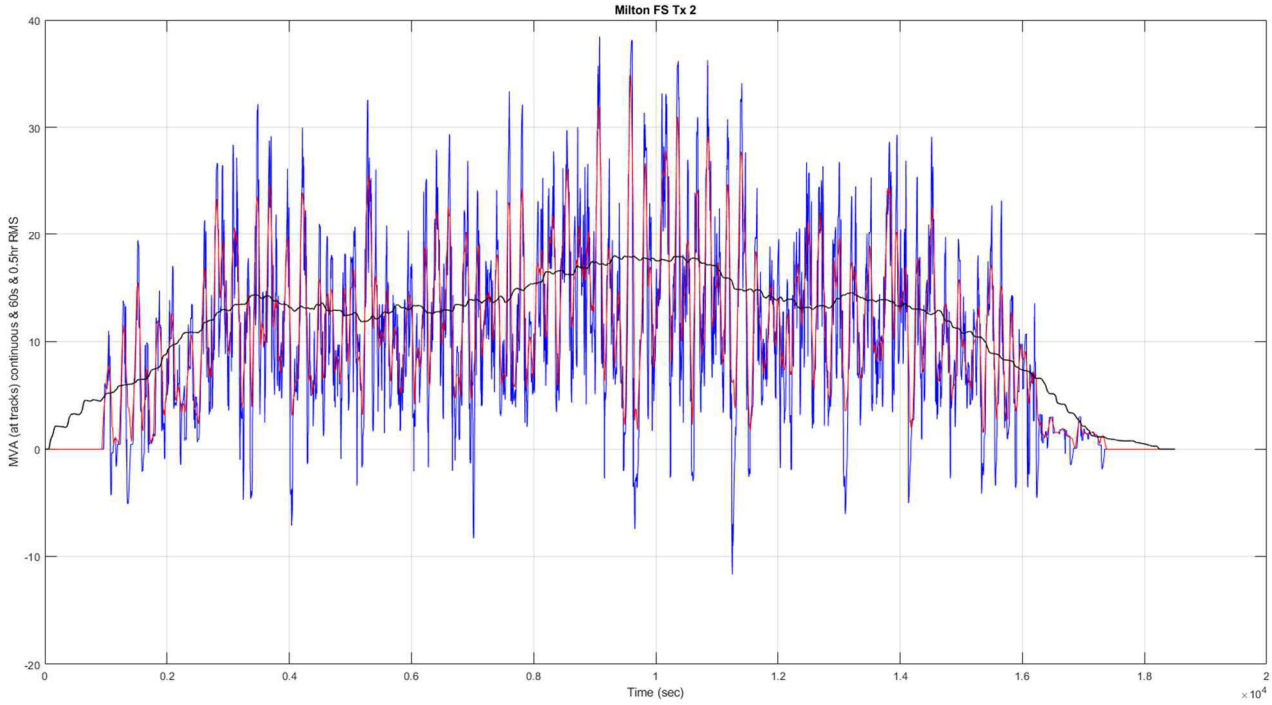


Instantaneous

1 Minute

30 Minute

Figure 43 MVA Load at Milton FS Tx 1 – Emergency Feeding Arrangement at Ugley FS with Regen On

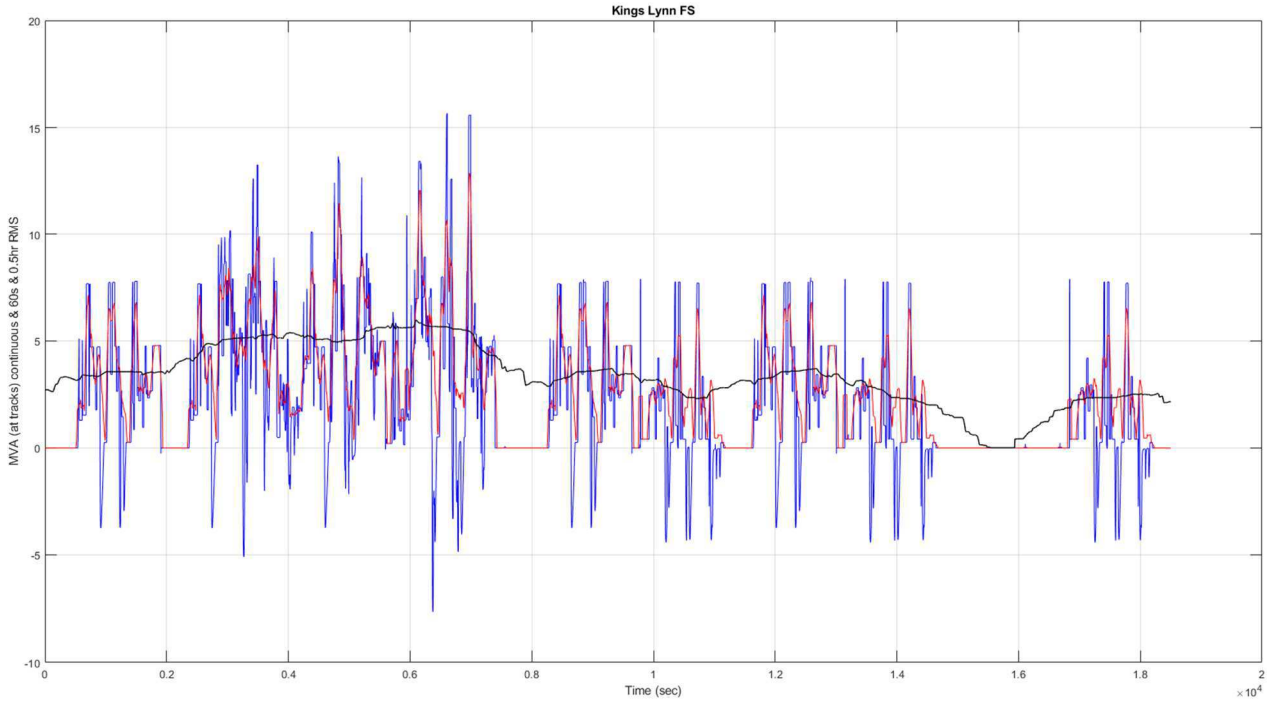


Instantaneous

1 Minute

30 Minute

Figure 44 MVA Load at Milton FS Tx 2 – Emergency Feeding Arrangement at Ugley FS with Regen On



Instantaneous

1 Minute

30 Minute

Figure 45 MVA Load at Kings Lynn FS – Emergency Feeding Arrangement at Ugley FS with Regen On

Appendix B – Sample of Simulation Results for Normal (N-0) and Emergency (N-1) Feeding Arrangement

This appendix presents sample waveforms for the Normal (with Regen On and Off) and Emergency Feeding Arrangement (with Regen On) at Milton FS, Kings Lynn FS, and Ugley FS to provide the reader the information available from the simulation output.

Figure 46 to Figure 49 (Normal Feeding Arrangement with Regen On), Figure 58 to Figure 61 (Normal Feeding Arrangement with Regen Off), Figure 70 to Figure 73 (Emergency Feeding Arrangement at Milton FS with Regen On), Figure 82 to Figure 85 (Emergency Feeding Arrangement at Kings Lynn FS with Regen On) and Figure 94 to Figure 97 (Emergency Feeding Arrangement at Ugley FS with Regen On) show the voltage profile against distance for Routes 1 & 2, 3 & 4, 5 & 6 and 7 & 8 respectively. Each plot shows the voltage profile for trains running in the up and down directions simultaneously superimposed on each other. The blue colour is for trains running in the up direction and red colour is for the down direction. The station locations are shown as vertical texts in black colour, and junction locations (which are between one branch and the next) are shown in purple colour.

Figure 50 to Figure 57 (Normal Feeding Arrangement with Regen On), Figure 62 to Figure 69 (Normal Feeding Arrangement with Regen Off), Figure 74 to Figure 81 (Emergency Feeding Arrangement at Milton FS with Regen On), Figure 86 to Figure 93 (Emergency Feeding Arrangement at Kings Lynn FS with Regen On) and Figure 98 to Figure 105 (Emergency Feeding Arrangement at Ugley FS with Regen On) show detailed results of randomly selected trains. It should be noted that there are many trains in the timetable, and it would be impractical to produce all these results in the report. The train performance can be assessed by considering speed, acceleration, tractive effort, voltage profile and power consumption, which all shown in these diagrams.

The different graphs in Figure 50 to Figure 105 are described as follow:

a) Train voltage is red colour, divide the scale by 10 to obtain the train voltage in kV;

b) Train current is black colour;

c) Line speed is straight black lines; target speed is purple and train actual speed in red (it can be differentiated from the train voltage);

d) Train tractive effort is cyan;

e) Station locations are shown as vertical texts in black colour, and junction locations (between two successive branches) are shown in purple colour.

One measure of train performance is to compare the actual speed to target speed. Significant deviations represent poor performance. This usually happens if the power supply is overloaded, and line voltage is low.

Normal Feeding Arrangement with Regen On

Voltage Profile:

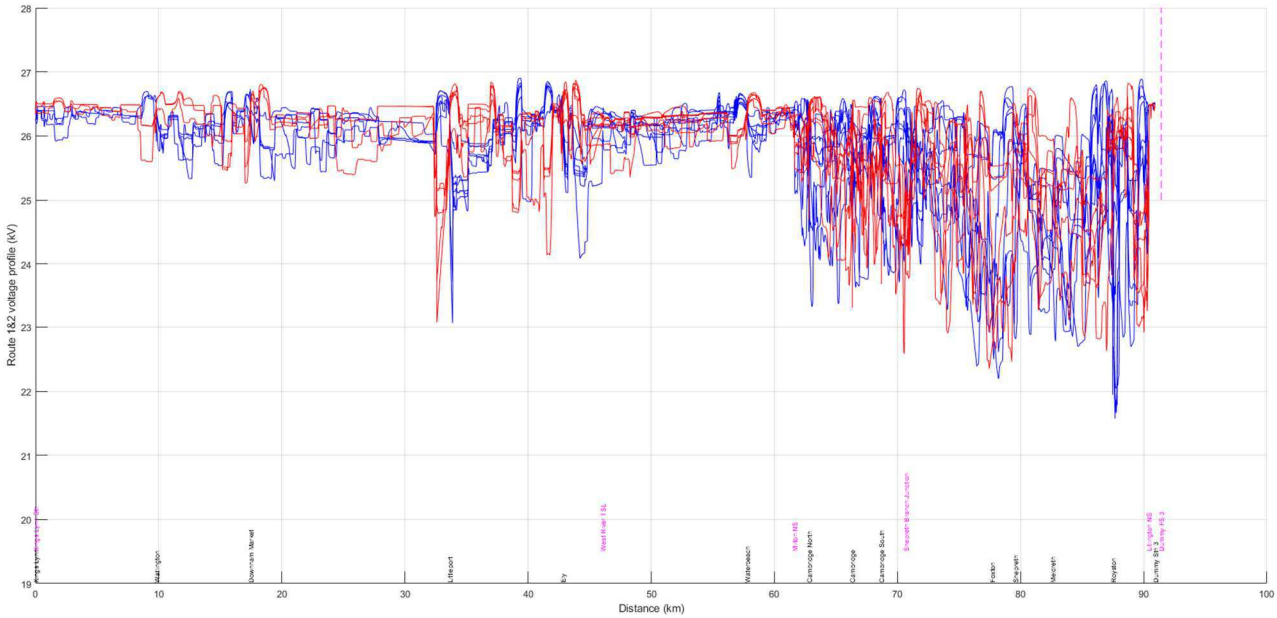


Figure 46 Normal Feeding Arrangement with Regen On – Voltage Profile for Route 1 and 2 for all trains

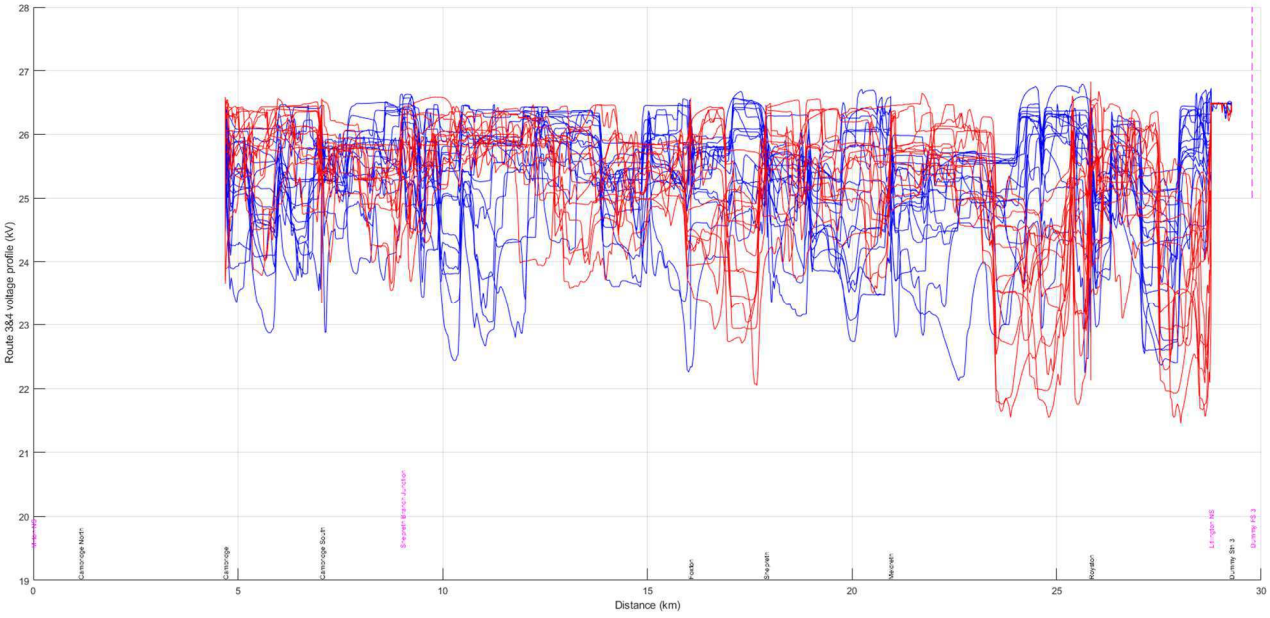


Figure 47 Normal Feeding Arrangement with Regen On – Voltage Profile for Route 3 and 4 for all trains

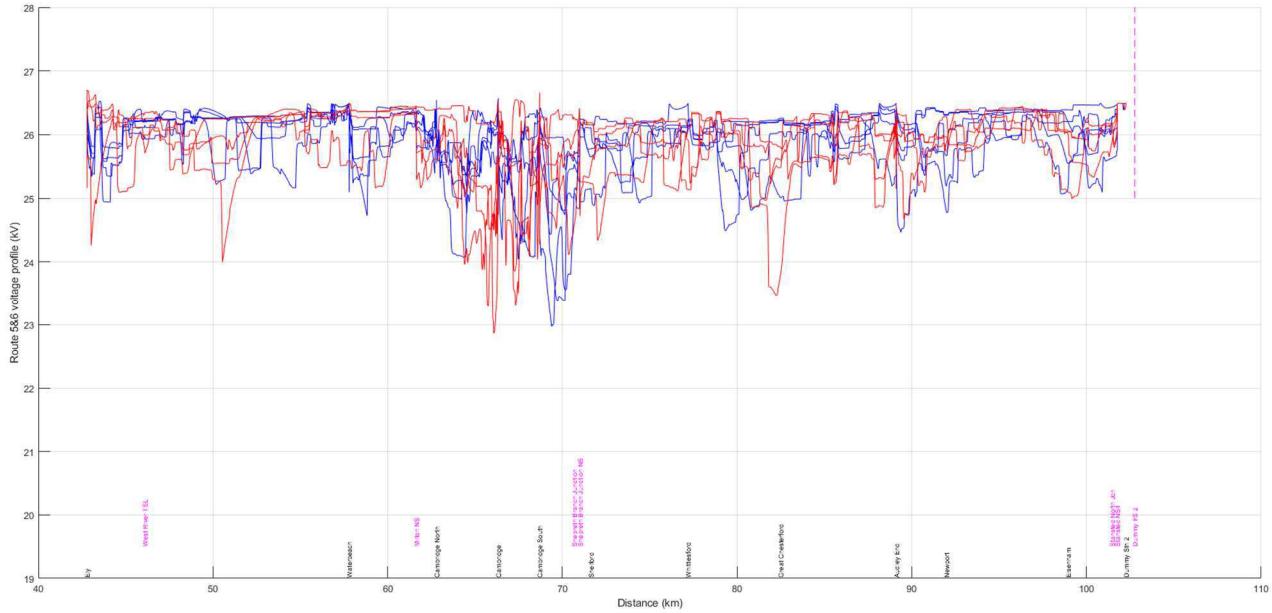


Figure 48 Normal Feeding Arrangement with Regen On – Voltage Profile for Route 5 and 6 for all trains

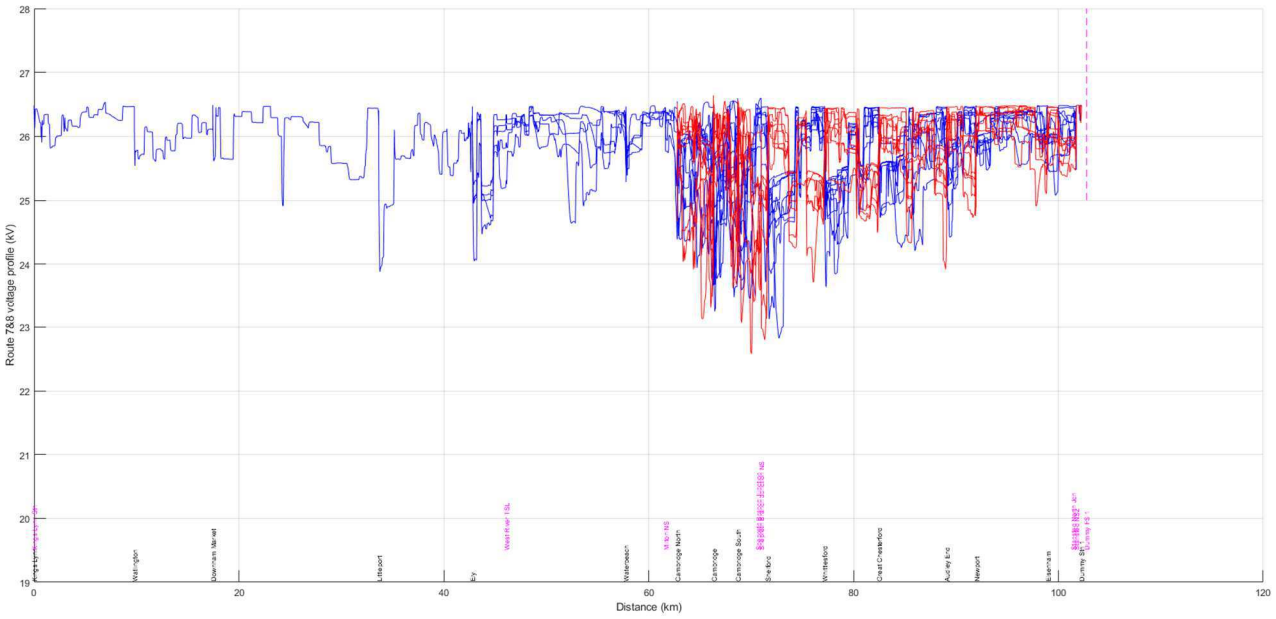


Figure 49 Normal Feeding Arrangement with Regen On - Voltage Profile for Route 7 and 8 for all trains

The following trains have been selected for Normal Feeding Arrangement with Regen On:

Figure 50: Train 01_03_02 Performance Result Class 375 12-Car on Route 1

Figure 51: Train 02_03_04 Performance Result Class 375 12-Car on Route 2

Figure 52: Train 03_11_01 Performance Result Class 700 12-Car on Route 3

Figure 53: Train 04_10_05 Performance Result Class 700 8-Car on Route 4

Figure 54: Train 05_06_01 Performance Result Class 710 5-Car on Route 5

Figure 55: Train 06_06_03 Performance Result Class 710 5-Car on Route 6

Figure 56: Train 07_11_07 Performance Result Class 700 12-Car on Route 7

Figure 57: Train 08_11_08 Performance Result Class 700 12-Car on Route 8

Route 1, Class 375 12-Car

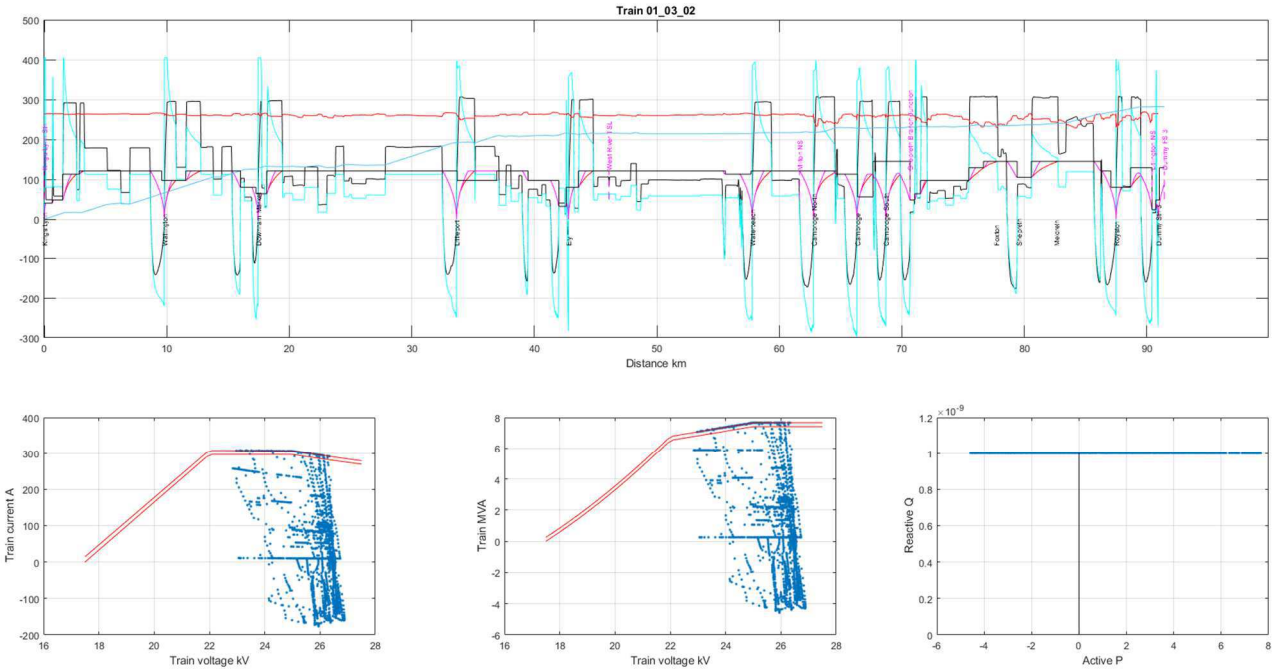


Figure 50 Normal Feeding Arrangement with Regen On – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1

Route 2, Class 375 12-Car

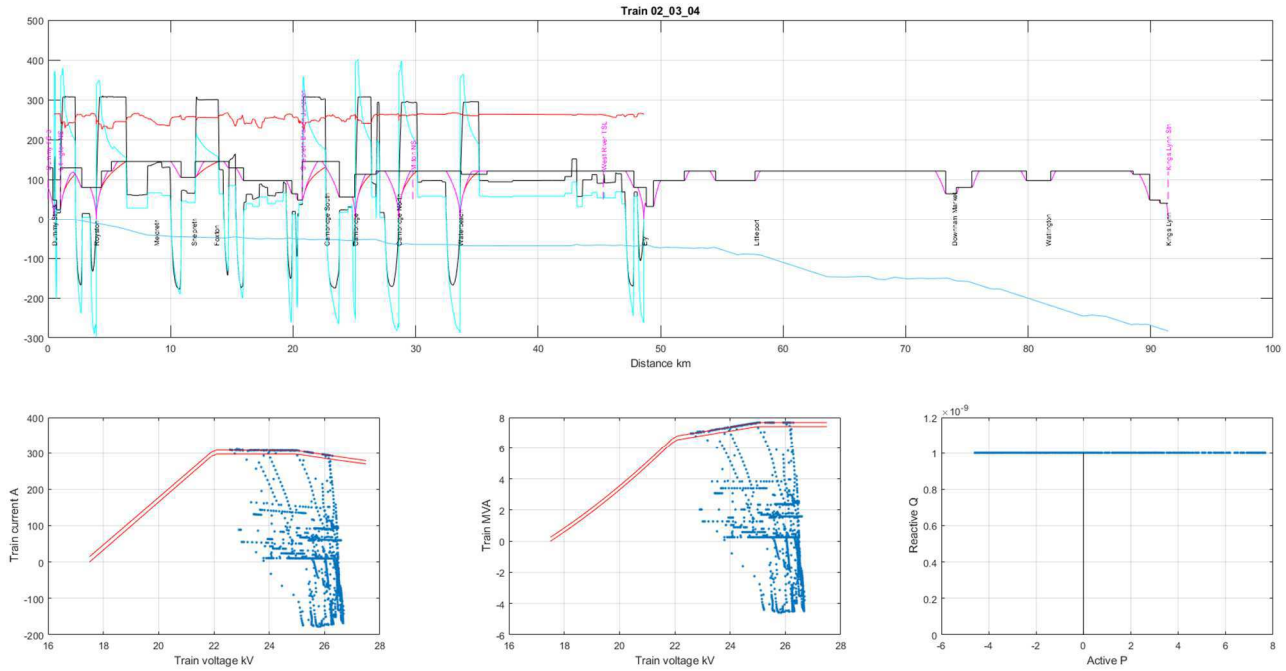


Figure 51 Normal Feeding Arrangement with Regen On – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2

Route 3, Class 700 12-Car

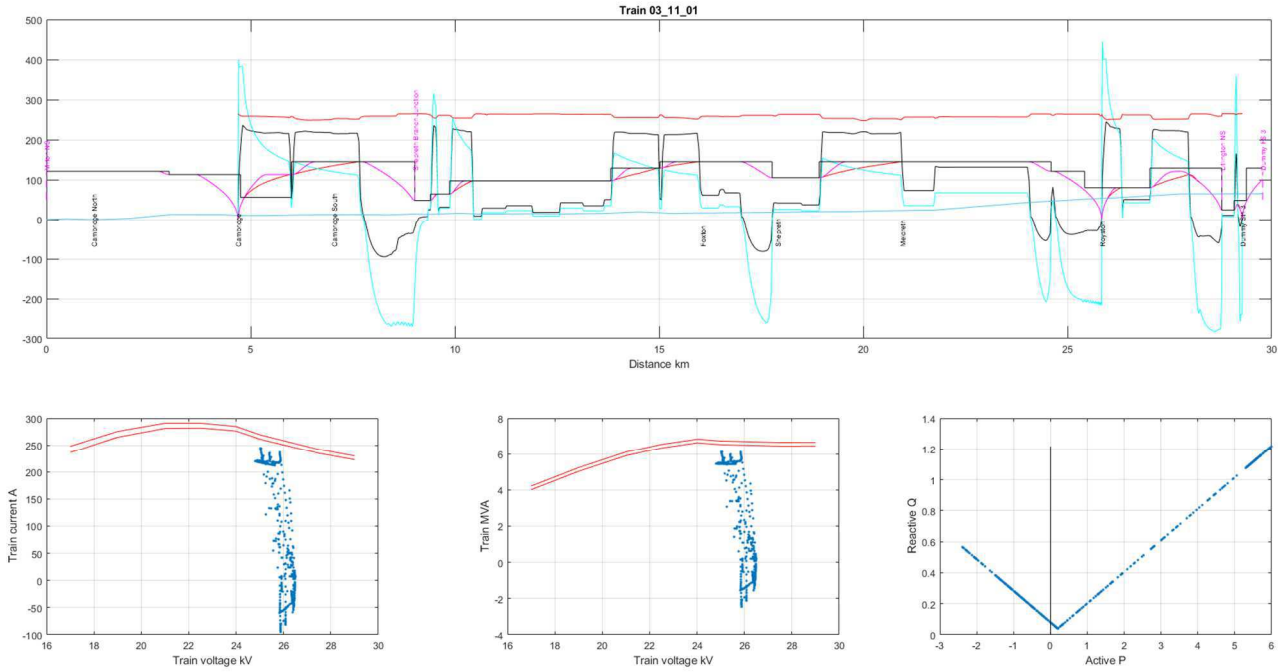


Figure 52 Normal Feeding Arrangement with Regen On – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3

Route 4, Class 700 8-Car

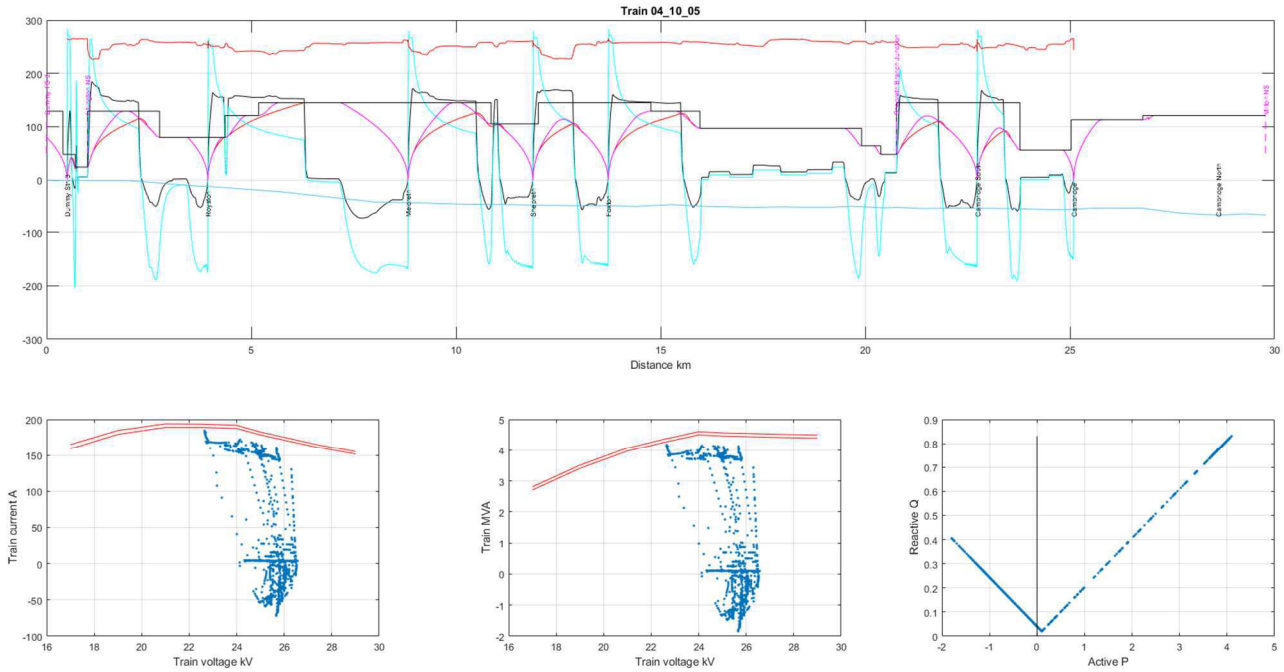


Figure 53 Normal Feeding Arrangement with Regen On – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4

Route 5, Class 710 5-Car

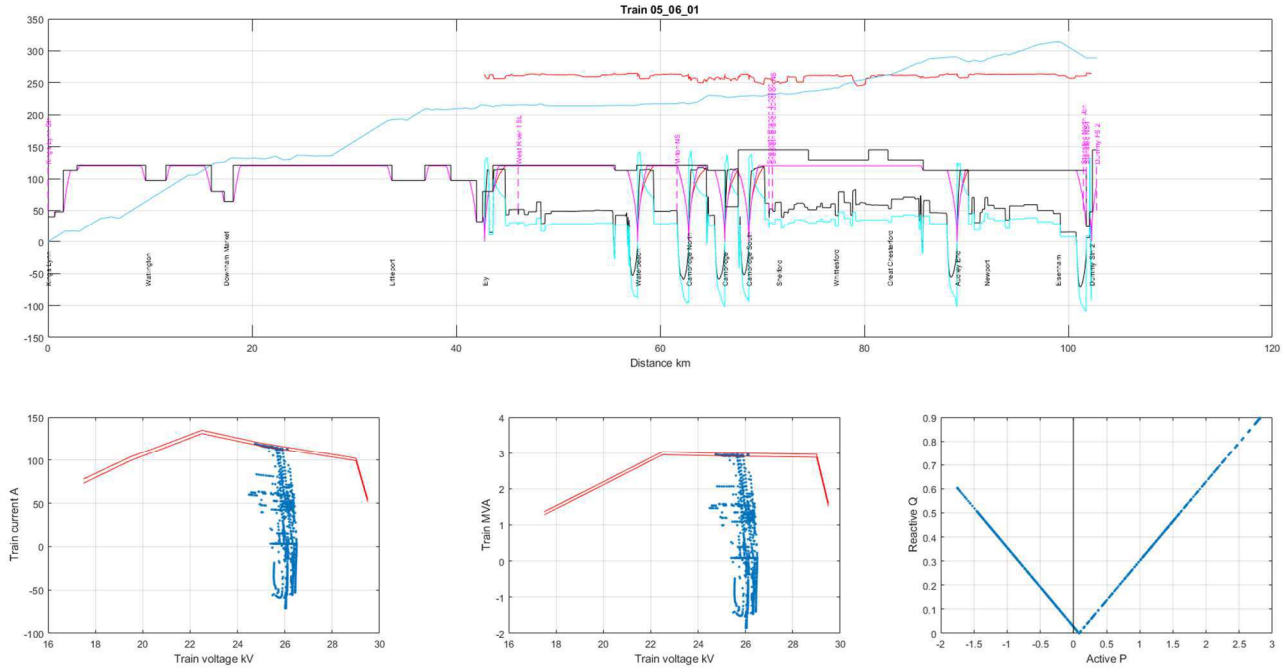


Figure 54 Normal Feeding Arrangement with Regen On – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5

Route 6, Class 710 5-Car

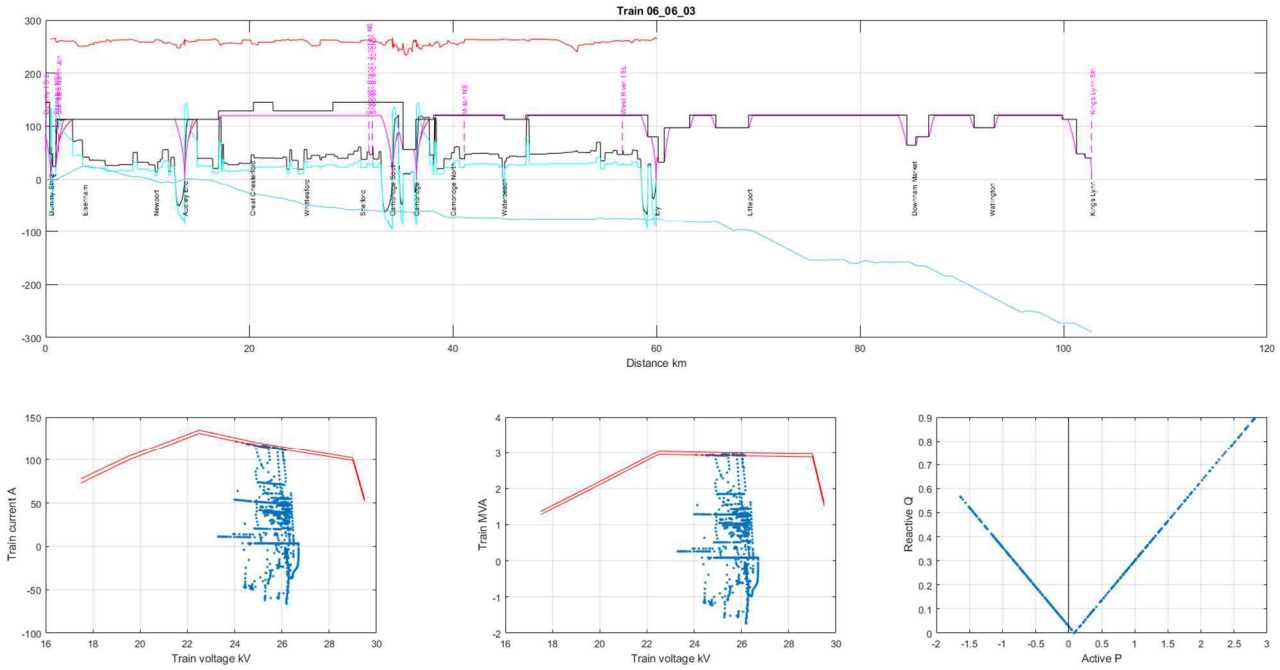


Figure 55 Normal Feeding Arrangement with Regen On – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6

Route 7, Class 700 12-Car

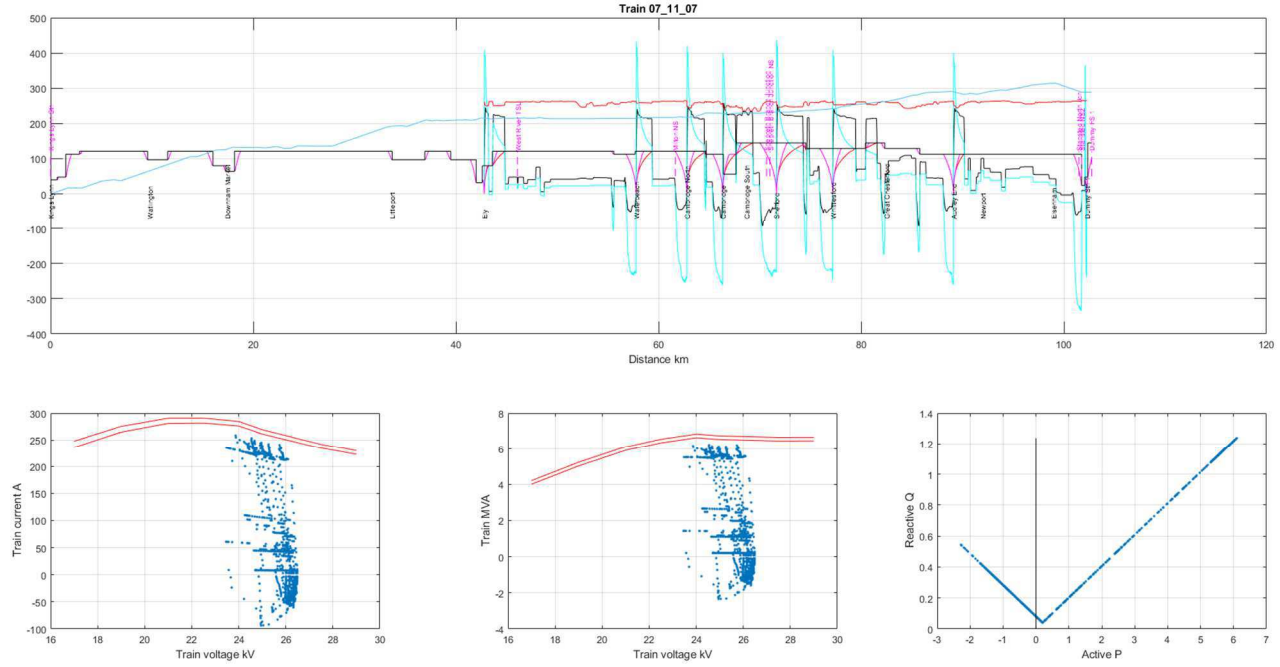


Figure 56 Normal Feeding Arrangement with Regen On – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7

Route 8, Class 700 12-Car

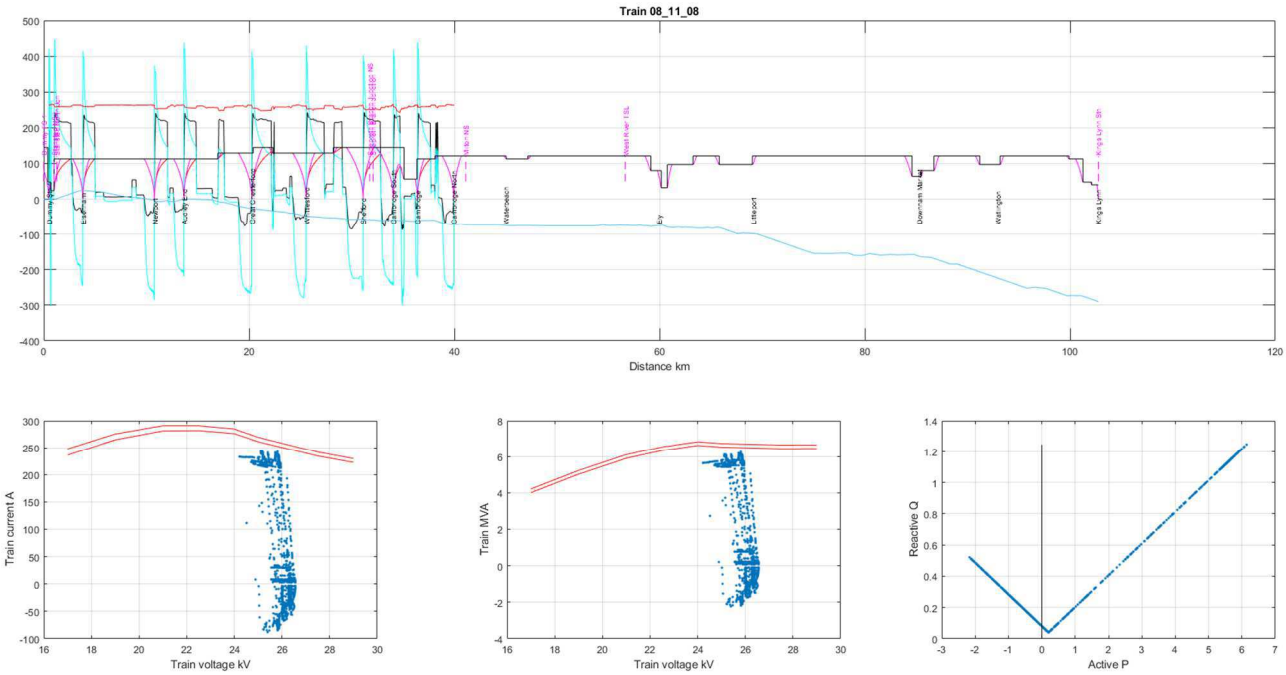


Figure 57 Normal Feeding Arrangement with Regen On – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8

Normal Feeding Arrangement with Regen Off

Voltage Profile:

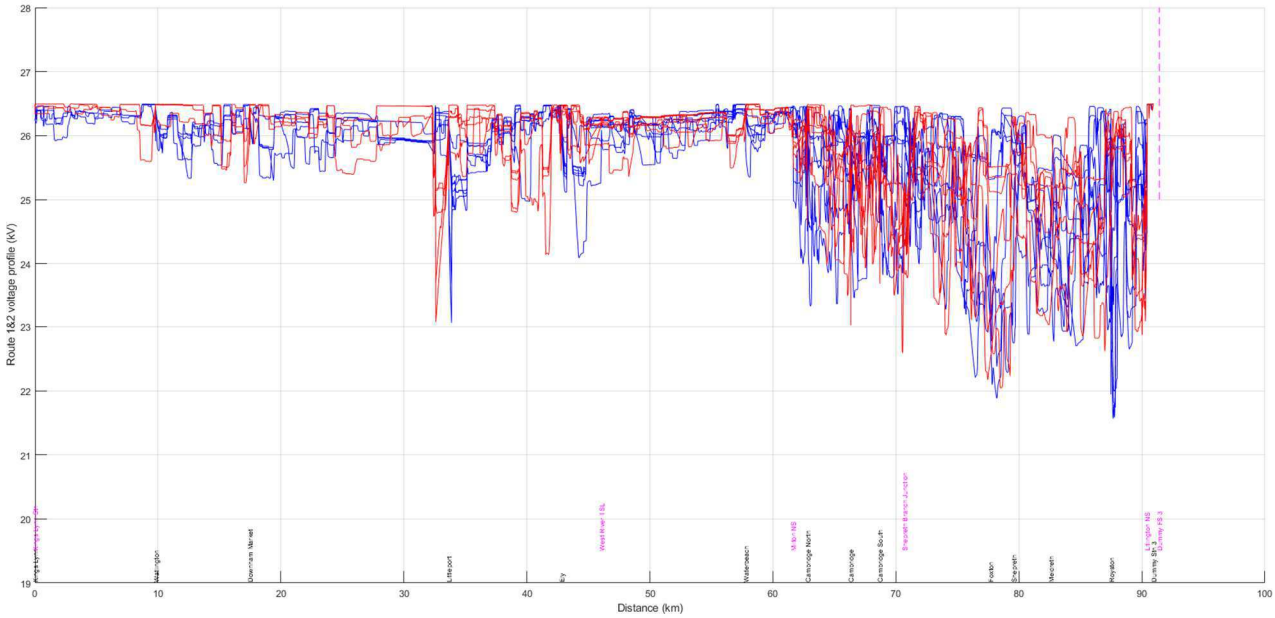


Figure 58 Normal Feeding Arrangement with Regen Off – Voltage Profile for Route 1 and 2 for all trains

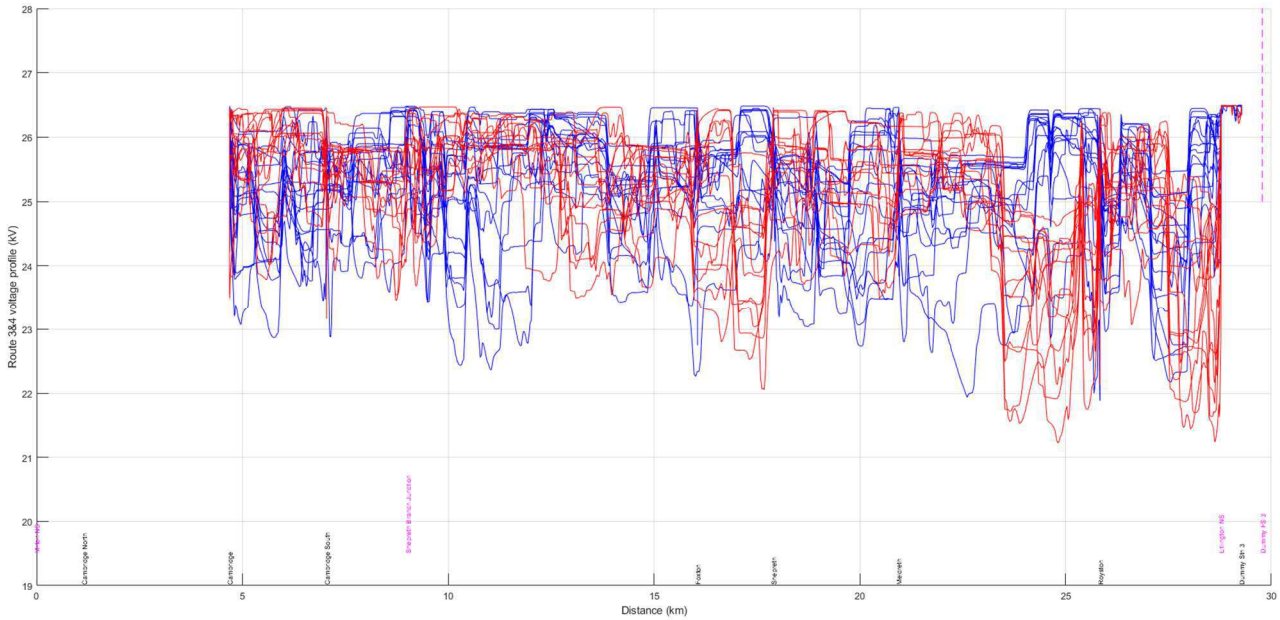


Figure 59 Normal Feeding Arrangement with Regen Off – Voltage Profile for Route 3 and 4 for all trains

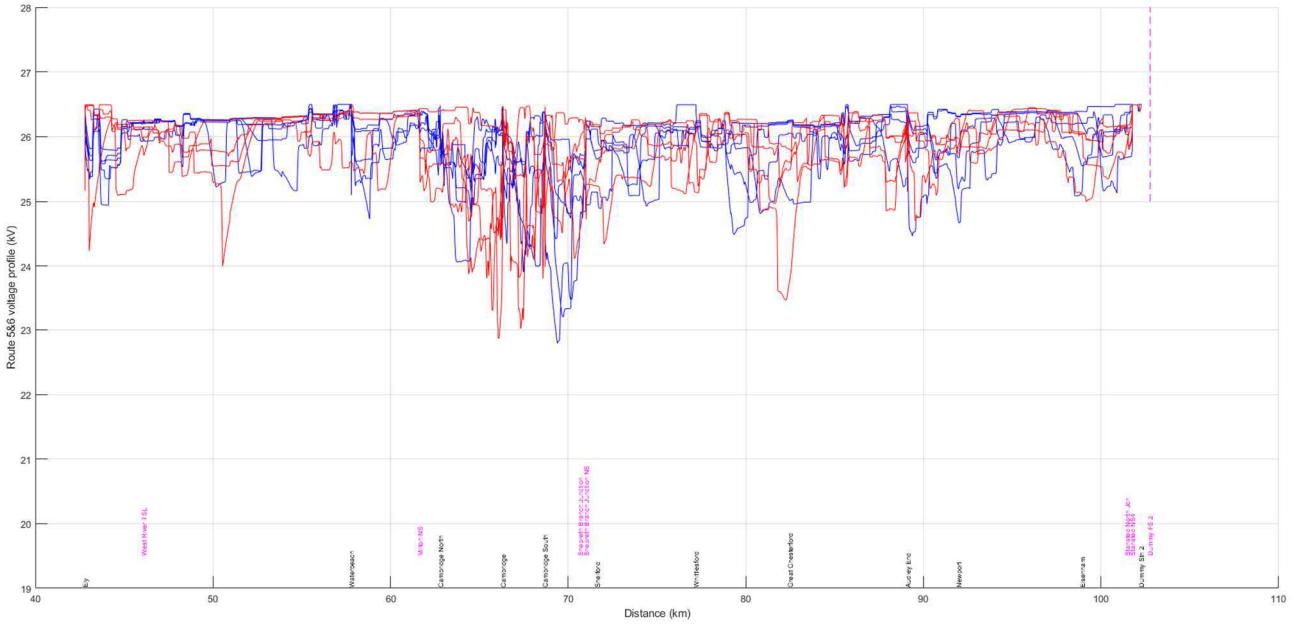


Figure 60 Normal Feeding Arrangement with Regen Off - Voltage Profile for Route 5 and 6 for all trains

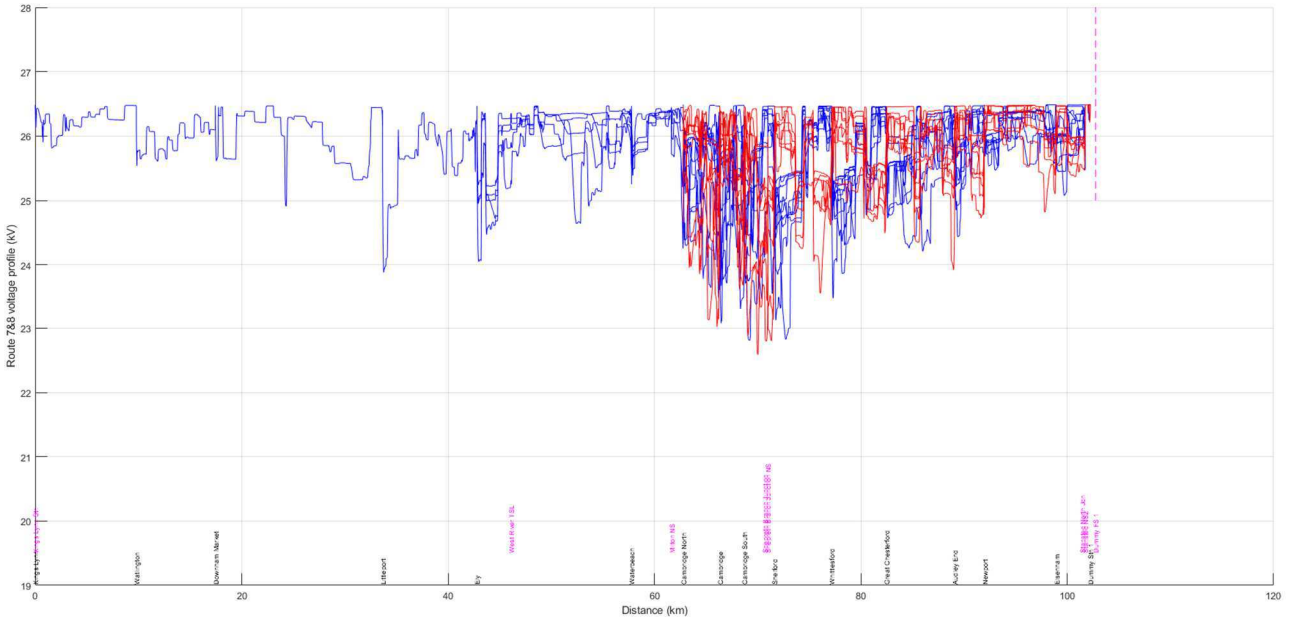


Figure 61 Normal Feeding Arrangement with Regen Off – Voltage Profile for Route 7 and 8 for all trains

The following trains have been selected for Normal Feeding Arrangement with Regen Off:

Figure 62: Train 01_03_02 Performance Result Class 375 12-Car on Route 1

Figure 63: Train 02_03_04 Performance Result Class 375 12-Car on Route 2

Figure 64: Train 03_11_01 Performance Result Class 700 12-Car on Route 3

Figure 65: Train 04_10_05 Performance Result Class 700 8-Car on Route 4

Figure 66: Train 05_06_01 Performance Result Class 710 5-Car on Route 5

Figure 67: Train 06_06_03 Performance Result Class 710 5-Car on Route 6

Figure 68: Train 07_11_07 Performance Result Class 700 12-Car on Route 7

Figure 69: Train 08_11_08 Performance Result Class 700 12-Car on Route 8

Route 1, Class 375 12-Car

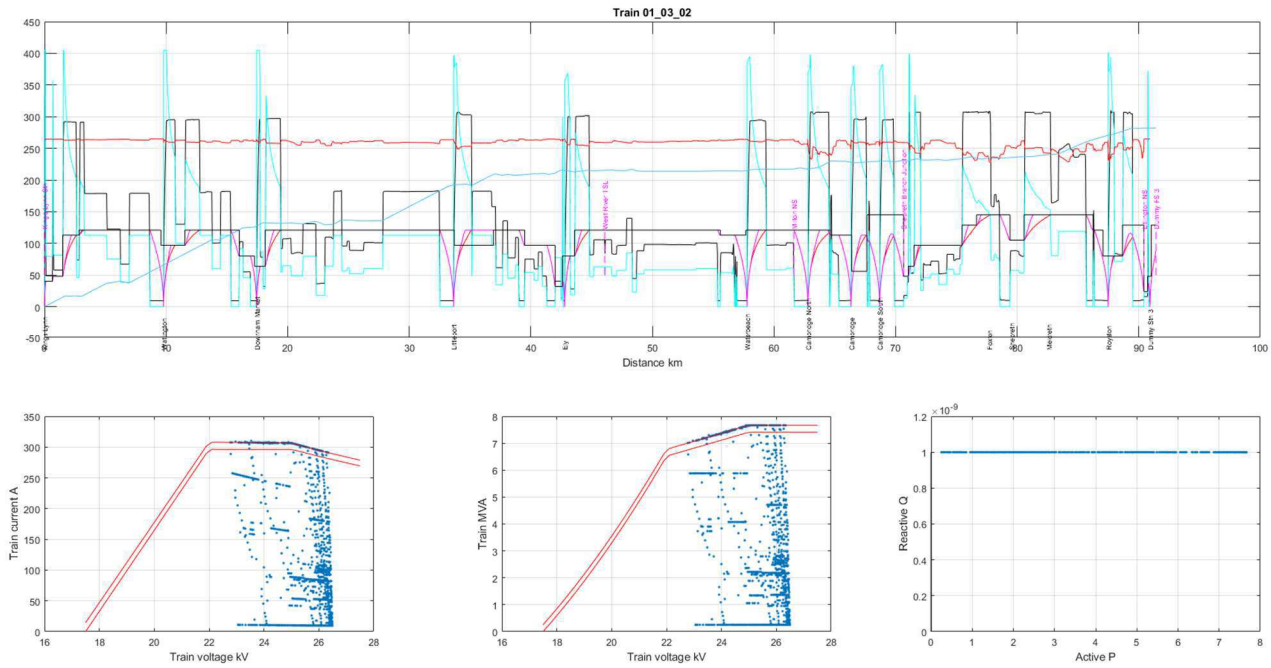


Figure 62 Normal Feeding Arrangement with Regen Off – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1

Route 2, Class 375 12-Car

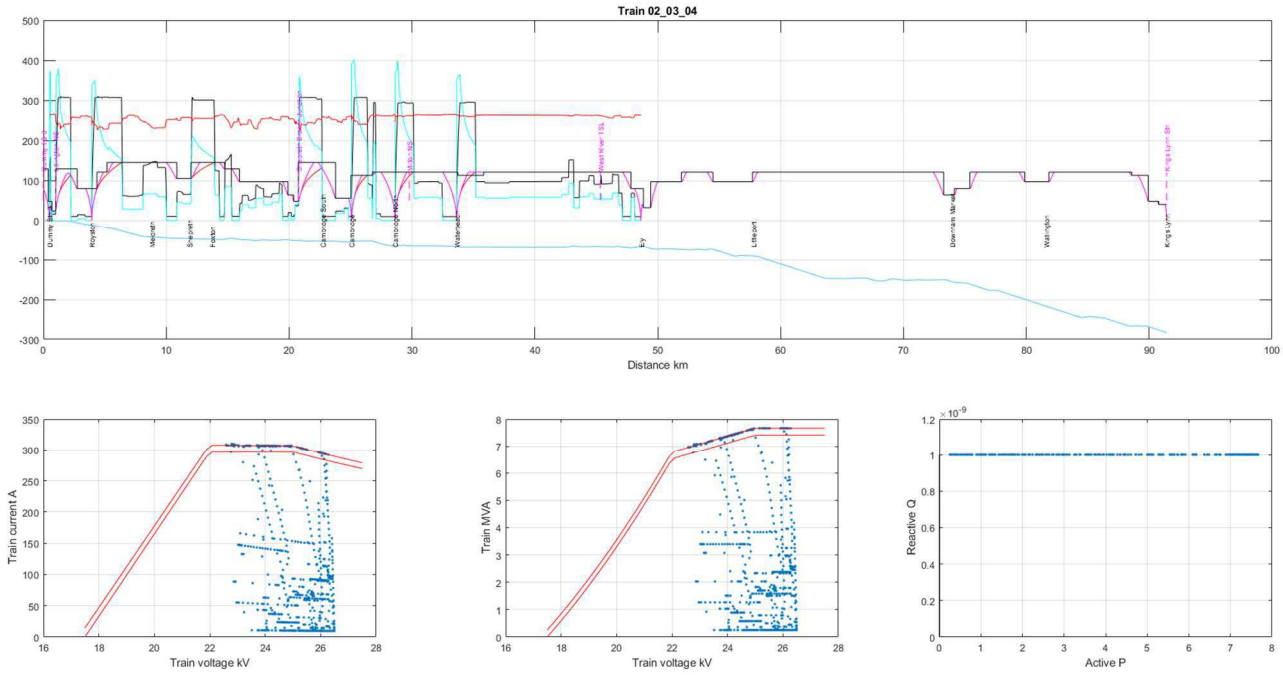


Figure 63 Normal Feeding Arrangement with Regen Off – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2

Route 3, Class 700 12-Car

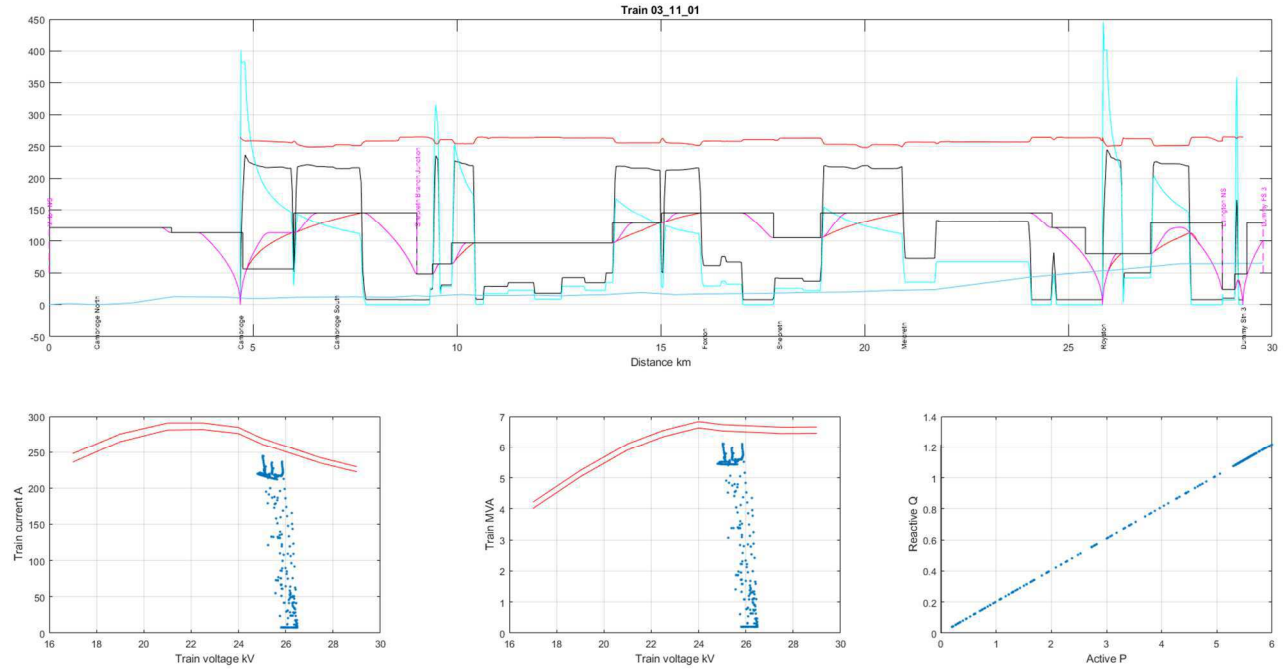


Figure 64 Normal Feeding Arrangement with Regen Off – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3

Route 4, Class 700 8-Car

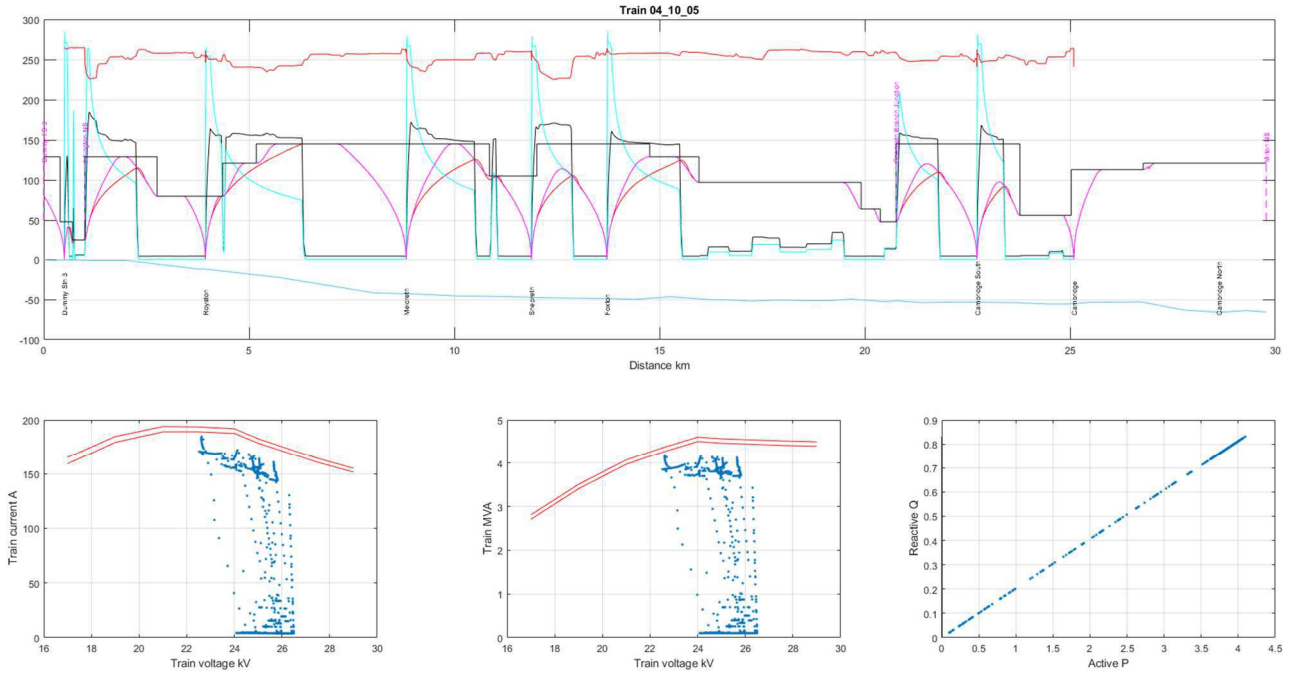


Figure 65 Normal Feeding Arrangement with Regen Off – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4

Route 5, Class 710 5-Car

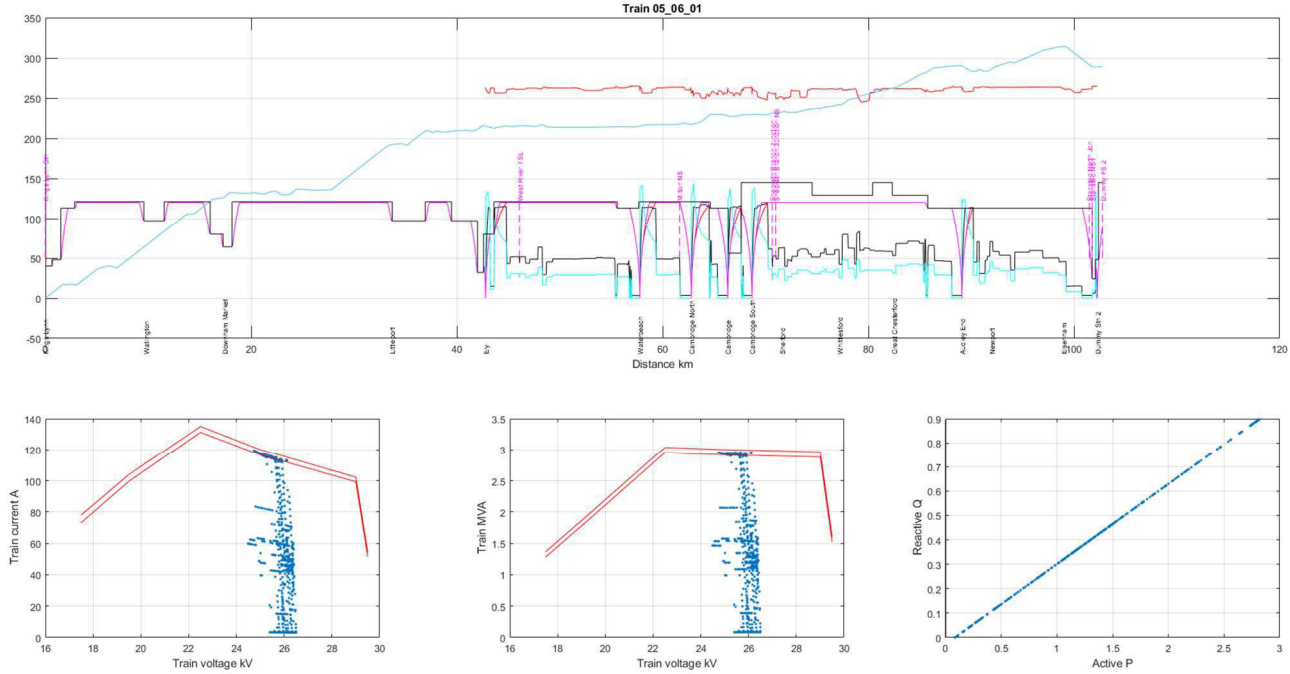


Figure 66 Normal Feeding Arrangement with Regen Off – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5

Route 6, Class 710 5-Car

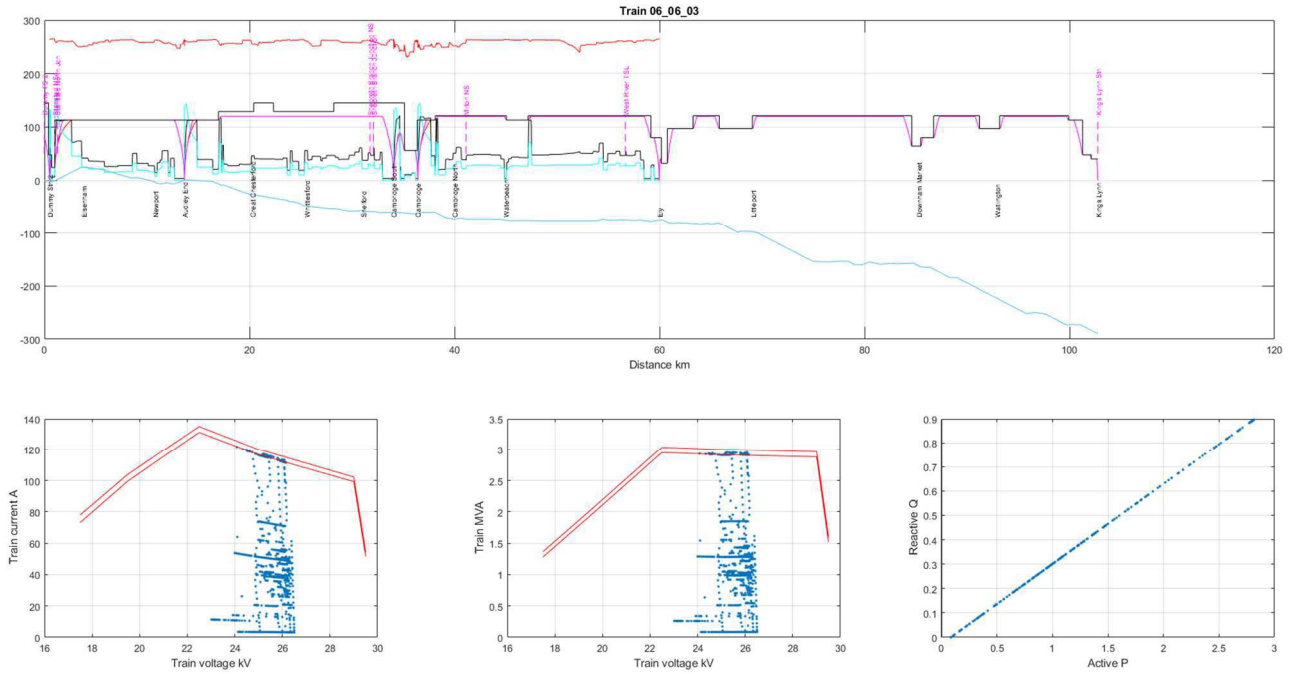


Figure 67 Normal Feeding Arrangement with Regen Off – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6

Route 7, Class 700 12-Car

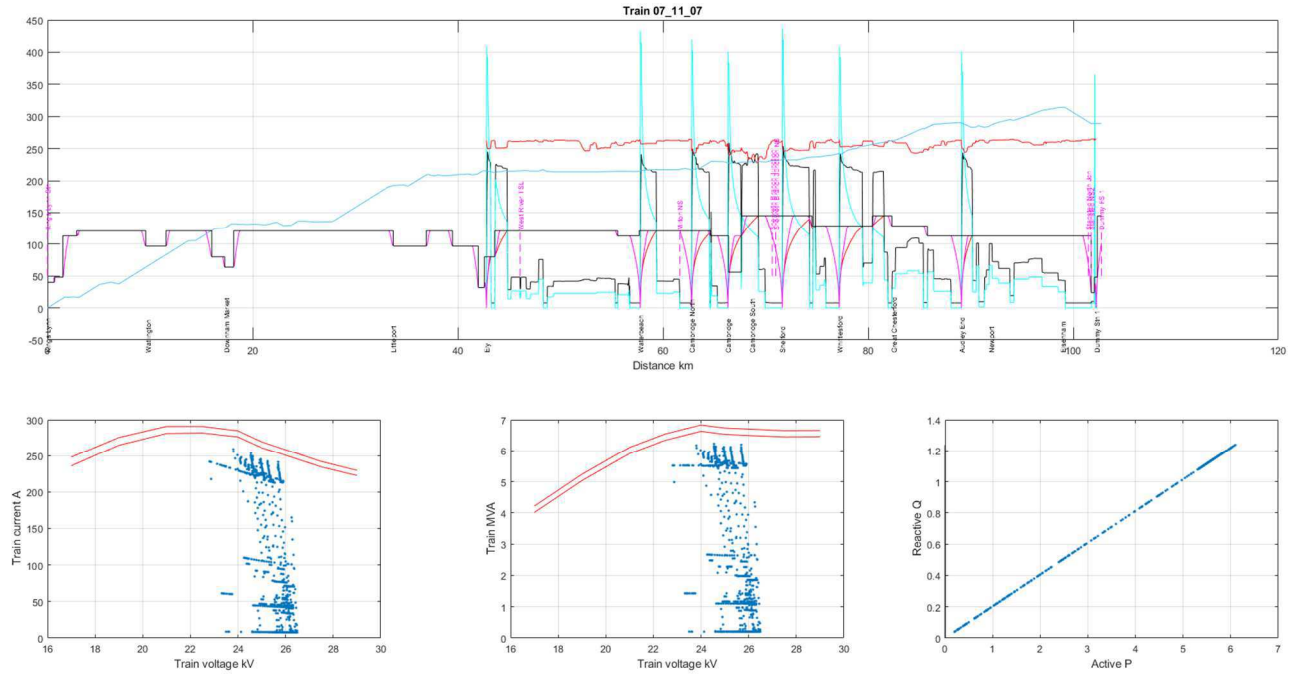


Figure 68 Normal Feeding Arrangement with Regen Off – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7

Route 8, Class 700 12-Car

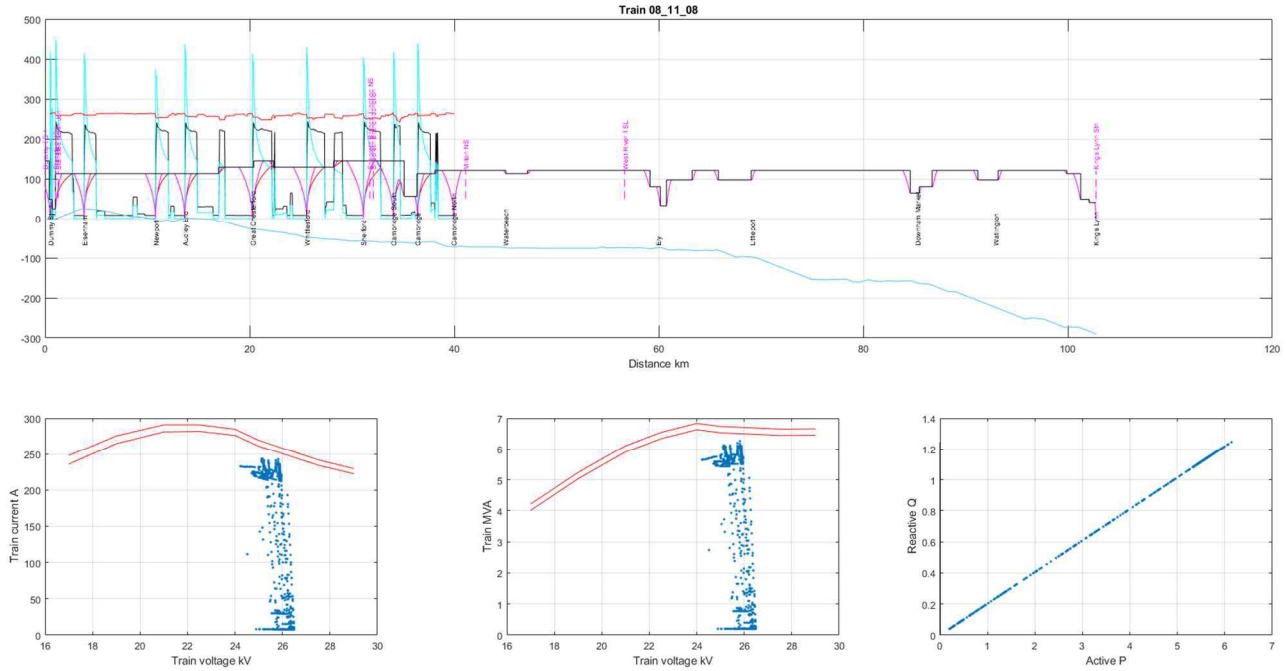


Figure 69 Normal Feeding Arrangement with Regen Off – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8

Emergency Feeding Arrangement at Milton FS with Regen On

Voltage Profile:

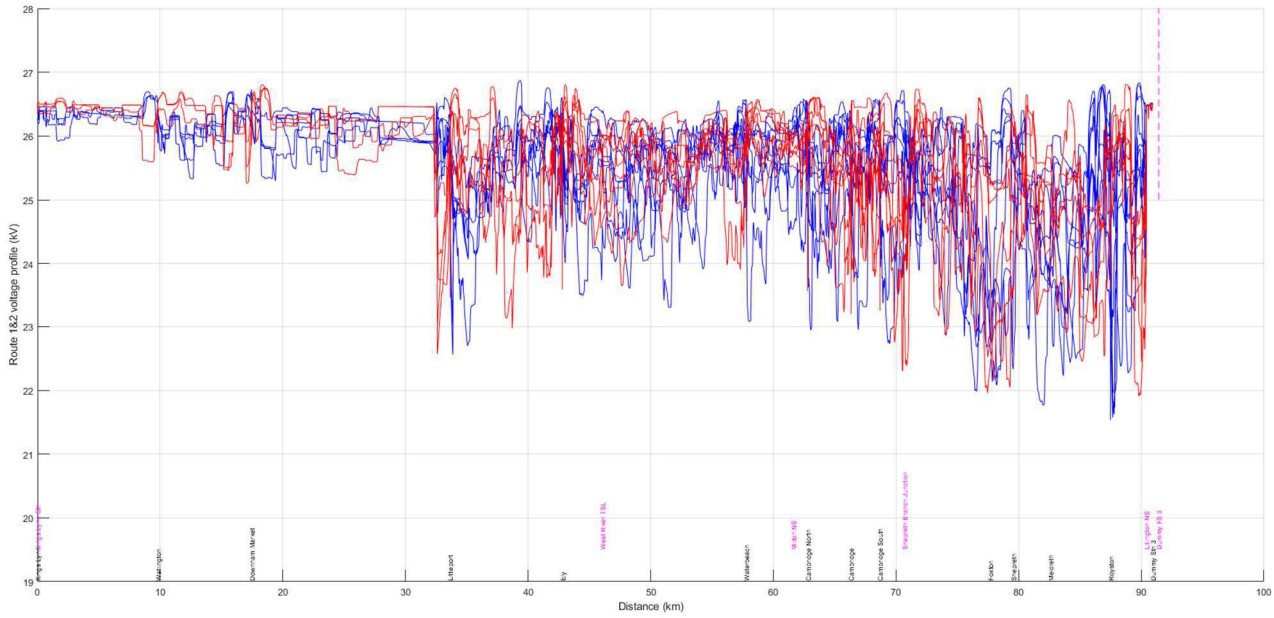


Figure 70 Emergency Feeding Arrangement at Milton FS with Regen On - Voltage Profile for Route 1 and 2 for all trains

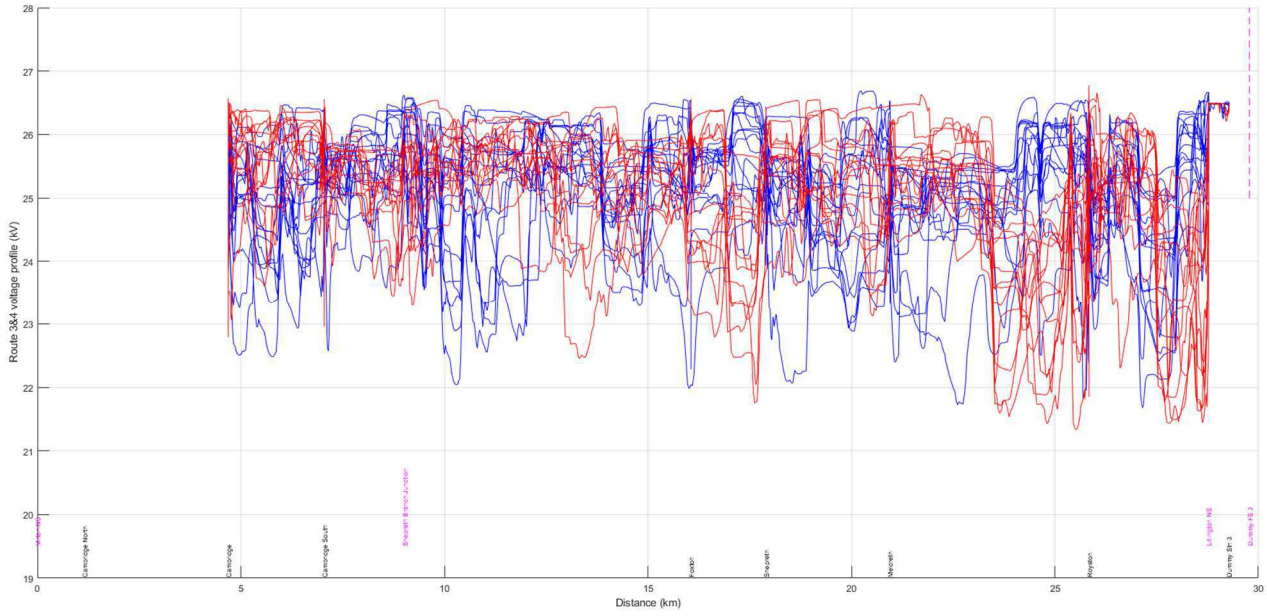


Figure 71 Emergency Feeding Arrangement at Milton FS with Regen On - Voltage Profile for Route 3 and 4 for all trains

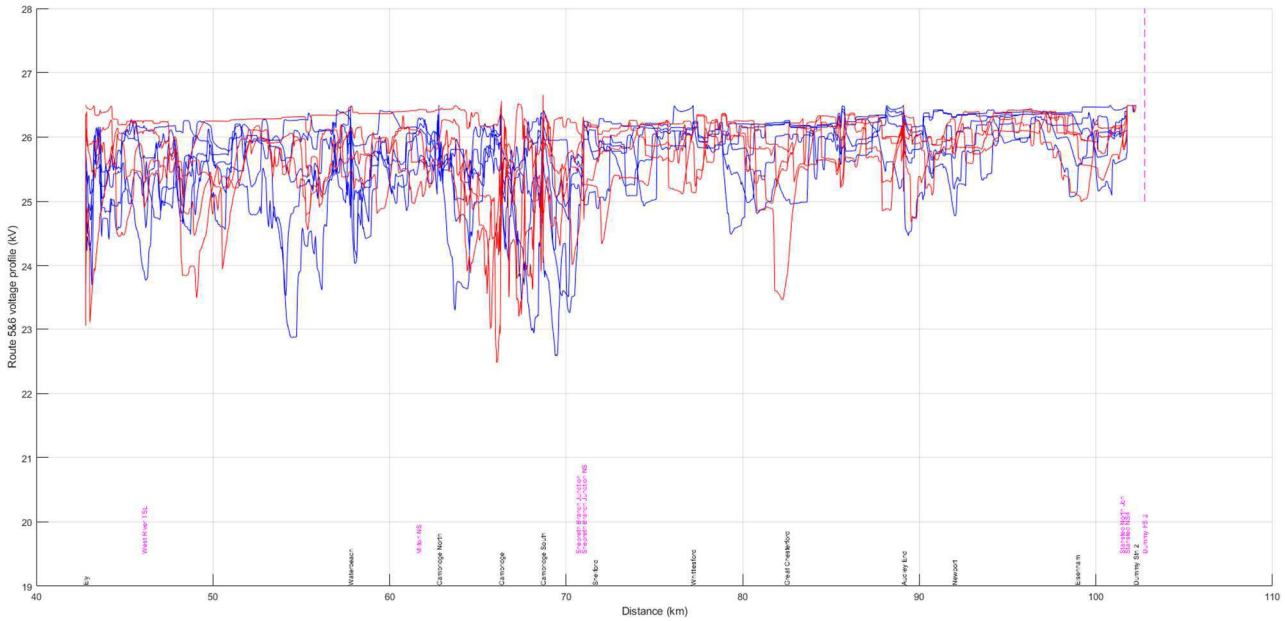


Figure 72 Emergency Feeding Arrangement at Milton FS with Regen On - Voltage Profile for Route 5 and 6 for all trains

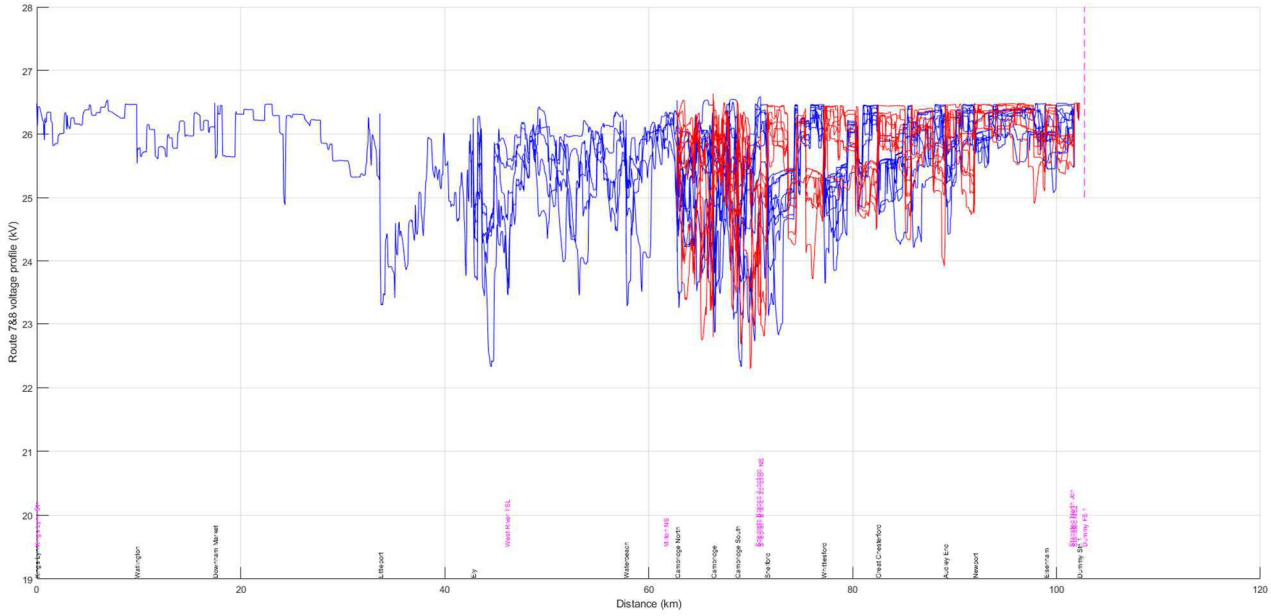


Figure 73 Emergency Feeding Arrangement at Milton FS with Regen On - Voltage Profile for Route 7 and 8 for all trains

The following trains have been selected for Emergency Feeding Arrangement at Milton FS with Regen On:

Figure 74: Train 01_03_02 Performance Result Class 375 12-Car on Route 1

Figure 75: Train 02_03_04 Performance Result Class 375 12-Car on Route 2

Figure 76: Train 03_11_01 Performance Result Class 700 12-Car on Route 3

Figure 77: Train 04_10_05 Performance Result Class 700 8-Car on Route 4

Figure 78: Train 05_06_01 Performance Result Class 710 5-Car on Route 5

Figure 79: Train 06_06_03 Performance Result Class 710 5-Car on Route 6

Figure 80: Train 07_11_07 Performance Result Class 700 12-Car on Route 7

Figure 81: Train 08_11_08 Performance Result Class 700 12-Car on Route 8

Route 1, Class 375 12-Car

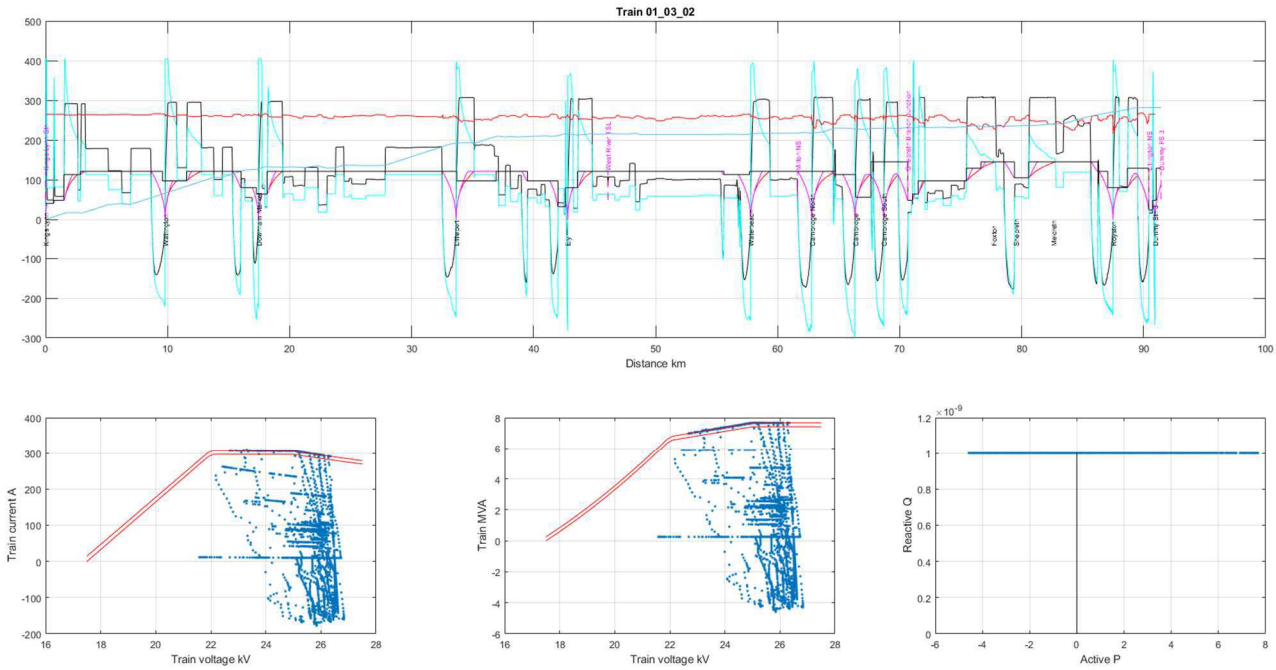


Figure 74 Emergency Feeding Arrangement at Milton FS with Regen On – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1

Route 2, Class 375 12-Car

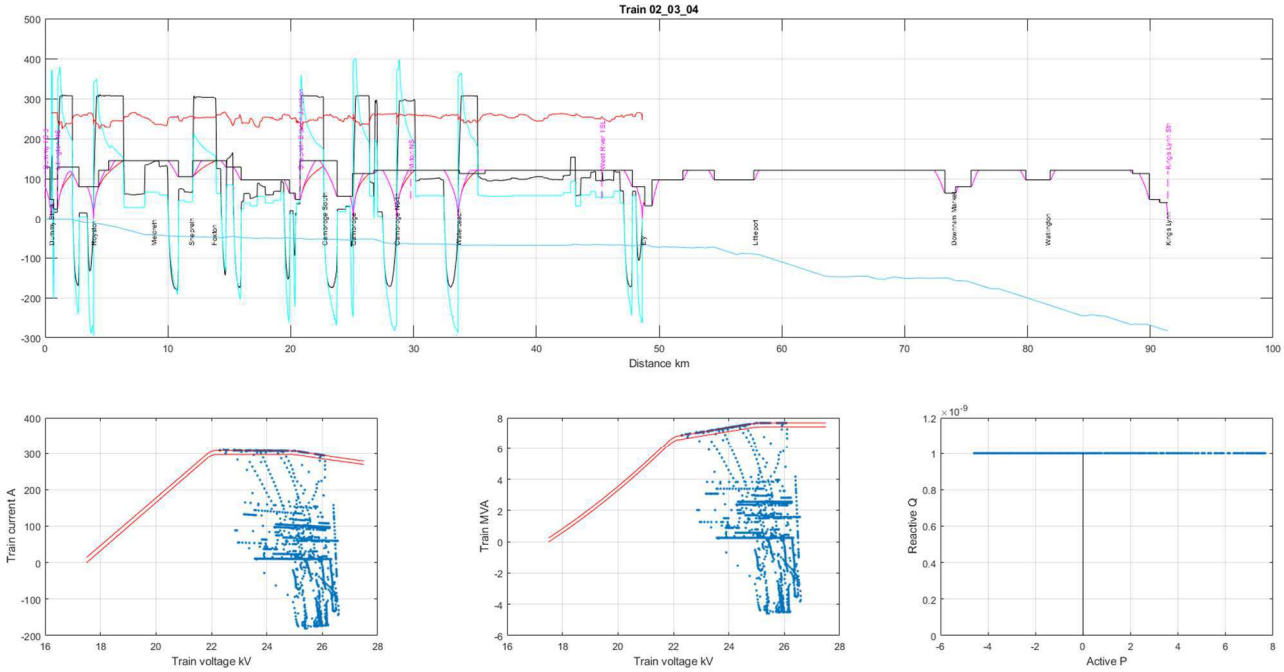


Figure 75 Emergency Feeding Arrangement at Milton FS with Regen On – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2

Route 3, Class 700 12-Car

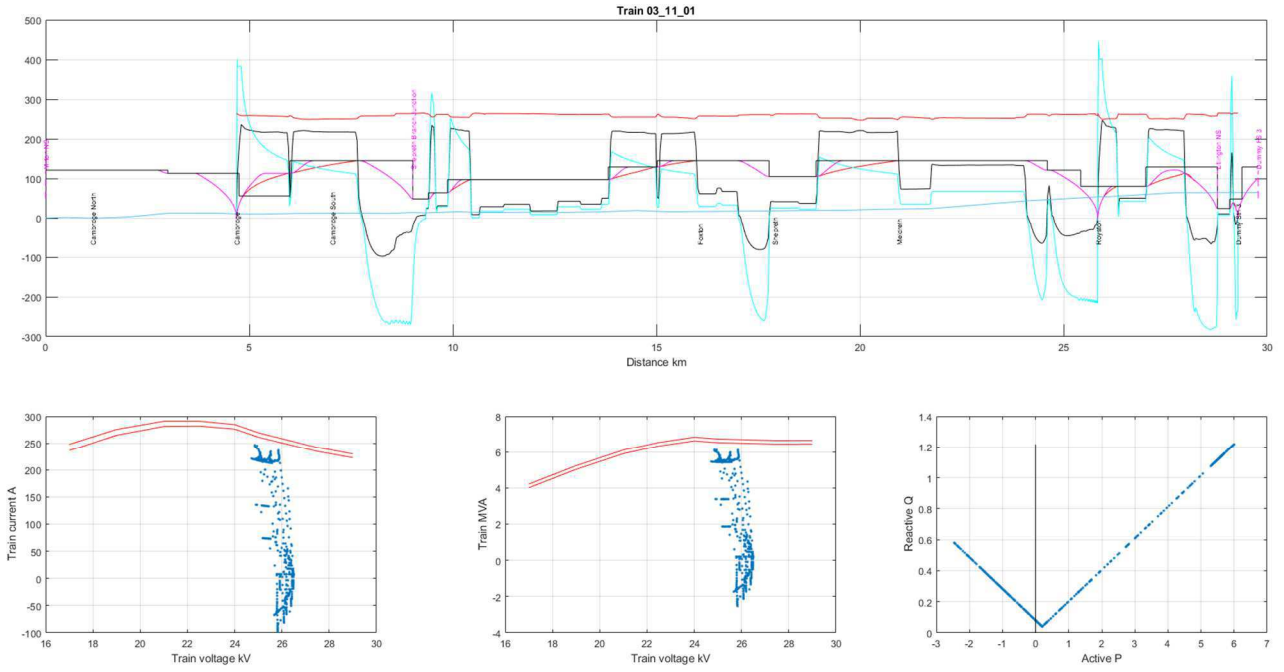


Figure 76 Emergency Feeding Arrangement at Milton FS with Regen On – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3

Route 4, Class 700 8-Car

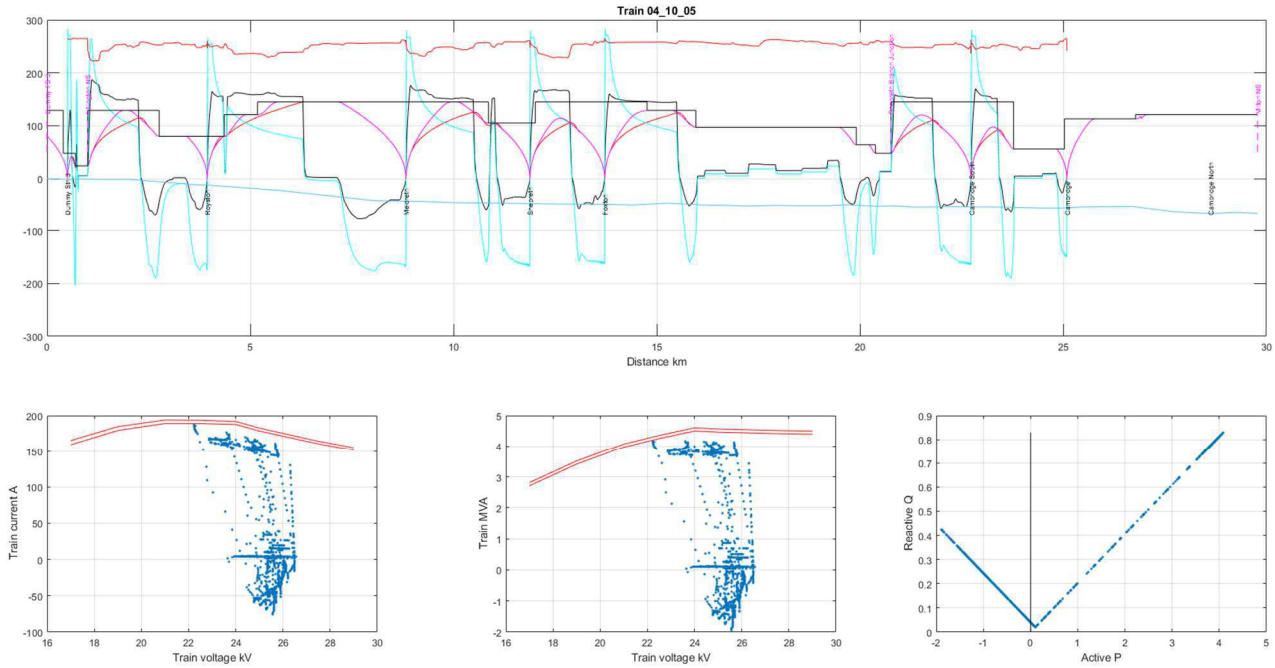


Figure 77 Emergency Feeding Arrangement at Milton FS with Regen On – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4

Route 5, Class 710 5-Car

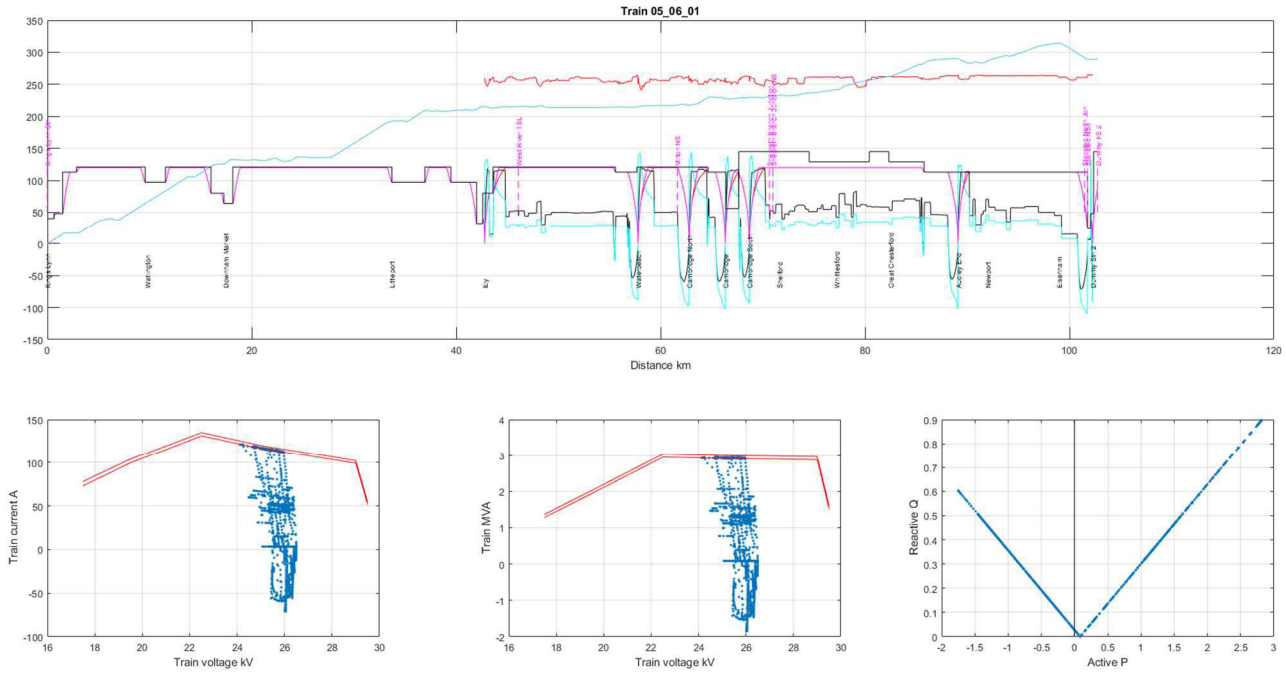


Figure 78 Emergency Feeding Arrangement at Milton FS with Regen On – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5

Route 6, Class 710 5-Car

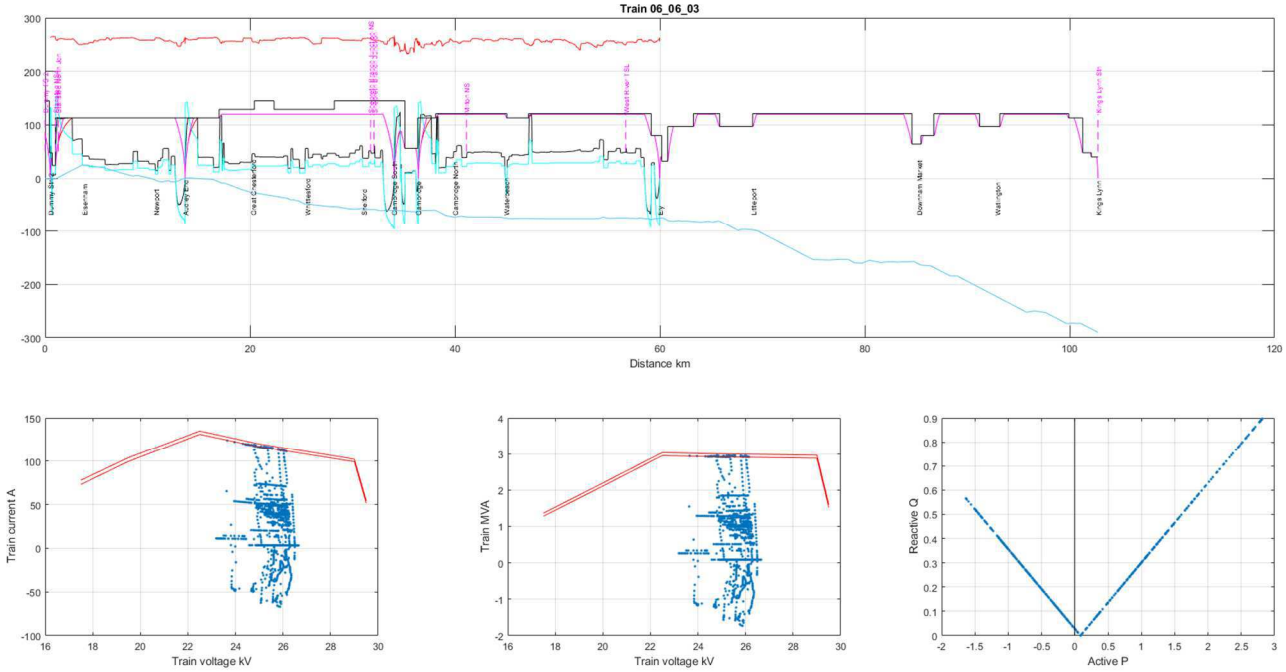


Figure 79 Emergency Feeding Arrangement at Milton FS with Regen On – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6

Route 7, Class 700 12-Car

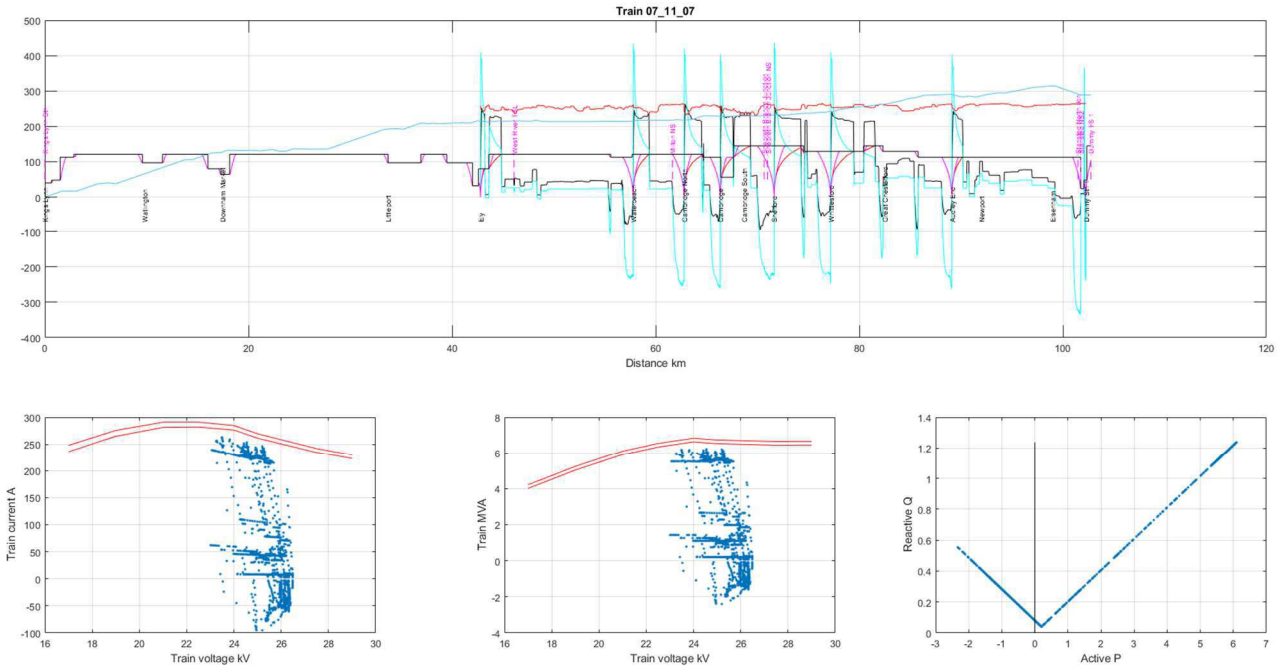


Figure 80 Emergency Feeding Arrangement at Milton FS with Regen On – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7

Route 8, Class 700 12-Car

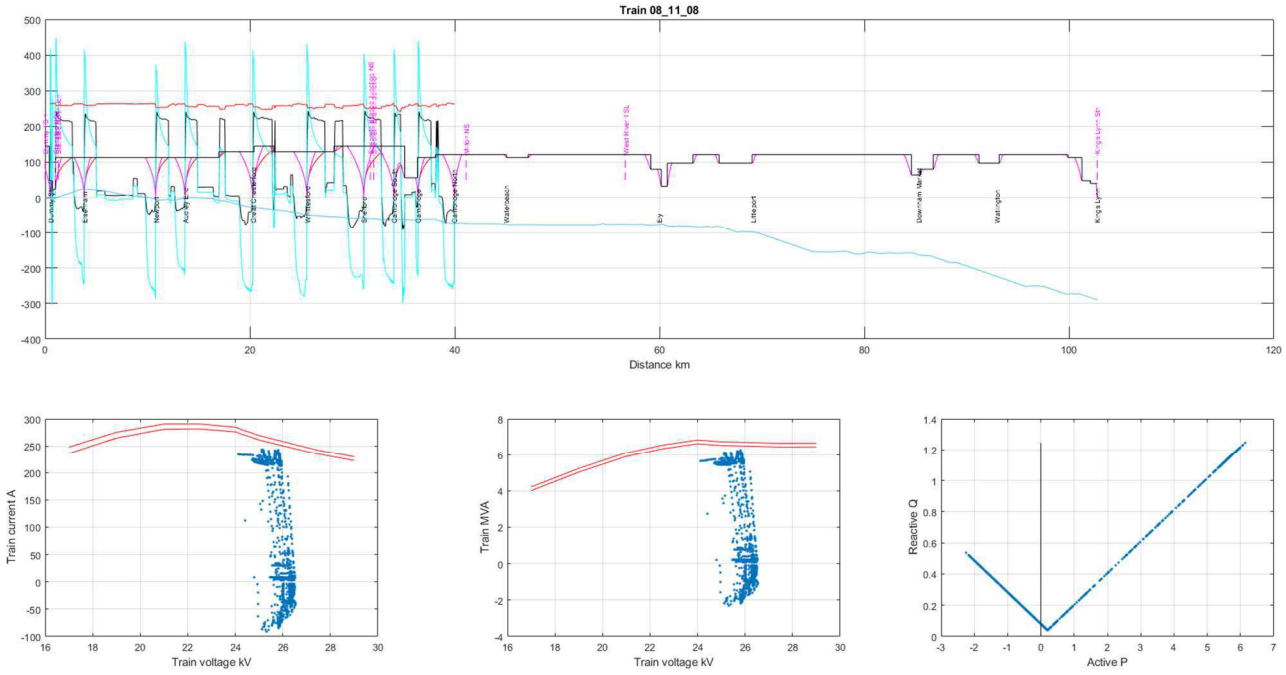


Figure 81 Emergency Feeding Arrangement at Milton FS with Regen On – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8

Emergency Feeding Arrangement at Kings Lynn FS with Regen On

Voltage Profile:

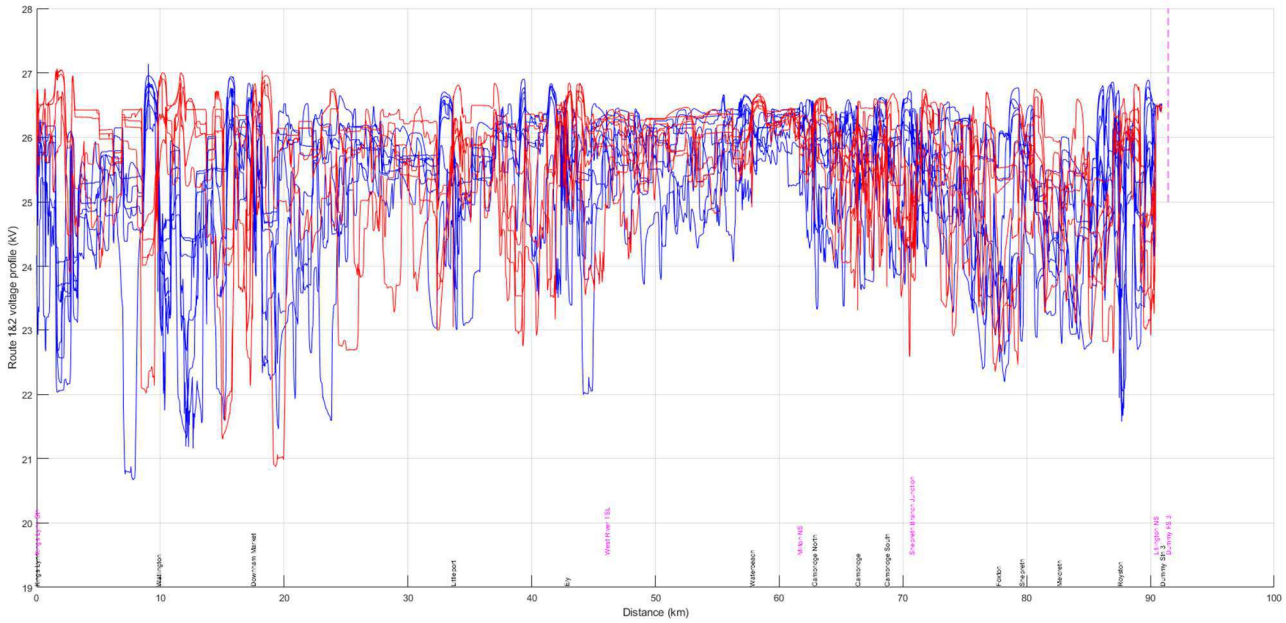


Figure 82 Emergency Feeding Arrangement at Kings Lynn FS with Regen On - Voltage Profile for Route 1 and 2 for all trains

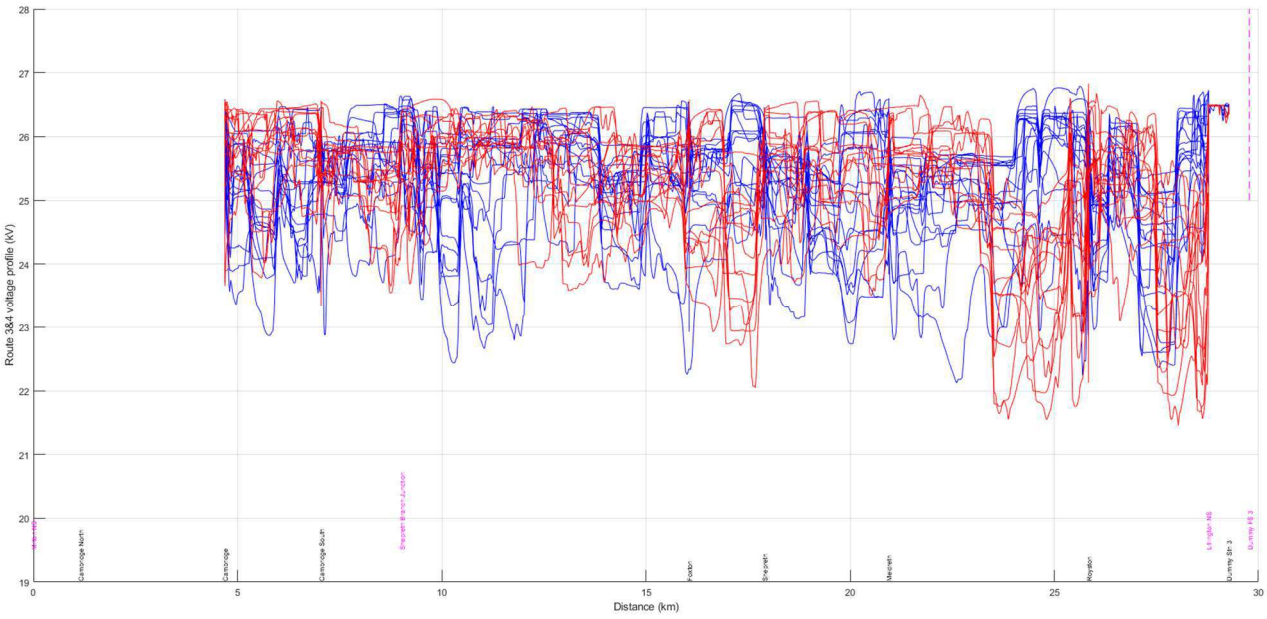


Figure 83 Emergency Feeding Arrangement at Kings Lynn FS with Regen On - Voltage Profile for Route 3 and 4 for all trains

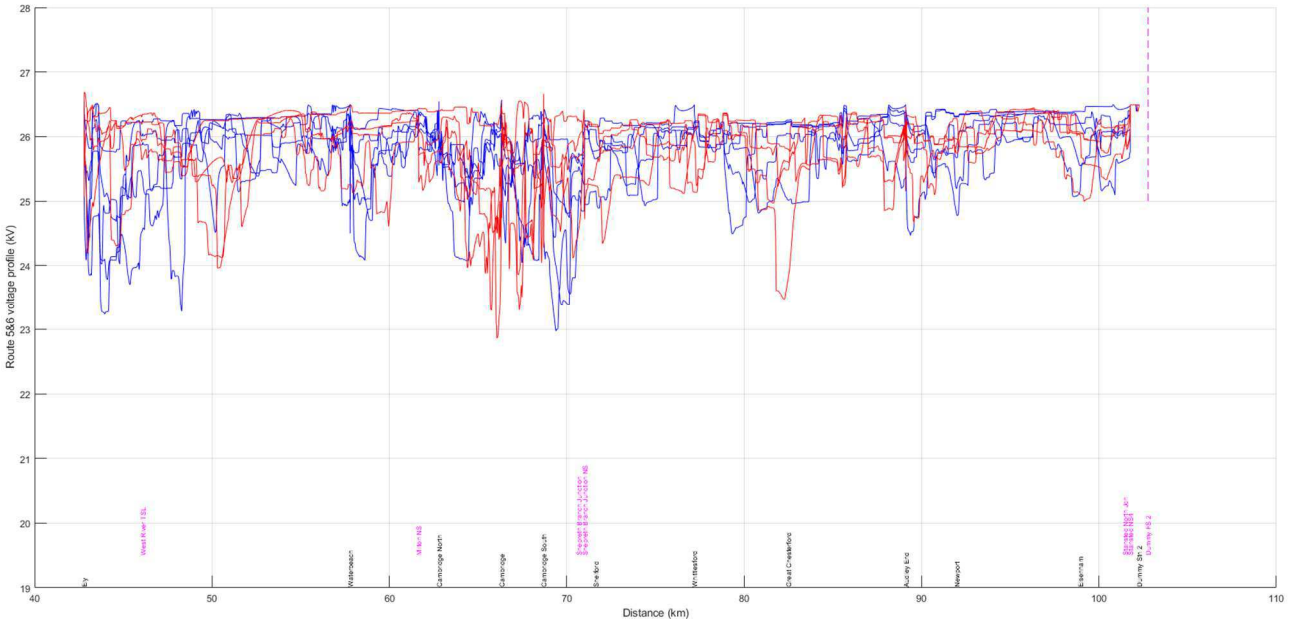


Figure 84 Emergency Feeding Arrangement at Kings Lynn FS with Regen On - Voltage Profile for Route 5 and 6 for all trains

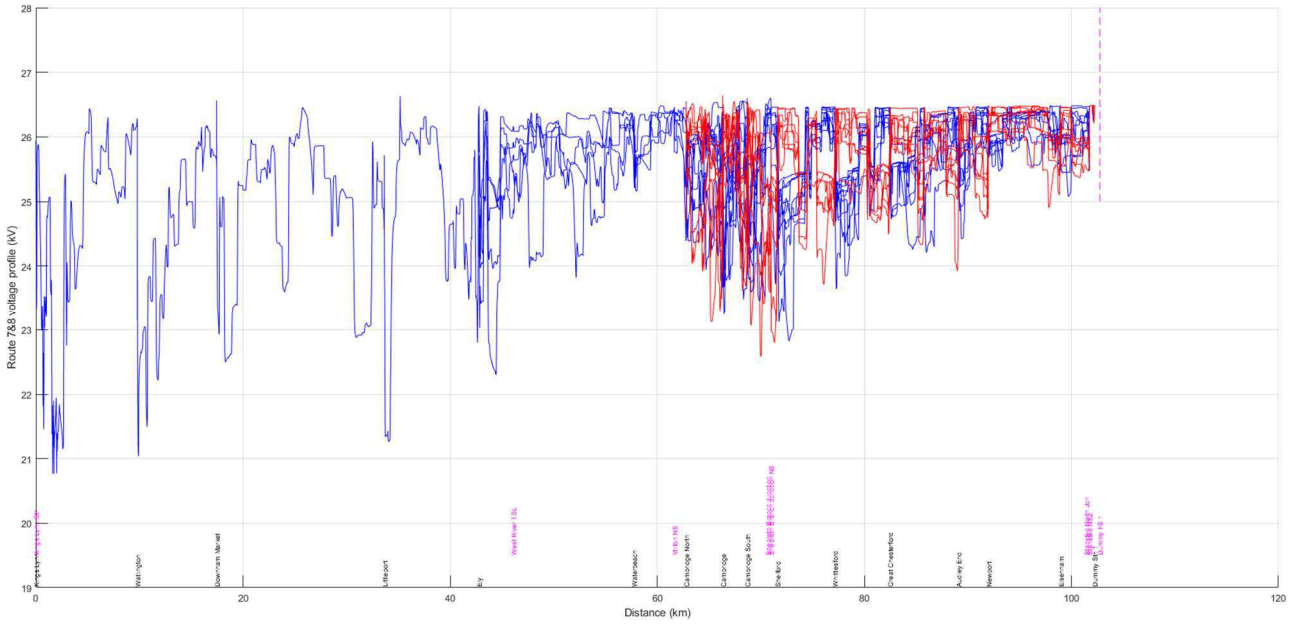


Figure 85 Emergency Feeding Arrangement at Kings Lynn FS with Regen On - Voltage Profile for Route 7 and 8 for all trains

The following trains have been selected for Emergency Feeding Arrangement at Kings Lynn FS with Regen On:

Figure 86: Train 01_03_02 Performance Result Class 375 12-Car on Route 1

Figure 87: Train 02_03_04 Performance Result Class 375 12-Car on Route 2

Figure 88: Train 03_11_01 Performance Result Class 700 12-Car on Route 3

Figure 89: Train 04_10_05 Performance Result Class 700 8-Car on Route 4

Figure 90: Train 05_06_01 Performance Result Class 710 5-Car on Route 5

Figure 91: Train 06_06_03 Performance Result Class 710 5-Car on Route 6

Figure 92: Train 07_11_07 Performance Result Class 700 12-Car on Route 7

Figure 93: Train 08_11_08 Performance Result Class 700 12-Car on Route 8

Route 1, Class 375 12-Car

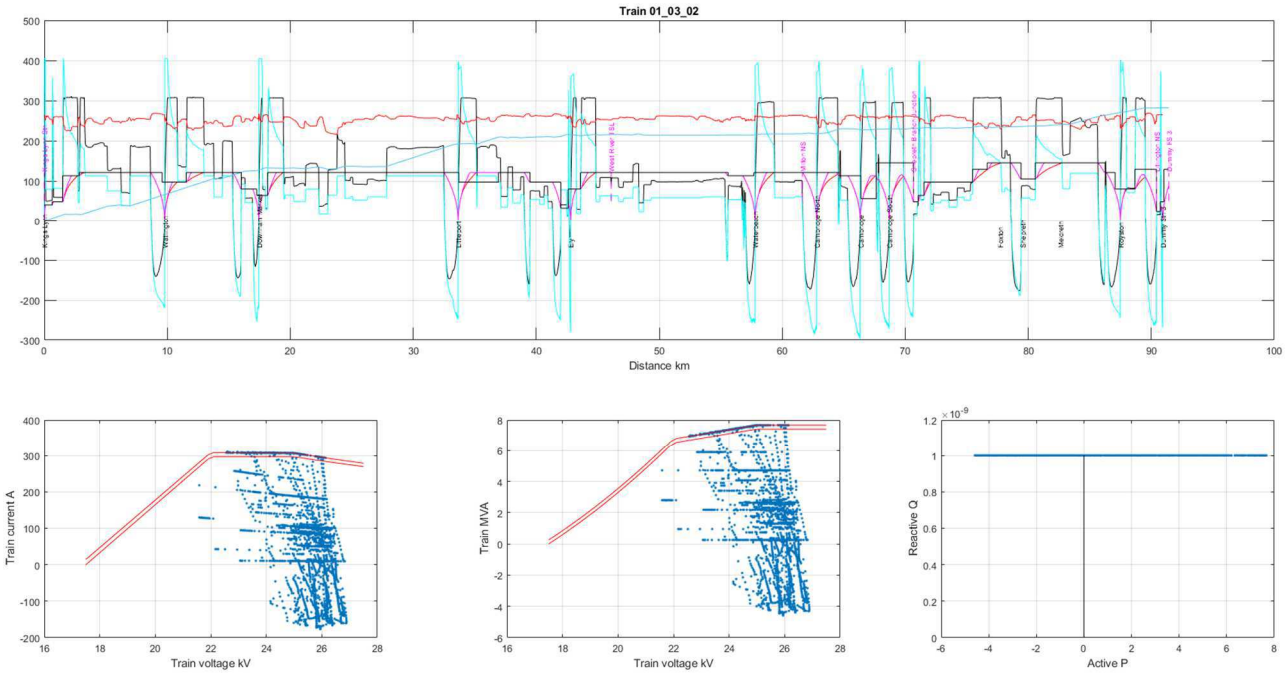


Figure 86 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1

Route 2, Class 375 12-Car

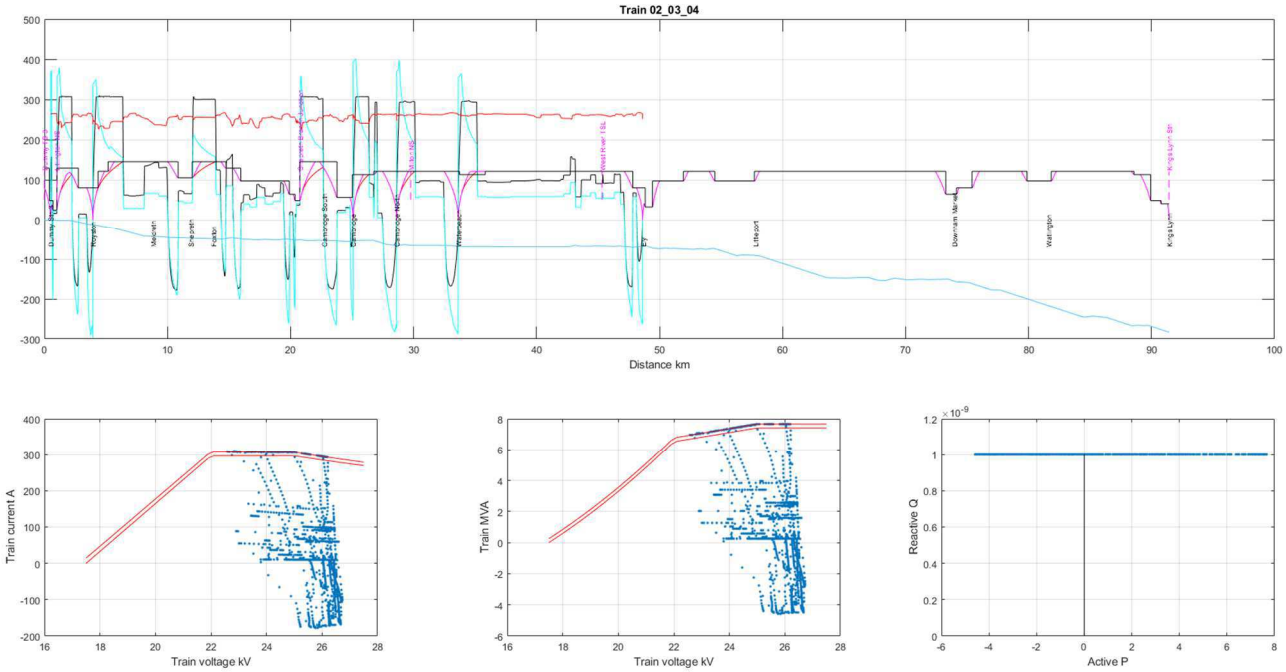


Figure 87 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2

Route 3, Class 700 12-Car

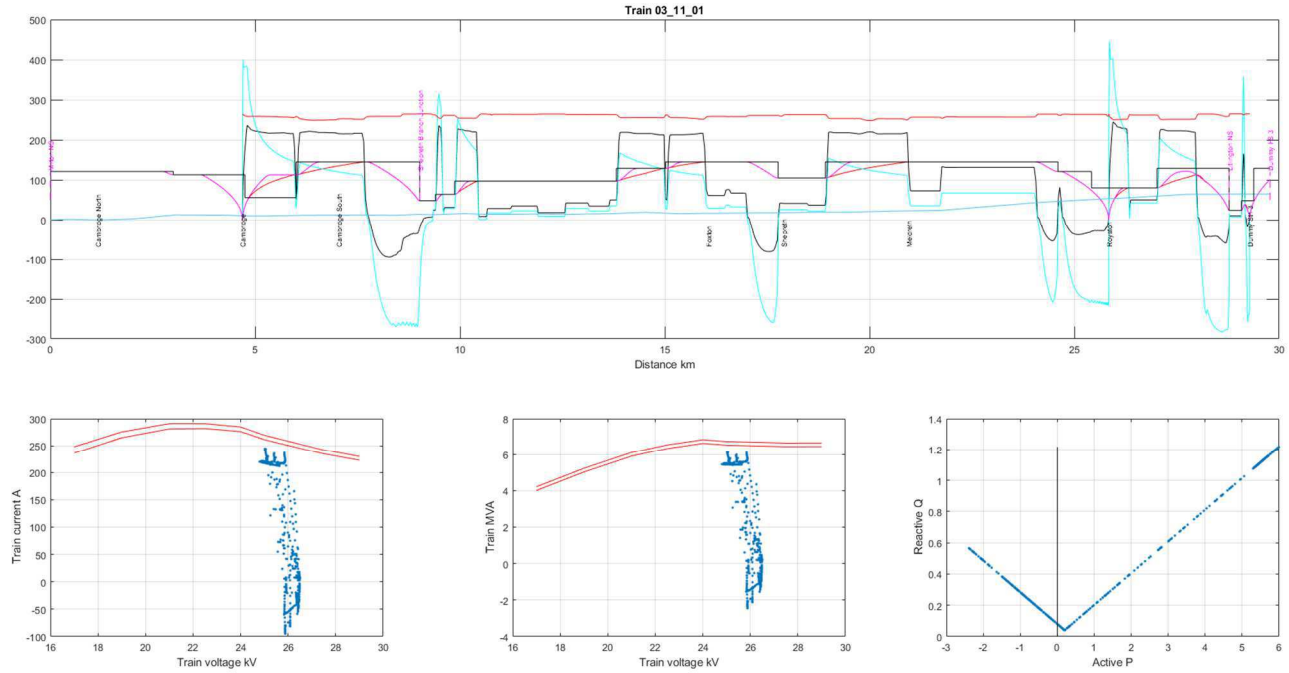


Figure 88 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3

Route 4, Class 700 8-Car

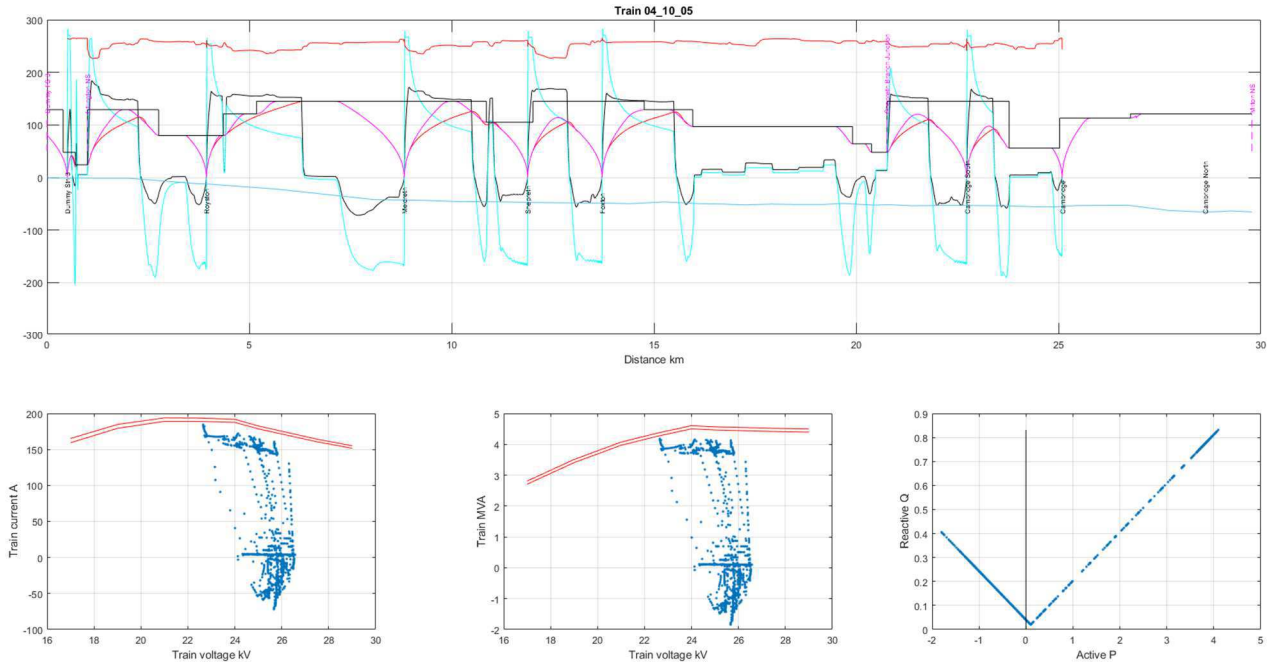


Figure 89 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4

Route 5, Class 710 5-Car

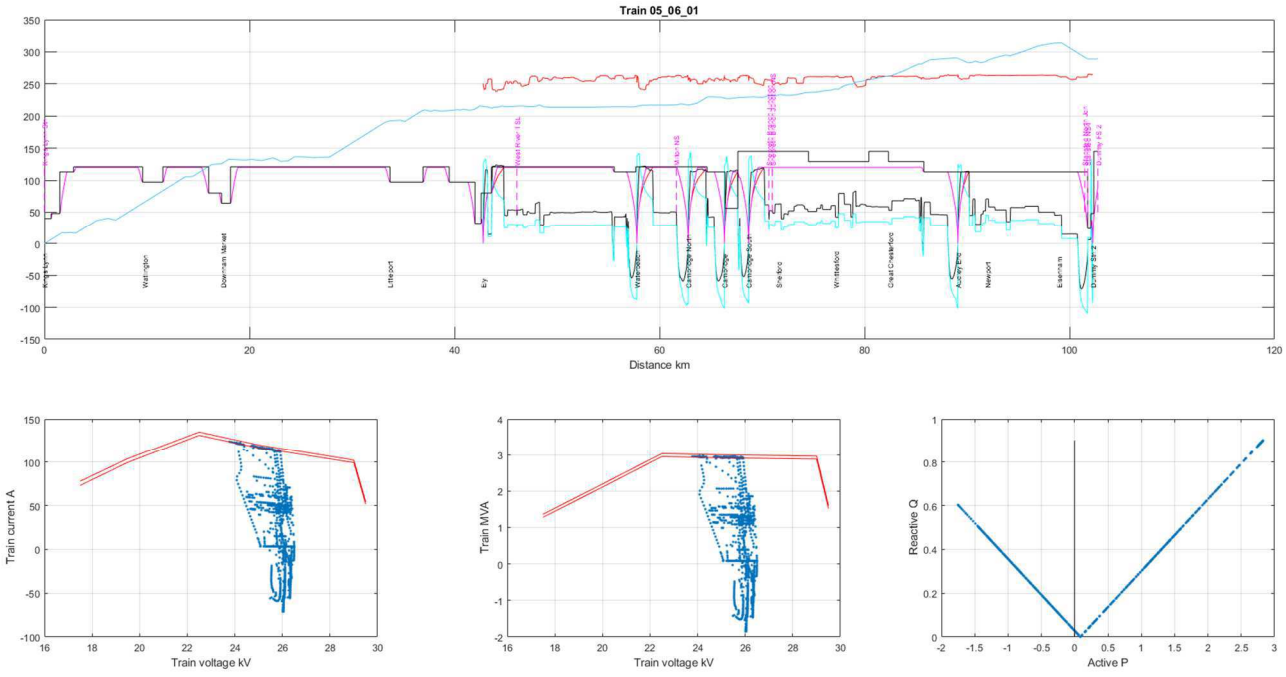


Figure 90 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5

Route 6, Class 710 5-Car

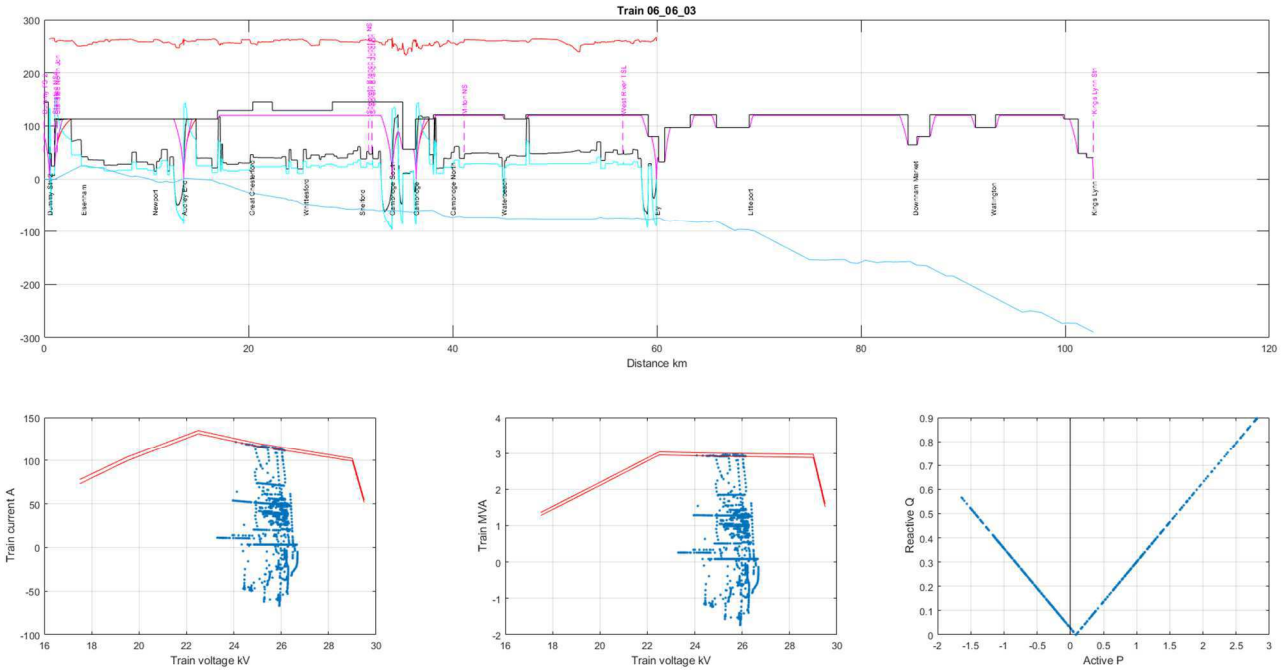


Figure 91 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6

Route 7, Class 700 12-Car

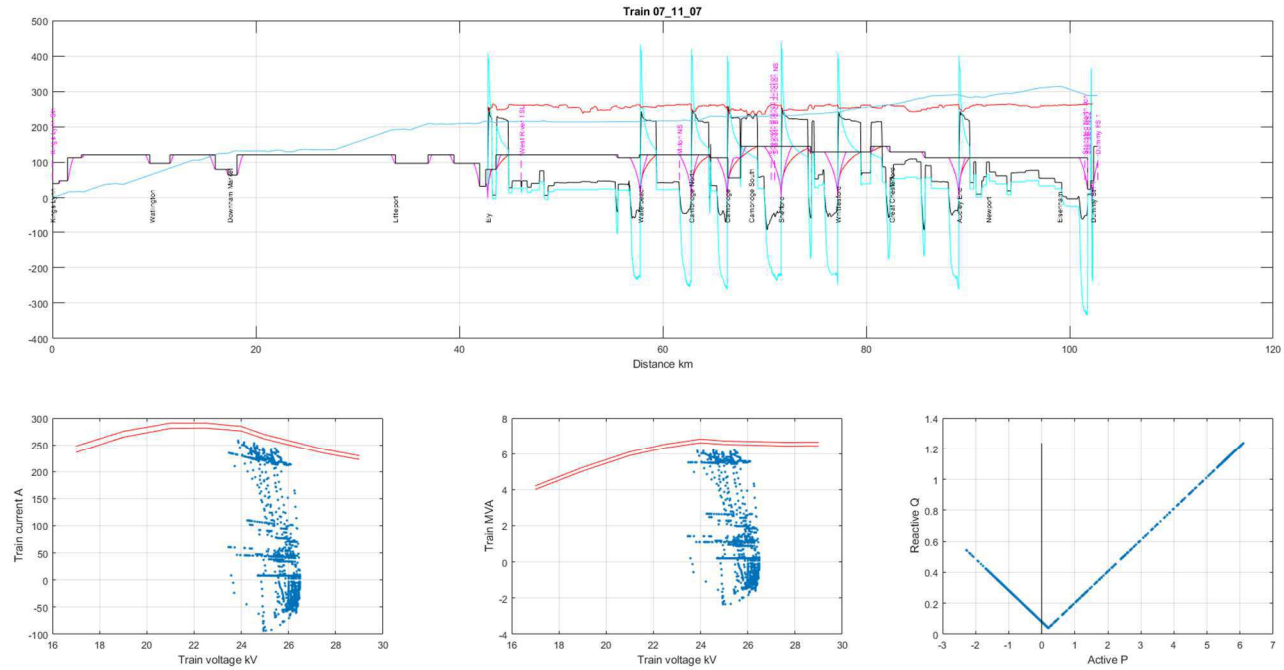


Figure 92 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7

Route 8, Class 700 12-Car

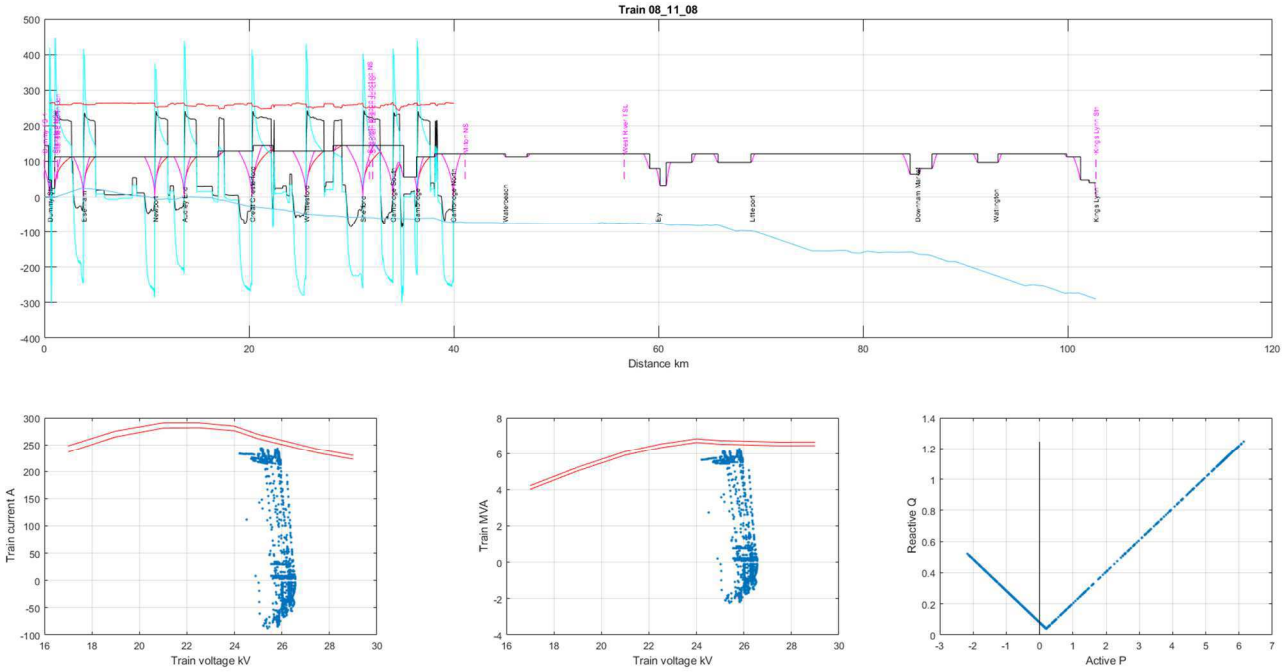


Figure 93 Emergency Feeding Arrangement at Kings Lynn FS with Regen On – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8

Emergency Feeding Arrangement at Ugley FS with Regen On

Voltage Profile:

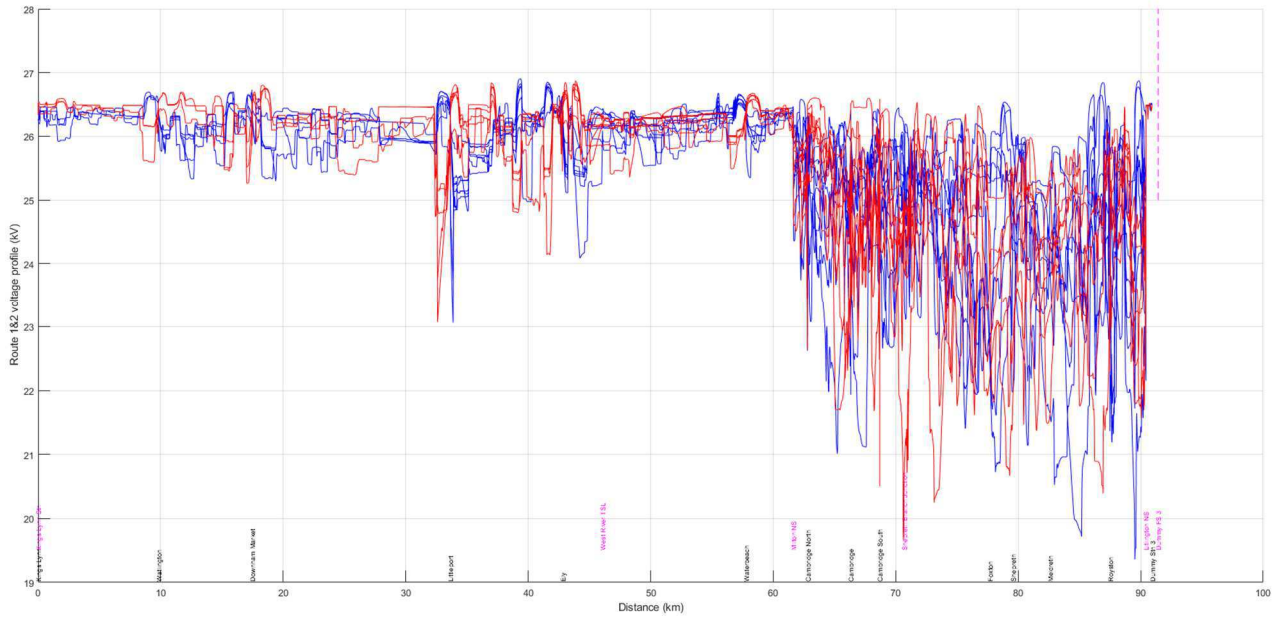


Figure 94 Emergency Feeding Arrangement at Ugley FS with Regen On - Voltage Profile for Route 1 and 2 for all trains

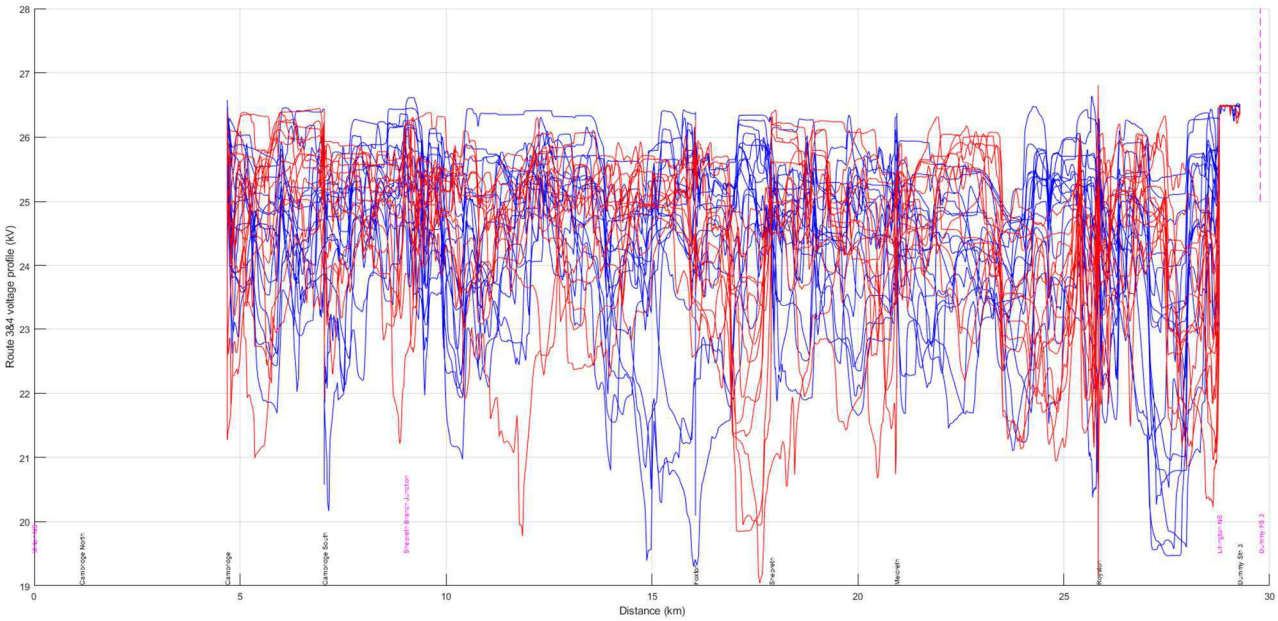


Figure 95 Emergency Feeding Arrangement at Ugley FS with Regen On - Voltage Profile for Route 3 and 4 for all trains

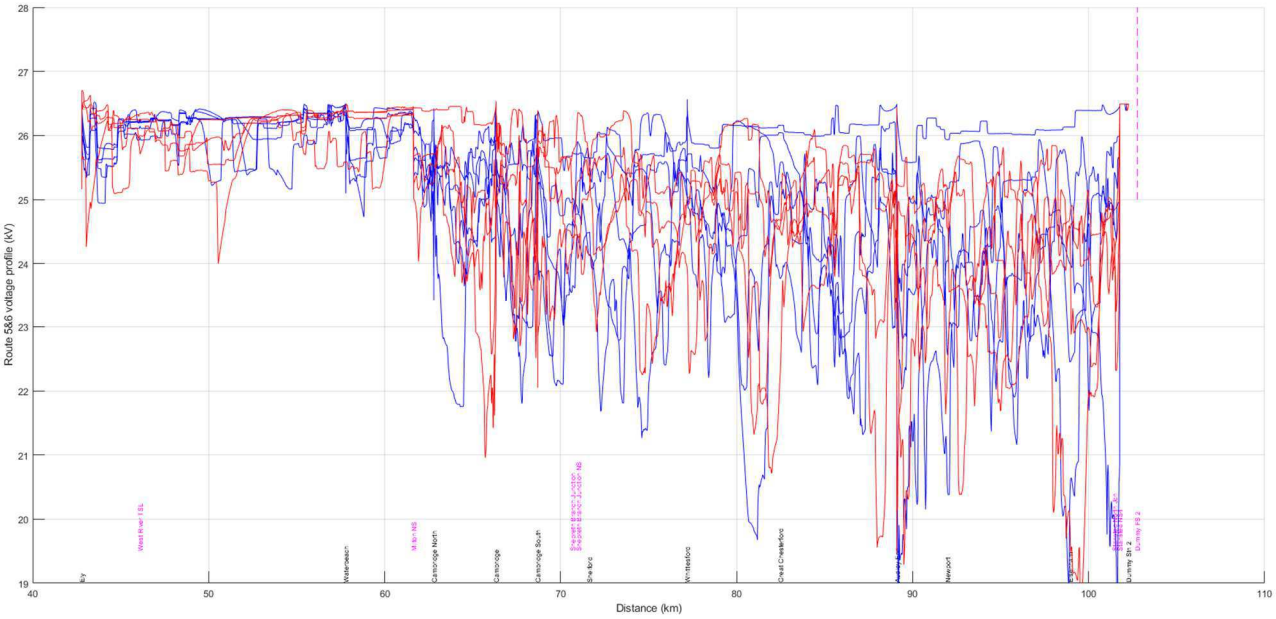


Figure 96 Emergency Feeding Arrangement at Ugley FS with Regen On - Voltage Profile for Route 5 and 6 for all trains

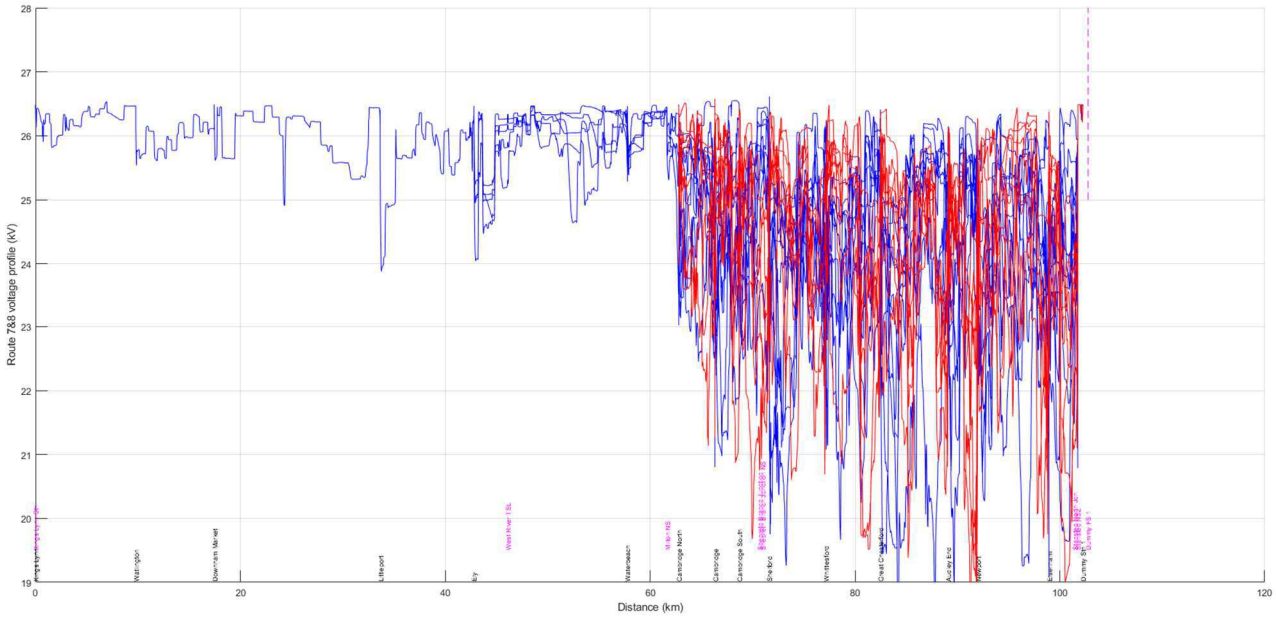


Figure 97 Emergency Feeding Arrangement at Ugley FS with Regen On - Voltage Profile for Route 7 and 8 for all trains

The following trains have been selected for Emergency Feeding Arrangement at Ugley FS with Regen On:

Figure 98: Train 01_03_02 Performance Result Class 375 12-Car on Route 1

Figure 99: Train 02_03_04 Performance Result Class 375 12-Car on Route 2

Figure 100: Train 03_11_01 Performance Result Class 700 12-Car on Route 3

Figure 101: Train 04_10_05 Performance Result Class 700 8-Car on Route 4

Figure 102: Train 05_06_01 Performance Result Class 710 5-Car on Route 5

Figure 103: Train 06_06_03 Performance Result Class 710 5-Car on Route 6

Figure 104: Train 07_11_07 Performance Result Class 700 12-Car on Route 7

Figure 105: Train 08_11_08 Performance Result Class 700 12-Car on Route 8

Route 1, Class 375 12-Car

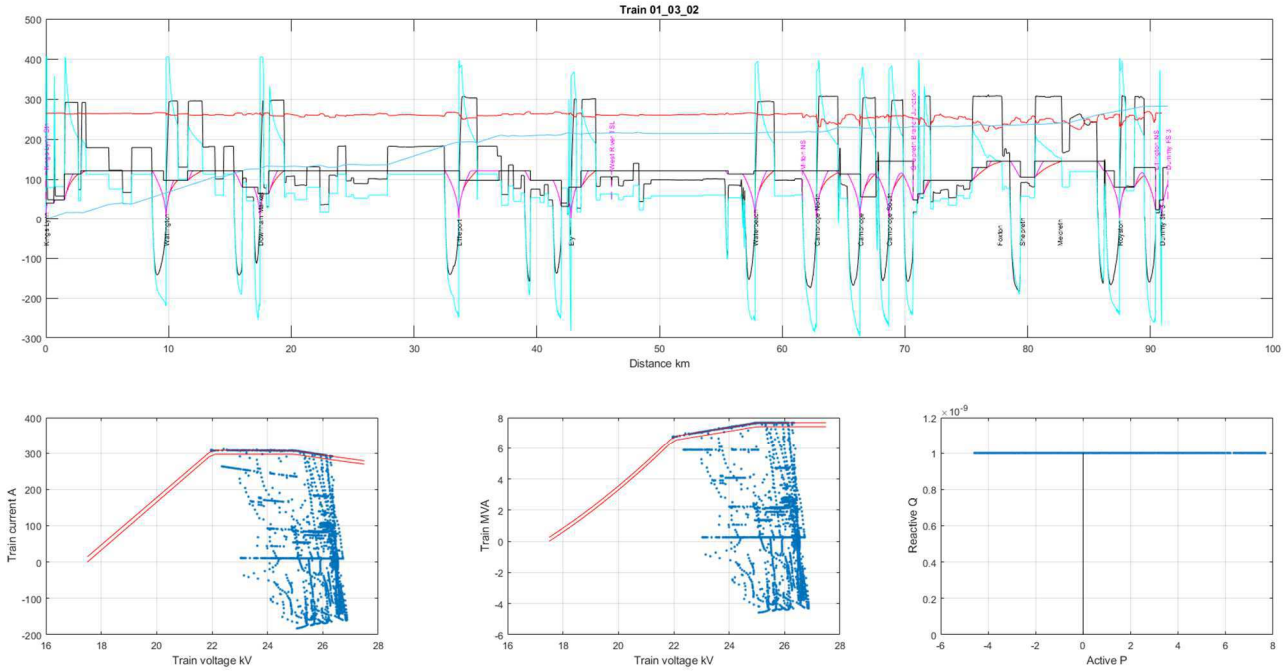


Figure 98 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 01_03_02 Performance Result, Class 375 12-Car on Route 1

Route 2, Class 375 12-Car

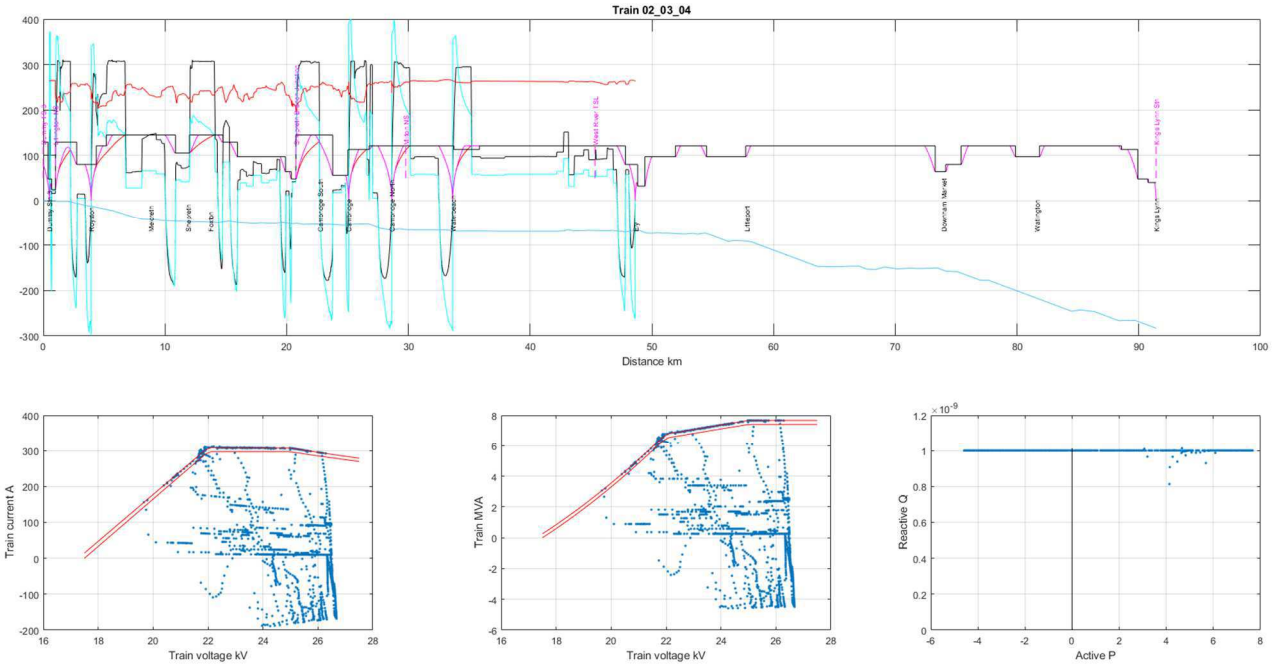


Figure 99 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 02_03_04 Performance Result, Class 375 12-Car on Route 2

Route 3, Class 700 12-Car

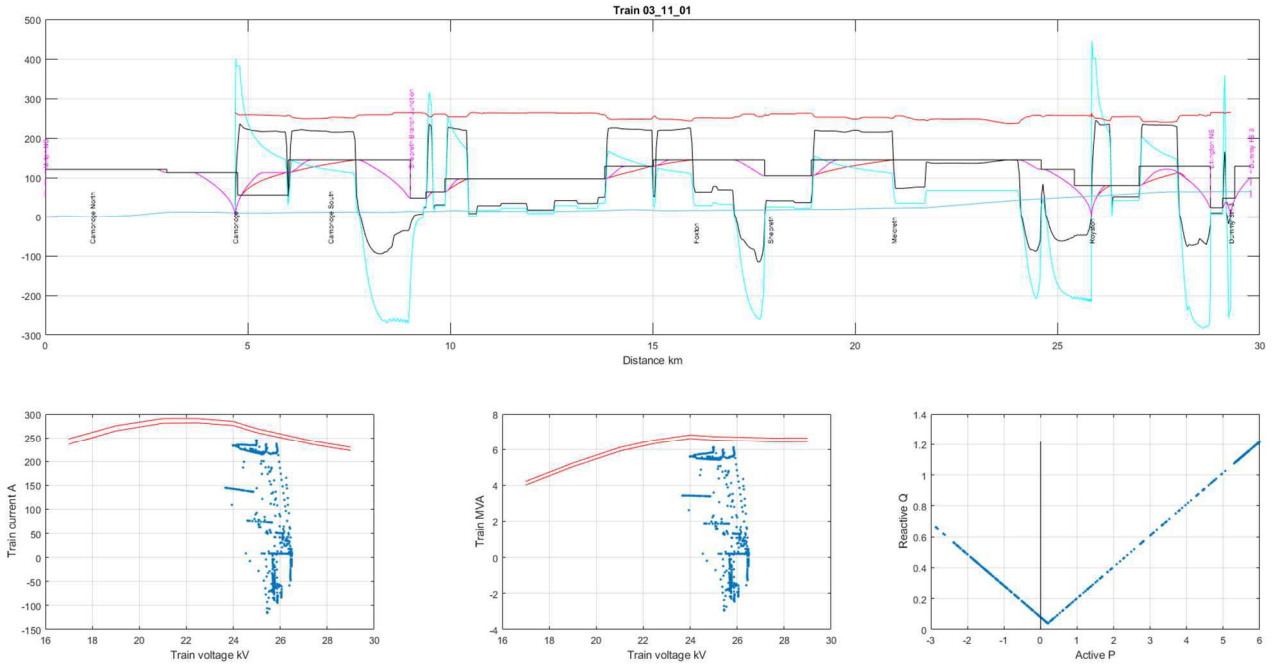


Figure 100 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 03_11_01 Performance Result, Class 700 12-Car on Route 3

Route 4, Class 700 8-Car

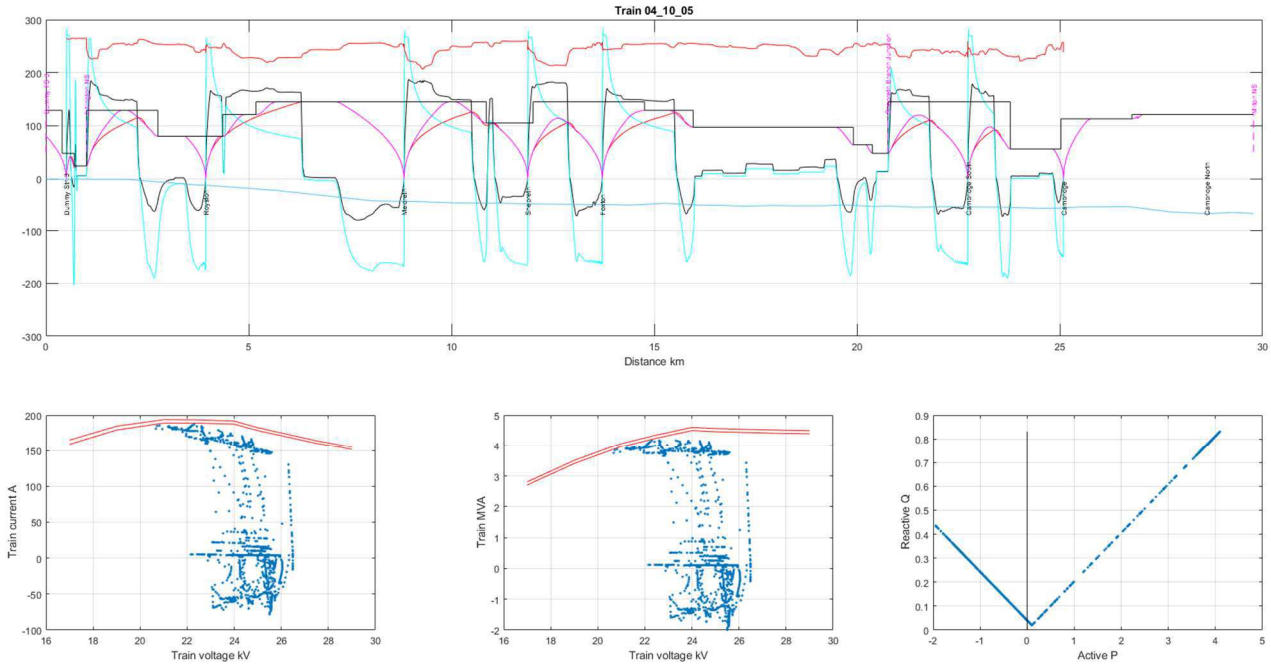


Figure 101 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 04_10_05 Performance Result, Class 700 8-Car on Route 4

Route 5, Class 710 5-Car

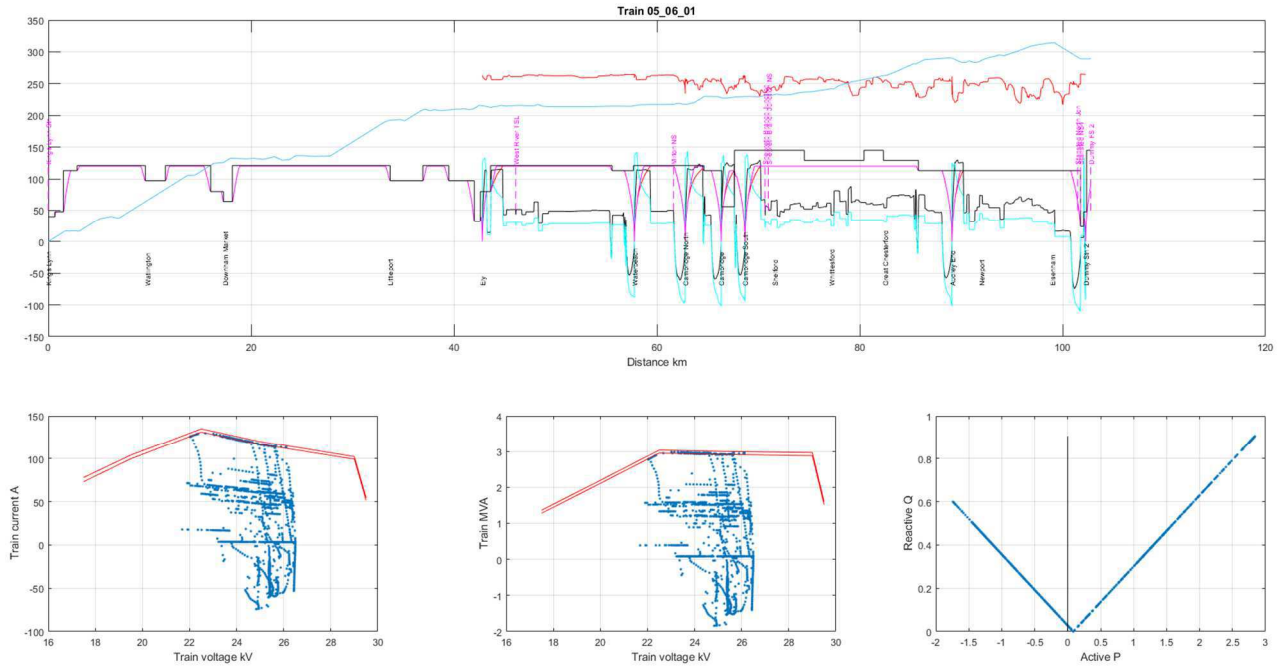


Figure 102 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 05_06_01 Performance Result, Class 710 5-Car on Route 5

Route 6, Class 710 5-Car

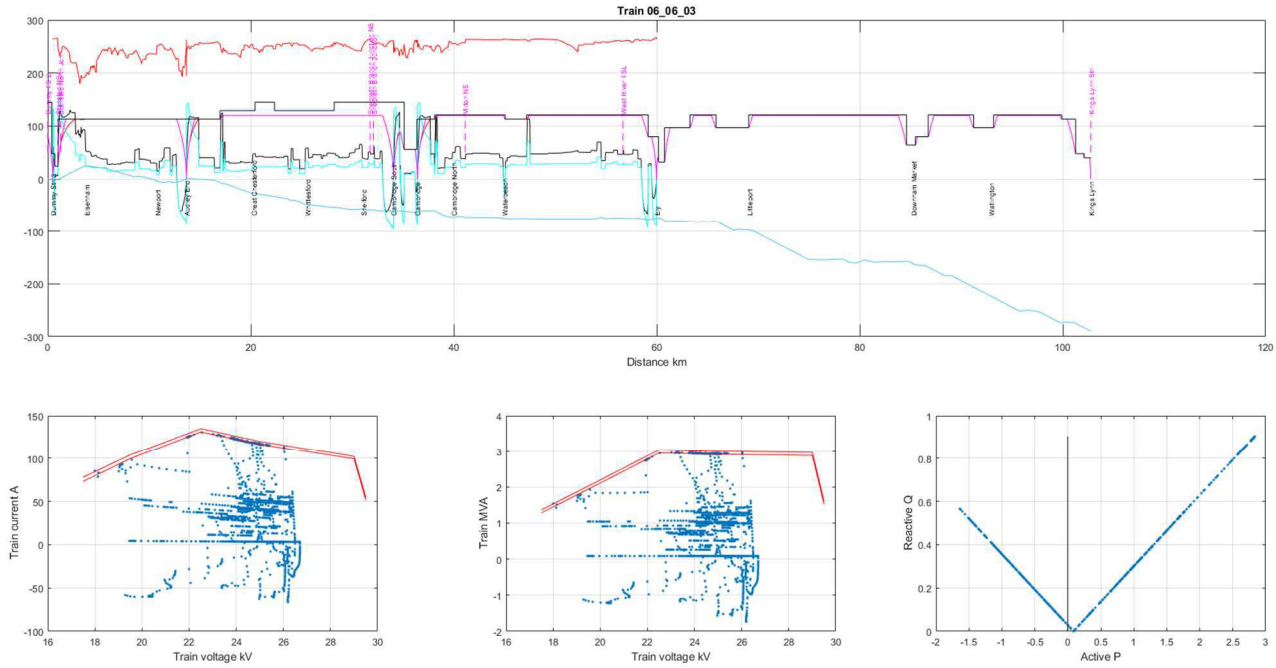


Figure 103 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 06_06_03 Performance Result, Class 710 5-Car on Route 6

Route 7, Class 700 12-Car

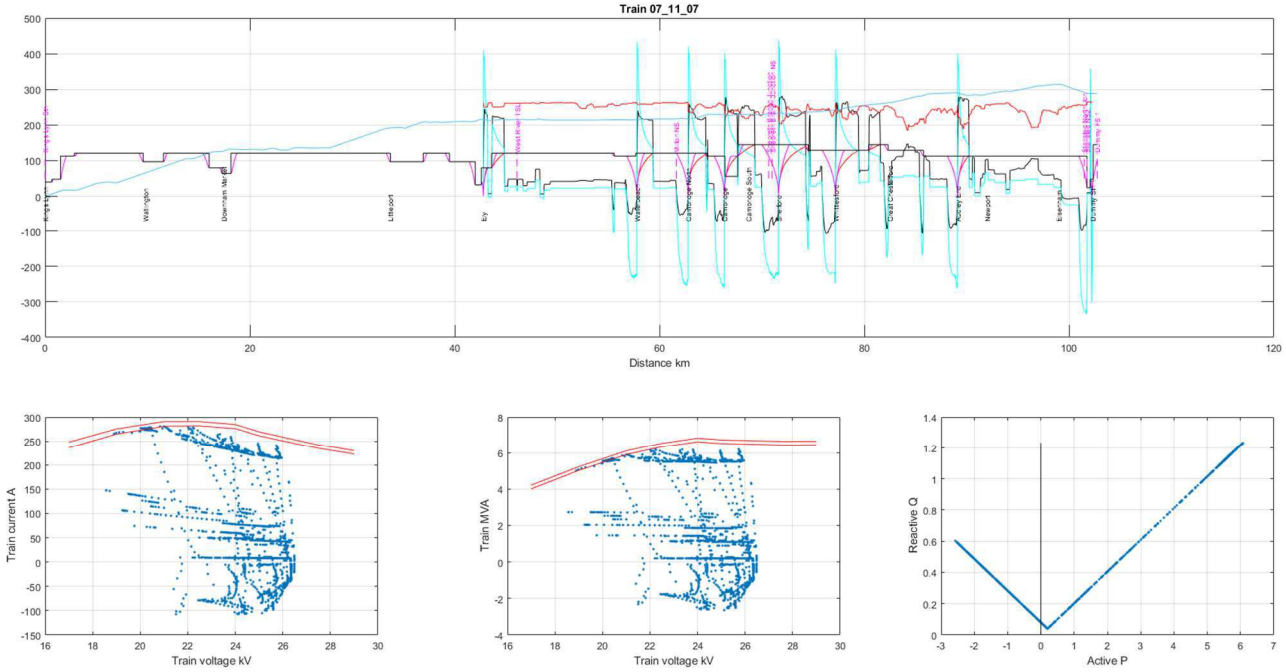


Figure 104 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 07_11_07 Performance Result, Class 700 12-Car on Route 7

Route 8, Class 700 12-Car

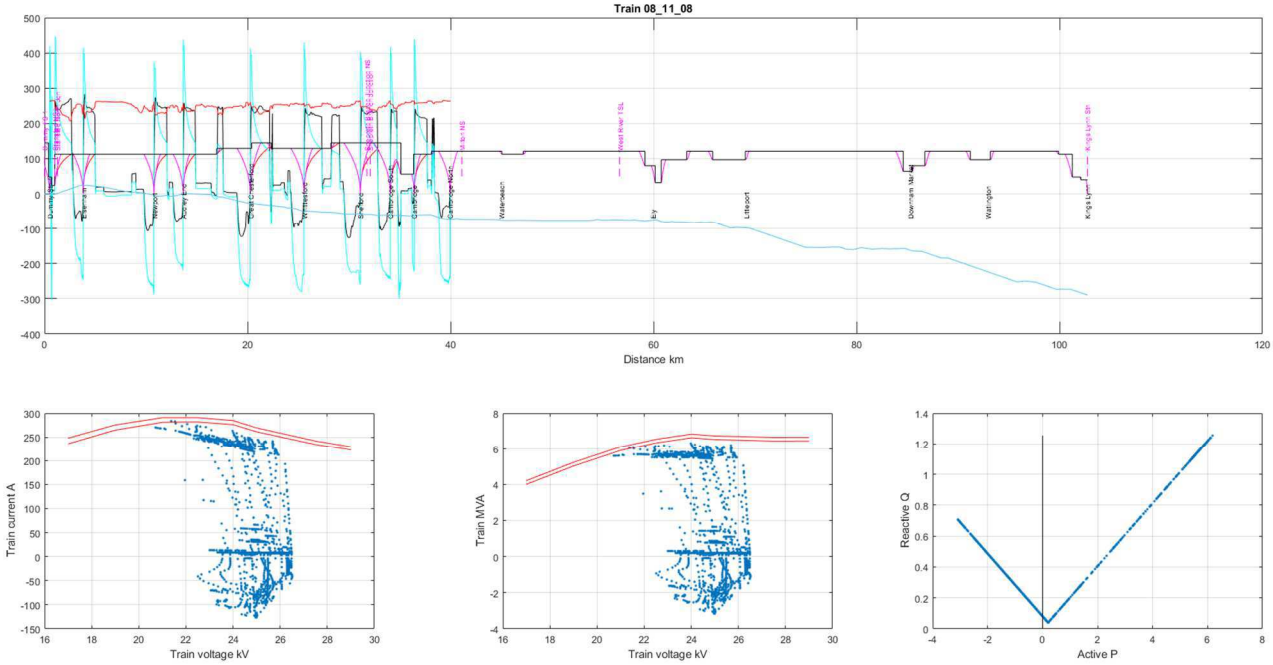


Figure 105 Emergency Feeding Arrangement at Ugley FS with Regen On – Train 08_11_08 Performance Result, Class 700 12-Car on Route 8

Appendix C – Major Feeding Diagram

xxxx

Appendix D – Traction Modelling Simulator

Overview

Modelling of the traction supply is a software suite used for designing electric railway traction networks. This software has been developed on experience gained over 30+ years, starting from the very earlier simulators like VCR in the eighties (developed for PhD research), MTS University of Birmingham and LUL, DCTS for BRP and AEAT, OSLO of BRR. The software has been validated by site measurements over many years on different railway projects and the results have been compared with at least six well established equivalent European simulators (as part of CENELEC work WG20). This simulator is TSI compliant and conforms to the key EN standards, including EN50388, EN50163, EN50152 and EN50119. The software enables carrying out analysis of DC and AC electric traction systems with an integrated approach incorporating:

- Timetabling and train operation in complex railway networks;
- Steady State simulations, Power System and load flow assessment;
- Short Circuit Calculations and Protection evaluation;
- Harmonic Penetration, Distortion and Resonance;
- Electro-Magnetic Compatibility and Immunisation assessment;
- Asset Management optimization.

A high-level structure of the modelling software is shown in Figure 106 below.

Validation

The software validation may be classified into three levels:

1. Validation of the numerical algorithms of traction supply simulation includes verifications of equations such as ohm's law, motion equations, track forces, etc. This type of validation is relatively straightforward as numerical verifications can be embedded within the code, examples are (a) compare losses by calculating difference between generated and consumed energy, and total I2R losses, (b) motion equations (time, distance, speed, tractive effort, acceleration) applied to individual trains, and there are many others self-checking processes embedded in the simulator;
2. Comparing results with other traction supply simulators. This has been done as part of the work carried out in CENELEC WG20 where results from a dozen of major simulators used in Europe, including this software, have been compared. There is no official document published but the results of comparison are available if required;
3. Comparing results with real-life measurements. It is recognised that it would be very expensive and complicated task to fully validate any traction simulator by measurements means. However, partial validations such as monitoring FS currents and/or a single train in normal operation have been carried out in the past. The concepts and principles of the software have been developed over the last 30 years. Over this time, there has been a multitude of measurements and calculation validation processes carried out comparing the numerical results with site measurements on both ac and dc supplies. These included LUL infrastructures for dc simulation in the late 90s, NR infrastructures both ac BT (Booster Transformer) and AT (Auto-Transformer) and dc, and extensive work was carried out on HS1 (almost all of the design work for CTRL was validated by site testing). Other railways included are Athens Metro and lately Perth, Australia railways;
4. The simulator has been built and developed over many years of experience on ac and dc traction supplies. The AC version of the simulator is based on multi-conductor OLE modelling that is capable of accurately modelling the traction supply and enables assessments of equipment and conductor rating individually, in addition inductive coupling, magnetic fields, stray currents, harmonics distortion, and others. The railway infrastructures can be built for multiple junctions and branches incorporating

track layout, gradients, speed limits, stations, and employing comprehensive timetabling that includes different types and formation of passenger and freight trains.

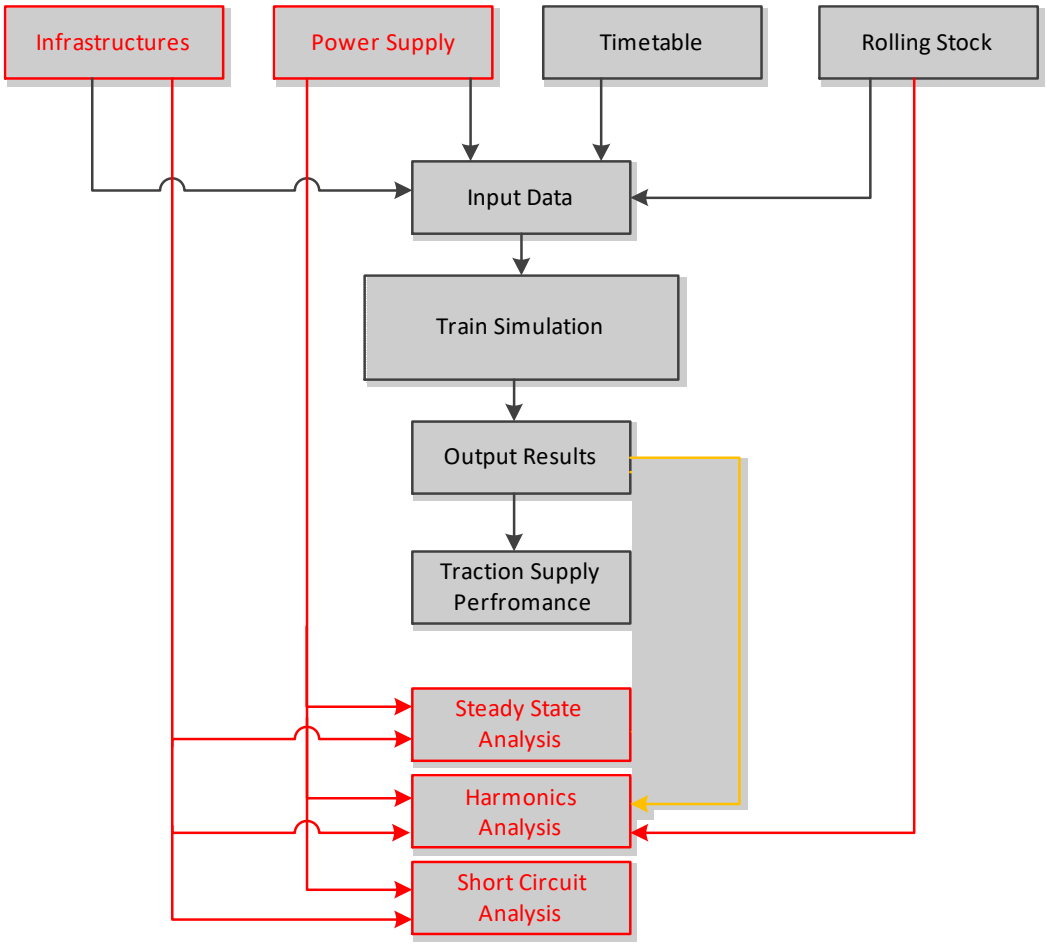


Figure 106 Architecture of the simulation software

Compliance

The Energy TSI clauses relevant to traction power system design and compliance statement have been considered and embedded in the simulator algorithms. For example, compliance of train voltages and line voltages are assessed using U_mean_useful definitions provided by BS EN 50388 for train mean and zone mean useful voltage. The relevant standards and guidance applied in the simulator are shown below.

Rolling stock have also been assessed for compliance with TSI and conform to BS EN50153 for example. Where information is not available, or inaccurate, the simulator provides estimates based on best engineering judgements.

The total energy demand in MWh of feeder stations and system losses can be determined. The system losses are calculated using two methods, the first is the difference between total energy generation and total energy consumption, and the second method is summation of active and reactive losses in the OLE conductors, bonds, BTs and earth leakages. The two results of the two methods are compared to ensure accuracy of the solution.

The MVA rating of feeder station transformers can be determined using instantaneous, one-minute r.m.s. rating, and half hour r.m.s. rating. Furthermore, the r.m.s. continuous current rating, and one-minute maximum current rating of the contact, catenary, return conductors and Return Screening Conductors (RSC) are determined.

The journey times for all trains are calculated in each run. Maximum and minimum times and dwell times can be determined. The energy consumption for very train run is also determined.

The simulator can provide detailed assessments in the following areas:

1. Traction power supply: the main parameters used to determine the adequacy of the traction supply are U_mean_useful defined in BS EN 50388, energy consumption, system losses, equipment rating, train performance, journey times, etc. These parameters have been extensively tested and verified;
2. Electromagnetic compatibility issues that cover touch voltages and induced voltages in normal and under short circuit conditions;
3. Magnetic fields assessment under steady state for the fundamental frequency 50 Hz and harmonics emission from the train;
4. Harmonics distortion and resonance assessment and determination of the levels of voltage distortion and the consequential effects. This is covered by BS EN 50388 part which is currently in draft format;
5. Low frequency stability of the traction supply which may result from concentration of multiple train operation within a small area such as depots and large stations. This is covered by BS EN 50388 part 2 which is currently in draft format;
6. Assessment of stray AC (or DC) current levels and the consequent effects;
7. Interaction between rolling stock and feeder station which may result in system failure and stability problems;
8. Assessment of the effects of regenerative braking;
9. Interaction between rolling stock and supply under short circuit event and transient events such as in rush current;
10. Compatibility of rolling stock with signalling equipment and track circuits such as audio frequency track circuits in steady state and DC track circuits in transient conditions under inrush currents or de-icing mode.

The simulator complies with the following standards and guidance:

- GM/RT2111 on Rolling Stock Subsystem and Interfaces to AC Energy Subsystem which will be superseded by draft GLGN1600, issue 1, January 2017 “Guidance on the Energy TSI;
- GM/GN2611 Guidance on Rolling Stock Subsystem and Interfaces to AC Energy Subsystem;
- GL/RT1210 AC Energy Subsystem and Interfaces to Rolling Stock Subsystem;
- GL/GN1610 Guidance on AC Energy Subsystem and Interfaces to Rolling Stock Subsystem;
- GM/GN2611 Guidance on Rolling Stock Subsystem and Interfaces to AC Energy Subsystem;
- GE/RT8015 Electromagnetic Compatibility between Railway Infrastructure and Trains;
- GE/RT8270 Assessment of Compatibility of Rolling Stock and Infrastructure;
- GK/RT0045 Lineside Signals, Indicators and Layout of Signals;
- GK/RT0058 Lineside Signal Aspect and Indication Requirements;
- GM/RT2113 Rolling Stock Subsystem and Interfaces to DC Energy Subsystem;
- GO/RT3215 Requirements for the Weekly Operating Notice, Periodical Operating Notice and Sectional Appendix;
- BR 12034/17 Railway Electrification 25 kV AC Design Acceptance Measures;
- Current TSI documents;
- BS EN 50388:2012 Railway applications. Power supply and rolling stock. Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability.

This will be split into two parts, the latest drafts prEN50388-1 and prEN50388-2 issued September 2016;

- BS EN 50119:2009+A1:2013 Railway applications. Fixed installations. Electric traction overhead contact lines;
- BS EN 50122-1:2011+A1:2011 Railway applications. Fixed installations. Electrical safety, earthing and the return circuit. Part 1: Protective provisions against electric shock;
- BS EN 50124-1:2001+A2:2005 Railway applications. Insulation coordination. Part 1: Basic requirements. Clearances and creepage distances for all electrical and electronic equipment;
- BS EN 50153:2002 Railway applications. Rolling stock. Protective provisions relating to electrical hazards;
- BS EN 50163:2004+A1:2007 Railway applications. Supply voltages of traction systems;
- BS EN 50206-1:2010 Railway applications. Rolling stock. Pantographs: Characteristics and tests. Part 1: Pantographs for main line vehicles;
- BS EN 50317:2012 Railway applications. Current collection systems. Requirements for and validation of measurements of the dynamic interaction between pantograph and overhead contact line;
- BS EN 50367:2012 Railway applications. Current collection systems. Technical criteria for the interaction between pantograph and overhead line (to achieve free access);
- BS EN 60077-4:2003 Railway applications. Electric equipment for rolling stock. Part 4: Electrotechnical components. Rules for AC circuit-breakers;
- BS EN 62271-100:2009+A1:2012 High-voltage switchgear and control gear. Alternating current circuit-breakers.

Features of Simulator – version 3.0

Infrastructure and Operation

- ‘Nodes’ are geographical locations characterising the railway network. Node can be a junction or terminus boundary;
- ‘Branches’ with each branch connecting two nodes. Branch is directional which requires defining the first and second Node;
- ‘Routes’ (bidirectional up and down) incorporating a sequence of branches and used for Timetable (services in both directions);
- Infrastructures defining detail of the branches such as ‘distance’, ‘gradients’, ‘speed limits’ and ‘station locations’;
- GIS representation (optional) of the infrastructure elements to identify exact co-ordinates;
- ‘Timetables’ defining train services along different routes. Route consists of sequence of branches with each branch contains number of stations. Timetable can be calculated automatically by the simulator or prepared manually. The timetable is based on fixed departure times;
- Rolling Stock tractive effort and line current against speed at various line voltages can be provided in analogous format or as a family of multiple curves;
- Multiple rolling stock types and mixed mode operation;
- Mixed tunnel and open line sections;
- Variable speed limits, acceleration rates and braking rates;
- Moving block or fixed block signalling for networks and junctions (currently not available);
- Driving style modelling (currently flat-out only).

AC Power Supplies

- AC network interconnected mesh and multi paths[1];
- Multi conductor model of the track and OLE;
- Return path, cross bonds, impedance bonds, earth leakages and variable structure earthing;
- Earth model can be either a simple rail to earth representation, or a 3D earth which linked to the GIS co-ordinates of the infrastructures;
- Normal 25 kV FS transformers, ATFS, AATFS, Static Converters (SC) with adjustable controllers for P-θ and Q-V and combination of SC and normal transformers;
- Different models of OLE types have been built including for RR, BT, AT and AAT (asymmetric auto transformer) with SRTC or DRTC employing variety of bonding and earthing methods;
- Comprehensive configuration of feeder stations and track sectioning cabins for FS sites, OLE, multiple tracks and different earthing and bonding arrangements;
- HV grid network model including load balancers at the PCC and SVC on the output side;
- Regenerative braking / rheostatic equipment;
- Adjustable taps, feeders and transformer;
- Non-linear current limiting at low voltage overloading and high voltage regenerative braking;
- Flexible circuit breaker configurations and arbitrary feeder station configurations;
- Static non-traction loads as power, current or pure resisters on the traction side;
- Losses in individual rails (conductor and running), feeders, cables, insulators and stray losses;
- Power and energy analysis;
- Short circuit analysis;
- Touch potentials and accessible voltages calculation;
- Harmonic distortion on both the HV and traction sides, resonance occurrence and voltage distortion;
- Transients analysis in time domain in events such as short circuits or inrush currents;
- Comprehensive post processing;
- Additional models for trackside and/or onboard energy storage devices.

DC Power Supplies

- DC network interconnected mesh and multi paths;
- Multi conductor model of the track and ETE;
- Return path, cross bonds, impedance bonds, earth leakages and variable structure earthing;
- Earth model can be either a simple rail to earth representation, or a 3D earth which linked to the GIS co-ordinates of the infrastructures. For DC stray currents assessment, the 3D model is recommended;
- Normal DC supply configuration incorporating different types of transformer rectifier units, including 6-pule, 12-pulse and 24 pule configurations in either series or parallel bridges;
- Different models of ETE types employing variety of bonding and earthing methods;
- Comprehensive configuration of substations and track paralleling and sectioning;

[1] *Electrical branches are overlaid on the operation branches. Each electrical branch incorporates multiple electrical Nodes with the first and last electrical node attached to the corresponding operation nodes. Electrical sections are then defined between each two successive electrical nodes. Therefore, the number of electrical sections equals the number of electrical nodes minus one. Each electrical node contains multiple electrical buses which are the same as number of conductors considered for a given OLE. For example, if the number of conductors in the OLE is 14 then there are 14 electrical buses per electrical node. If there is, say, 20 electrical nodes in the electrical branch then the total number of electrical buses in that branch is 14X20.*

- HV grid AC distribution network model including SVC (static Var compensator), filters, etc should it required;
- Regenerative braking / rheostatic equipment;
- Adjustable taps, substation and transformer setting;
- Non-linear current limiting at low voltage overloading and high voltage regenerative braking;
- Flexible circuit breaker configurations and arbitrary substation configurations;
- Static non-traction loads as power, current or pure resisters on the traction side;
- Losses in individual rails (conductor and running), substations, cables, insulators and stray current losses;
- Power and energy analysis;
- Short circuit analysis;
- Touch potentials and accessible voltages calculation;
- Harmonic distortion on both the DC side and HV network distribution side, resonance occurrence and voltage distortion;
- Transients analysis in time domain in events such as short circuits or inrush currents;
- Comprehensive post processing;
- Additional models for trackside and/or onboard energy storage devices.

Proof of Evidence – Electromagnetic Compatibility (Mr Rasheed R. Hameed) Appendix 05
EMC Technical Methodology [158454-ARC-ZZ-ZZZ-REP-EDS-000001]

(Inquiries Procedure (England & Wales) Rules 2004

January 2022

[This page is left intentionally blank]

ARCADIS Design & Consultancy for natural and built assets

Demonstration of EMC Compliance

Cambridge South Infrastructure Enhancement

158454-ARC-ZZ-ZZZ-REP-EDS-000001

Proposed Project Technical Methodology

December 2021

CONTACTS

RAFAT KADHIM
Associate Technical Director

df: +44 (0)2030 149 221
m: +44 (0)7545 701 108
e: rafat.kadhim@arcadis.com

Arcadis.
80 Fenchurch Street
London
EC3M 4BY
United Kingdom

RASHEED HAMEED
Technical Director

df: +44 (0)2920 926723
m: +44 (0)7801 907100
e: rasheed.hameed@arcadis.com

Arcadis.
80 Fenchurch Street
London
EC3M 4BY
United Kingdom

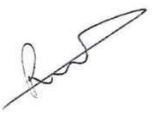
Demonstration of EMC Compliance

Proposed Methodology

Author	Rafat Kadhim
Checker	Pierre Fayet
Approver	R. Rasheed Hameed
Document No	
Date	December 2021







VERSION CONTROL

Version	Issue	Date	Author	Changes
P01	Draft	30/11/2021	RJK	First Draft
P02	Draft	22/12/2021	P. Fayet	Itemised technical proposal
P03	Final	22/12/2021	P. Fayet	Updated to comments

This report dated December 2021 has been prepared for Network rail. Arcadis agrees that, in addition to the Client, the contents of this report may be used and relied upon by Network rail. For avoidance of doubt, no other person(s) may use or rely upon this report or its contents, and Arcadis accepts no responsibility for any such use or reliance thereon by any other third party.

CONTENTS

1 INTRODUCTION 6
1.1 Background 6
1.2 Neighbouring Medical Centres 6
1.3 Changes to Railway Infrastructure 7

2 OVERARCHING METHODOLOGY 8

3 TECHNICAL PROPOSAL 9
3.1 Item A. Pre-construction EMC site survey 9
3.1.1 EMC Site measurement strategy 9
3.1.2 EMC Site survey 9
3.2 Item B. EMC Hazard Log and EMC assessment 9
3.2.1 Collating the immunity requirements 9
3.2.2 EMC HAZID workshop and hazard log 10
3.2.3 EMC Engineering report 11
3.3 Item C. Theoretical Studies 13
3.4 Item D. EMC Control Plan and EMC File 14
3.5 Item E. Commissioning EMC Test 14

APPENDIX A: RELEVANT EMC STANDARDS AND GUIDANCE 15
Applicable Legislation 15
National Standards 15
Railway Group Standards 16
Network Rail Standards and Documents 16
Other Relevant Documents 16

APPENDIX B: PERMISSIBLE LIMITS (FOR INFORMATION) 17
50 Hz Power Frequency 17
Traction Harmonics 17
ELF and DC and quasi static 17
Transient and Electrostatic Discharge 17
RFI 17

APPENDIX C: DETAILED METHODOLOGY FOR EMC ASSESSMENT 19
Conductive Coupling 19
Inductive Coupling 19

Capacitive Coupling 19
Radiated Coupling 20
Fast transients 20

LIST OF FIGURES

Figure 1 Overarching methodology to demonstrate EMC Compliance 8
Figure 2. Proposed measurements in each frequency range 9
Figure 3. Cut view of a 4-track area 13
Figure 4 Typical calculation method of magnetic fields surrounding the OLE 13
Figure 5 Peak RFI limits stated in BS EN 50121-2 18
Figure 6 Quasi-peak RFI limits stated in BS EN 50121-2 18

LIST OF TABLES

Table 1 Initial Hazard matrix for UoC neighbours 12

Abbreviations

List of Abbreviations	
AiP	Approval in Principle
APC	Automatic Power Control
BSP	Bulk Supply Point
CB	Circuit Breaker
CBC	Cambridge Biomedical Campus
CSIE	Cambridge South Infrastructure Enhancements
E&B	Earthing and Bonding
ELF	Extremely Low Frequency
EMC	Electromagnetic Compatibility
EM	Electron Microscope
EMI	Electromagnetic Interference
FBC	Full Business Case
FFT	Fast Fourier Transform
iFFT	Inverse Fast Fourier Transform
JMS	J. Murphy & Sons Limited
MR	Magnetic Resonance
NMR	Nuclear Magnetic Resonance
NR	Network rail
OLE	Overhead Line Equipment
RFI	Radio Frequency Interference
S&T	Signalling and Telecommunication
TSC	Track Sectioning Cabin
TWAO	Transport and Works Act Order
VCB	Vacuum Circuit Breaker

1 Introduction

1.1 Background

The Cambridge South Infrastructure Enhancements (CSIE) Project is a multi-disciplinary project being undertaken by Arcadis for the client, J. Murphy & Sons Limited (JMS) as Principal Contractor for Network Rail. The aim of the Cambridge South Infrastructure Enhancement Project is to develop infrastructure options to improve connectivity in the Cambridgeshire region. As outlined by Network Rail, the objective of GRIP 4 is to complete deliverables and surveys to an Approval in Principle (AiP) Design for all disciplines (including provision of agreed surveys) that will enable the project to proceed to GRIP 5 and achieve a successful decision to deliver following Full Business Case (FBC) submission. Alongside this the project needs to secure the necessary consents to proceed, namely Network Change Approval and a Transport and Works Act Order (TWAO).

The aim of the Cambridge South Infrastructure Enhancements Project is to develop infrastructure options to improve connectivity and capacity in the Cambridgeshire region meeting rail demand forecast up to 2043.

1.2 Neighbouring Medical Centres

As part of the CSIE project, a new station will be built at Cambridge South, in the vicinity of the Cambridge Biomedical Campus. This facility is expected to be the largest concentration of biomedical centres in Europe. The railway runs alongside several sites of this complex. Four of these sites have been identified as the closest to the railways. These are:

- University of Cambridge Anne McLaren Building
- MRC Laboratory of Molecular Biology
- AstraZeneca R&D Building
- Royal Papworth Hospital

However, other sites have been identified in the vicinity of the railway. These sites are not as close to the railway as the ones listed above, however there might be at risk to the sensitive biomedical equipment that can be used. These are:

- Cambridge Centre for Brain Repair
- Institute of Metabolic Science
- University of Cambridge School of Clinical Medicine.
- Rosie Hospital
- Addenbrooke's Hospital
- The Deakin Centre
- Jeffrey Cheah Biomedical Centre
- Strangeways Research Laboratory
- Cancer Research UK Cambridge Institute
- Cambridge Academy for Science and Technology
- Barracudas Activity Day Camps - Cambridge Long Road
- Ambulance Station
- Long Road Sixth Form College

A number of the Cambridge Biomedical Campus stakeholders have raised objections to the CSIE project, on the ground that noise & vibration and Electromagnetic emission will interfere with the operation and sensitivity of the biomedical labs adjacent to the new railway infrastructure including the proposed Cambridge South station.

It is Network Rail's responsibility to ensure the proposed changes on the existing railway will have minimum impact on the sensitive neighbours in the area.

This document presents a methodology to demonstrate compliance of Electromagnetic compatibility (EMC) between the new railway infrastructures and the Cambridge Biomedical Campus neighbouring laboratories, hospitals and medical institutions addressed above.

1.3 Changes to Railway Infrastructure

Cambridge is served by the West Anglia Main Line. Both routes offer services to and from London. In addition, the city is served by Cross Country services which provide connectivity between Stansted Airport and Birmingham as well as several intermediate locations. Thameslink services provide direct trains across central London to Maidstone East and Brighton via Gatwick Airport.

Early-stage operational feasibility work and timetable analysis undertaken by Network Rail and train operating companies in 2017, identified the need for several interventions to accommodate long term capacity needs. The CSIE project is proposing the following changes to meet these requirements:

- Four-track of the West Anglia Main Line between Shepreth Branch Junction and the existing Cambridge Station;
- Reconstruction of the A1134 Long Road overbridge (Structure BGK/1544a) to facilitate four tracks;
- A new station at Cambridge South;
- Improvements to Shepreth Branch Junction to provide for future East West Rail requirements.

2 Overarching Methodology

Figure 1 below presents a summary of the different EMC elements that need to be considered on this project to demonstrate EMC compliance between the new electrification scheme at Cambridge South station and the Cambridge Biomedical Campus neighbours. It also presents how those elements interact with each other.

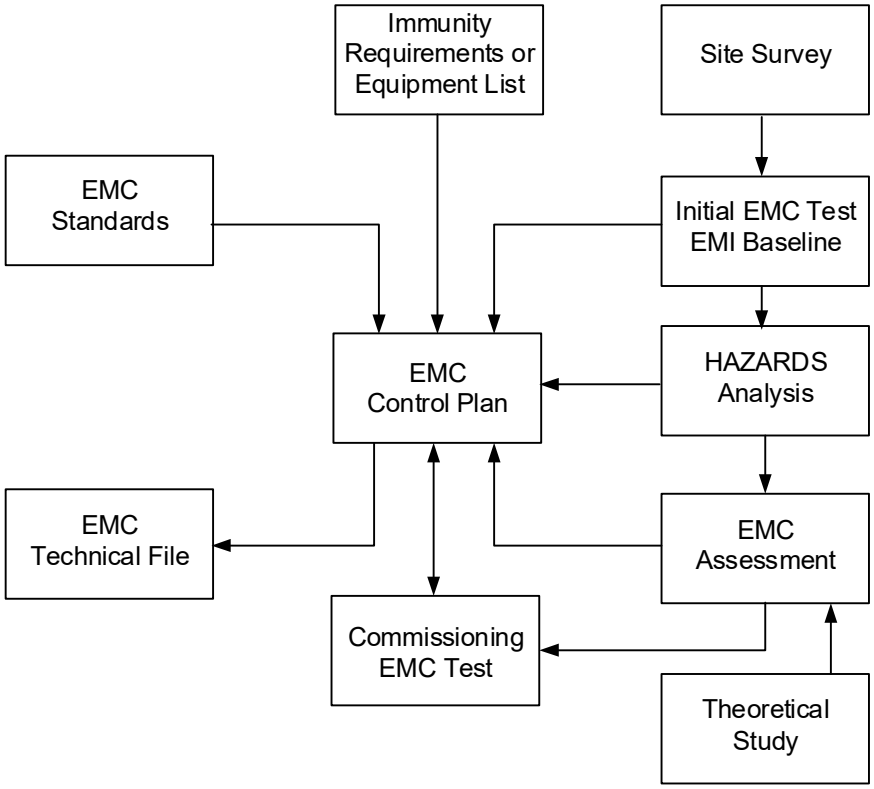


Figure 1 Overarching methodology to demonstrate EMC Compliance

The main standard for EMC compliance in the railway industry is BS EN 50121 in its five parts, and in particular part 2 which defines the “Emission of the whole railway system to the outside world”.
A more comprehensive list of EMC directives and standards is provided in Appendix A of this document.

This document is Arcadis’ technical offer to meet the overarching methodology presented on the figure above. Following EMC activities are proposed:

- Item A: EMC Site survey and site testing
- Item B: EMC Hazard Log and EMC assessment
- Item C: Theoretical studies
- Item D: Update of the EMC Control Plan and EMC Technical file
- Item F: Commissioning EMC test

3 Technical proposal

3.1 Item A. Pre-construction EMC site survey

3.1.1 EMC Site measurement strategy

Arcadis will coordinate with the site measurement contractor to establish the EMC site measurement strategy. This document will clarify the location of the sites and the exact types of measurements that will be undertaken.

3.1.2 EMC Site survey

Our technical proposal includes the delivery of the EMC site measurement strategy, EMC site survey and measurements. Some EMC measurements on site prior the start of the works are included at five (5) sites to get a record of the existing EMC background noise in the area, and then make a comparison after construction to bring evidence of the impact of the project on the EMC environment.

The site measurements will be undertaken by a specialised subcontractor with recognised experience in the railway industry.

Figure 2 below provides details of the frequency range covered by the proposed measurements recording the peak hold values and the values for each frequency scan. Each measurement will have multiple scans. 10 scans are usually recommended for railway applications.

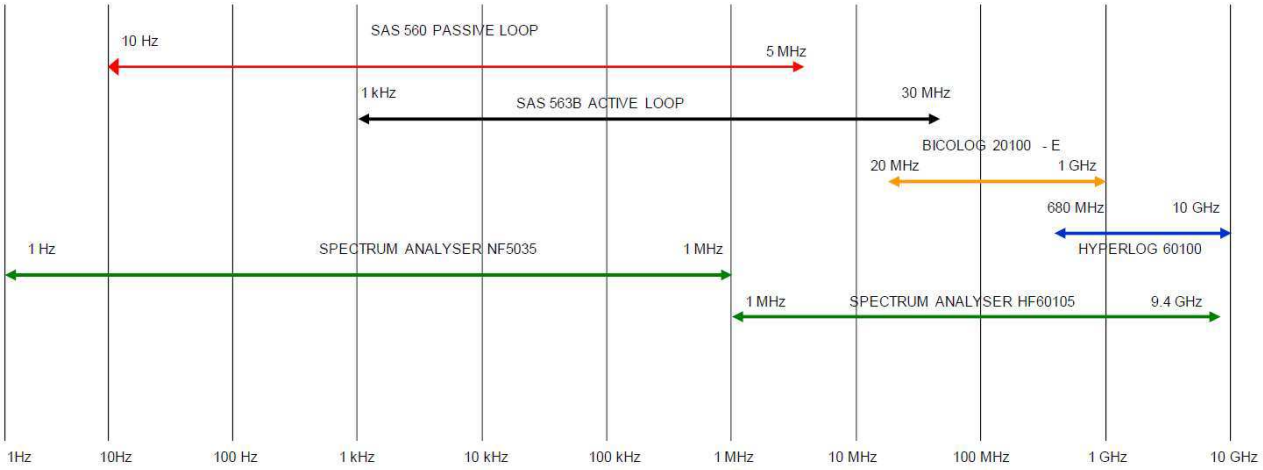


Figure 2. Proposed measurements in each frequency range

3.2 Item B. EMC Hazard Log and EMC assessment

3.2.1 Collating the immunity requirements

The EMC immunity levels of the 'victim' circuits and systems that could be affected by EMI are key input data of the proposed EMC assessment. The immunity levels shall be expressed in relevant parameters and shall cover all EMI sensitive equipment installed in the institutions of Cambridge Biomedical Campus neighbours.

The stakeholders (CBC neighbours) will be asked to provide EMI immunity levels for their equipment. In the absence of such data, the CBC stakeholders will be asked to provide a list of equipment that is deemed susceptible to EMI interference. In the absence of a comprehensive EMC immunity data, the alternative approach is to carry out a survey of equipment and apparatus that are EMI susceptible. In this case, the EMC immunity levels will be derived from the manufacturers data and/or equipment performance specifications.

The equipment will then be categorised into different groups according to their susceptibility to EMI fields. This information will be used to develop the EMC Hazard log.

Note the immunity levels may be classified into the following categories, depending on type of equipment in use:

1. Radiated emission, RFI, high frequency up to 1 GHz
2. Power frequency 50 Hz magnetic fields
3. Trains' harmonic currents magnetic fields
4. ELF & quasi-static DC EMI, some equipment, e.g., NMR and MR, are susceptible to these fields
5. Fast transients

3.2.2 EMC HAZID workshop and hazard log

Arcadis will be the consultant acting on behalf of Network Rail. We will prepare a comprehensive hazard log identifying all possible hazards as shown in the red cells of Table 1. Each of the identified risks will be assessed by estimating a probability of occurrence and severity. The hazard log will include mitigations, applicable standards, and whether the risk can be closed out immediately, or further mitigation actions will be required.

This hazard log will come as a complement to the Hazard log that will be delivered by the GRIP 5 designer.

The hazard log will be reviewed jointly by NR, or its representative, and the CBC stakeholders, or their representatives, in joint workshops.

The workshops will finalise the levels of risk for all hazards identified and shall identify risks that can be closed out immediately by applying relevant actions, such as compliance with standard, installation method, etc. Where a risk cannot be closed out immediately, then this risk will be treated as 'Open Risk', in which case further actions are considered necessary to close it out.

Further scope of work shall be defined depending on the 'Open Risks' identified.

The hazard log and risk assessment are key tasks in the EMC compliance process. The first step is to establish a hazard matrix which links the 'source' to 'victim' equipment and systems.

This EMC Hazard log will use the Railway project's EMC Hazard log as a basis; however, a wider geographical area will be considered to include all the sensitive third-party owned facilities that have been identified above.

Table 1 presents an example assessment of equipment and systems installed on both sides, the railways and CBC neighbours. The green cells, clearly, assume there is internal compatibility between systems that belong to both the railways on one side and the CBC and its neighbours on the other side. The amber cells are equipment and systems that belong to the railways and could be affected by EMI emission from the CBC and its neighbours. It is expected that the amber cells hazards can be closed out relatively easily.

The last remaining set represented by the red cells is where the hazard log to be developed and will be used for demonstration of EMC compliance. For this to be performed, first, it is required to populate the CBC and CBC neighbours equipment list which are expected to be susceptible to EMI. This shall be followed by identifying the hazards associated with the type of interference.

A more detailed risk assessment shall be undertaken for hazards that cannot be closed out immediately, which may require further investigation, test, etc, i.e., mostly for the red cells, and possibly some of the amber cells.

3.2.3 EMC Engineering report

Arcadis will produce a report that will contain:

- The immunity information provided by the stakeholders;
- The hazard log;
- A detailed assessment of the EMC hazards that have been identified;
- The conclusions from the EMC assessment

Victim / Source		CBC / and CBC neighbours								Railway									
		EMI sensitive equipment	NMR equipment	Radio and telecom systems, and others	Lighting	Staff	Other equipment, see section	EM sensitive equipment		Signalling system	Protection and control	Train detection	Other signalling SSI, TPWS, AWS	Copper wires, PA, telephone, SCADA	Station CCTV	Radio GSM-R, Station radio, Wireless coms.	Lighting	Staff	Public
UoC CBC	Source of EMI equipment																		
	NMR/MRI equipment																		
	HV/LV DNO																		
	Radio, telecom, and other systems																		
	Lighting																		
Railway	25kV traction supplies																		
	Rolling stock																		
	Signalling system																		
	LV DNO																		
	HV DNO																		
	Radio GSM-R, Station radio, Wireless Comms.																		
	Lighting																		
	Transients / arcing																		

Table 1 Initial Hazard matrix for UoC neighbours

3.3 Item C. Theoretical Studies

A theoretical study is proposed to:

a) determine the magnetic field levels at 50 Hz power supply frequency.
b) determine the expected magnetic field levels at frequencies above 50 Hz, up to 150 kHz.

This study will assist in quantifying the future expected levels of magnetic fields at the CBC neighbours after introducing changes to the railways. A digital model will be built and calibrated for the existing railway configuration and services against the initial EMC measurements. It is then possible to use the same model to predict the levels of magnetic fields in the future after introducing changes to the railways.

Typical modelling method and magnetic fields calculations surrounding OLE are shown in Figure 4.

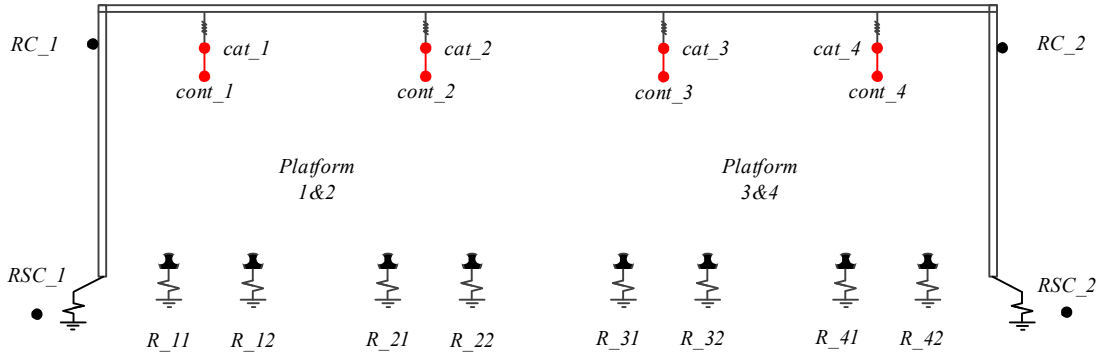


Figure 3. Cut view of a 4-track area

Below presents an example of magnetic field calculations at 50 Hz. This type of output can be used to inform the EMC risk assessment and confirm the level of risk at a given location on or near the railway.

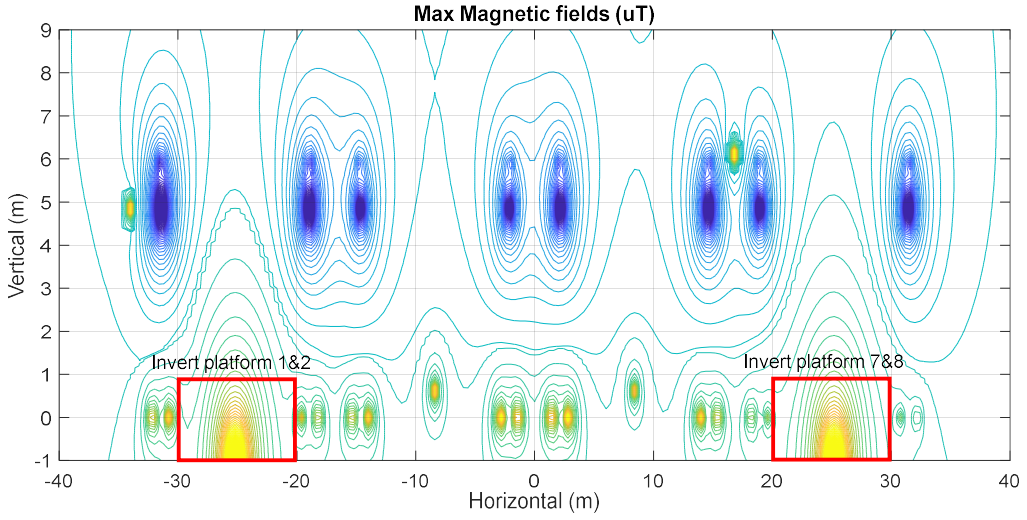


Figure 4 Typical calculation method of magnetic fields surrounding the OLE

3.4 Item D. EMC Control Plan and EMC File

These documents will be continually updated and modified until the end of the project. The EMC file can be used as evidence of compliance by Network Rail, should it be required in the future.

Those documents have been delivered recently on the project and will be kept updated to reflect the findings of all the studies and measurements that are currently being proposed in this technical proposal.

3.5 Item E. Commissioning EMC Test

This test shall be conducted post-construction activities in the same way as that for the initial EMC test specified in section 3.1 above.

The same measurement will be undertaken at the same locations, using the same equipment and the same equipment parameter settings. This will enable a direct comparison between the railways EMC footprint before and after introducing the changes. The two tests will be repeated under the same circumstances and conditions.

Appendix A: Relevant EMC Standards and Guidance

Applicable Legislation

Ref. 1 *Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast)*

Ref. 2 *SI 2016/1091 Electromagnetic Compatibility Regulations 2016 - UK EMC Regulations*

Ref. 3 *2014/53/EU Radio Equipment Directive (RED)*

Ref. 4 *Directive, 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC*

Ref. 5 *Directive 2008/57/EC of the European Parliament and of the Council of 17 June 2008 on the interoperability of the rail system within the Community (Recast)*

Ref. 6 *Directive 2004/49/EC of the European Parliament and of the Council of 29 April 2004 on safety on the Community's railways and amending Council Directive 95/18/EC on the licensing of railway undertakings and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification (Railway Safety Directive)*

Ref. 7 *The Construction (Design and Management) Regulations 2015*

National Standards

Ref. 8 *BS EN 50121-1:2017 - Railway applications — Electromagnetic compatibility — Part 1: General*

Ref. 9 *BS EN 50121-2:2017 - Railway applications — Electromagnetic compatibility — Part 2: Emissions of the whole railway system to the outside world*

Ref. 10 *BS EN 50121-4:2016+A1:2019 - Railway applications — Electromagnetic compatibility — Part 4: Emission and immunity of the signalling and telecommunications apparatus.*

Ref. 11 *BS EN 50121-5:2017+A1:2019 - Railway applications - Electromagnetic compatibility - Part 5: Emission and immunity of fixed power supply installations and apparatus.*

Ref. 12 *BS EN 50122-1:2011+A4:2017 - Railway applications - Fixed installations - Electrical safety, earthing and the return circuit Part 1: Protective provisions against electric shock*

Ref. 13 *BS EN 50122-2:2010 - Railway applications - Fixed installations - Electrical safety, earthing and the return circuit Part 2: Provisions against the effects of stray currents caused by DC traction systems*

Ref. 14 *BS EN 61000-3-2:2019 - Electromagnetic compatibility (EMC) Limits. Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*

Ref. 15 *BS EN 61000-3-4:1998 - Electromagnetic compatibility (EMC). Limits. Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A*

Ref. 16 *BS EN 61000-3-3:2013 - Voltage changes, fluctuations and flicker ... rated current <=16 A per phase*

Ref. 17 *BS EN 61000-3-5:2009 - Voltage changes, fluctuations and flicker ... rated current >16 A per phase*

Ref. 18 *EN 61000-4-16:2015 - EMC test for immunity to conducted, common mode disturbances in the frequency range 0 - 150 kHz.*

Ref. 19 *BS EN 61000-4-11:2004+A1:2017 - Voltage dips, short interruptions and voltage variations (immunity tests)*

Ref. 20 *BS EN 61000-4-14:1999+A1:2001+A2:2009 - Voltage fluctuation immunity test.*

Ref. 21 *BS IEC 61000-5-2:1997 - Electromagnetic Compatibility (EMC) – Part 5: Installation and mitigation guidelines Section 2: Earthing and Cabling*

Ref. 22 BS EN 61000-6-1:2016 - Electromagnetic compatibility (EMC) - Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments

Ref. 23 BS EN 61000-6-2:2016 - Electromagnetic compatibility (EMC) - Part 6-2: Generic standards – Immunity for industrial environments

Ref. 24 BS EN 61000-6-3:2006+A1:2010 - Electromagnetic compatibility (EMC) - Part 6-3: Generic standards — Emission standard for residential, commercial and light-industrial environments

Ref. 25 BS EN 61000-6-4:2018 - Electromagnetic compatibility (EMC) - Part 6-4: Generic standards — Emission standard for industrial environments

Ref. 26 BS 7430:2011+A1:2015 - Code of Practice for Earthing.

Ref. 27 BS 7671:2018 - Requirements for Electrical Installations - IEE Wiring Regulations 17th Edition.

Ref. 28 BS EN 45502-2-1:2004, Active implantable medical devices – Part 2-1: Particular requirements for active implantable medical devices intended to treat bradyarrhythmia (cardiac pacemakers).

Ref. 29 BS EN 50500:2008+A1:2015 – Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure

Ref. 30 BS EN 62305 - Protection against lightning (Part 1:2011, Part 2:2012, Part 3:2011, Part 4:2011)

Railway Group Standards

Ref. 31 GLGN1620 Issue 1 - Guidance on the Application of the Control of Electromagnetic Fields at Work Regulations

Network Rail Standards and Documents

Ref. 32 NR/L1/RSE/30040 Issue 1 – EMC Strategy for Network Rail (formerly NR/L1/SIG/30040)

Ref. 33 NR/L2/RSE/30041 Issue 2 – Electromagnetic Compatibility (EMC) assurance process

Ref. 34 NR/SP/ELP/21085 Issue 4 - Specification for the Design of Earthing and Bonding Systems for 25 kV AC Electrified Lines

Other Relevant Documents

Ref. 35 G5/4-1 Issue 4 - Engineering Recommendation – Planning levels for harmonic voltage distortion and the connection of non-linear equipment to transmission systems and distribution networks in the United Kingdom. (Electricity Association)

Ref. 36 Guidelines on Limits of Exposure to Static Magnetic Fields, ICNIRP, 2009

Ref. 37 Guideline for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz), ICNIRP, 1998

Ref. 38 European Commission recommendation 1999/519/EC - limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)

Ref. 39 T515 Issue 04, Investigation into the Effects of the Electromagnetic Fields Directive on Railways Operations (Rail safety & Standards Board)

Appendix B: Permissible limits (For information)

This section presents the initial threshold EMC limits which will be used to demonstrate EMC compatibility between the railways and the UoC neighbours.

50 Hz Power Frequency

Based on our experience from previous projects, we usually consider that the immunity limit for equipment installed on the railways is 100 A/m, or 126 μT at 50 Hz. However, for sensitive equipment outside railways environment the recommended immunity level is smaller than 1 A/m, in the order of 1 μT. Note, BS EN 61000-6-3 for residential, commercial, & light industrial environment. However, the limit recommended in this assessment is lower as biomedical equipment may have more stringent requirement.

Traction Harmonics

For traction harmonic currents in a frequency range up to 20 kHz (could be extend it up to 150 kHz subject to agreed client requirements), the recommended immunity levels for sensitive equipment must be considerably lower than that for 50 Hz, smaller than 0.3 μT (based on experience from recent projects).

Note, the magnetic fields in this frequency range are determined by traction power supply simulation using the harmonic current injections of trains. This is part of traction supply design and simulation which also include the immunisation study.

ELF and DC and quasi static

For DC and quasi static fields, the recommended immunity level for sensitive equipment is 0.1 μT (based on experience from recent projects). Some of the biomedical equipment could be susceptible to this type of interference.

Transient and Electrostatic Discharge

In railways environment fast transients, the BS EN 50121-4 standard requires ±2 kV. However, for residential and light industrial apparatus BS EN 55024 standard recommends only 0.5 kV. The latter limit will be used. Note, some types of transients may be treated similar to that for the electrostatic discharge since transients such as lightning strike would create large voltage spikes on the OLE.

RFI

The RFI limits is shown in Figure 5. For peak values, the range of the H field is defined between 150 kHz and 300 MHz, and for the E field the range is defined between 300 MHz and 1 GHz, see BS EN 50121-2.

For a frequency range between 9kHz and 150kHz the quasi-peak limits are defined in the superseded 2006 version of BS EN 50121-2 and shown in Figure 6.

Note, quasi-peak levels are weighed values according to the repetition rate and it is always lower than the peaks.

The limits for arcing and power switching transients must be the peak values stated in Figure 5.

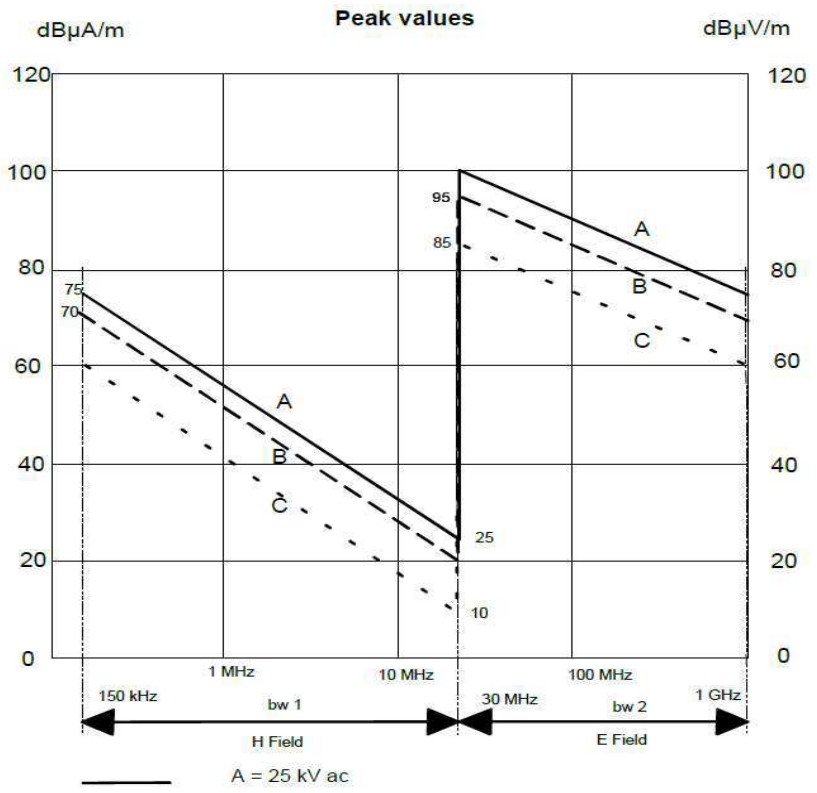


Figure 5 Peak RFI limits stated in BS EN 50121-2

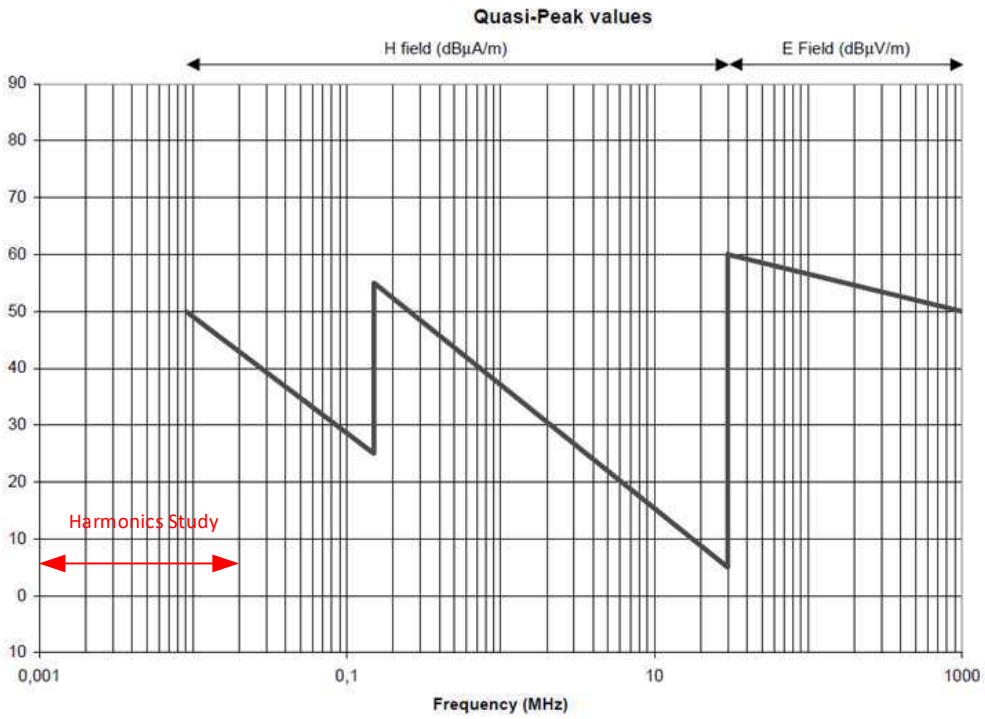


Figure 6 Quasi-peak RFI limits stated in BS EN 50121-2

Appendix C: Detailed methodology for EMC assessment

Arcadis will develop the EMC assessment for Network Rail based on evaluating the mechanisms of EMI coupling, estimates the levels of EMI in susceptible equipment and compare these levels with the maximum permissible limits to demonstrate EMC compliance. The coupling mechanisms and permissible interference levels are described in this section.

Conductive Coupling

Conducted coupling mechanism could take place through indirect galvanic path between the railways and any of the institutes within CBC. This type of coupling is unlikely to materialise as the likelihood of such a path existing is very remote. This however shall be confirmed in the site survey.

Inductive Coupling

Inductive coupling mechanism is through indirect contact between the railways and sensitive equipment within the CBC, and can be in one of the following forms,

a) Power frequency 50 Hz magnetic fields.

This is expected to be the largest magnetic field emitted by the railways. The levels of magnetic fields at this frequency can be determined reasonably accurately using a simulation model as described in the Desktop Theoretical Study (see section below). A maximum limit of 100 A/m is recommended for equipment installed within the railway collider. However, for neighbouring systems within CBC the expected levels of 50 Hz magnetic fields are expected to be considerably lower, and as such this interference mechanism is not anticipated to pose problem.

b) Trains' harmonic currents magnetic fields.

The coupling mechanism of these fields is similar to that for 50 Hz. However, given that the harmonic currents at higher frequencies are considerably lower than the power frequency the expected magnetic fields at higher frequencies are expected to be lower than 50 Hz. Note, although harmonic currents are in the order of a few amps compared with 100 s of amps at 50 Hz, the magnetic coupling is proportional to the frequency, e.g., at 5kHz the inductive coupling coefficient is 100 times than that for 50 Hz. An assessment will be carried out qualitatively in the Desktop Theoretical Study (see section below).

c) ELF and quasi-static DC EMI.

These are DC fields that are slowly changing with time causing what is known as ELF or quasi-static DC. For example, the earth DC magnetic field (which is permanently steady) can be disturbed by a passing train (being large lump of steel) causing ELF and quasi-static DC EMI. Some of the sensitive biomedical equipment, e.g., for NMR equipment the immunity limit is 500 nT p-p and EM it is 30 nT, could be susceptible to these fields.

Both the 50 Hz and harmonic currents magnetic fields shall be measured in the initial test and the commissioning in addition to RFI. It would also be possible to measure the ELF and quasi-static DC EMI in the same tests.

Capacitive Coupling

Capacitive coupling is caused by the virtual capacitance between the OLE and its surrounding. This coupling is not considered an issue due to the relatively large spacing between the source and victim circuits. Also, the OLE voltage is considered medium distribution voltage (compared with HV transmission lines at 132 kV or 400 kV) and have relatively small effect in terms of capacitive interference.

Radiated Coupling

Radiated coupling mechanism through radio interference emission from the railways and coupled into sensitive equipment within the CBC. This type of interference is the most plausible interference if there were to be a credible threat of EMI interference into CBC.

RFI emission in a frequency range up to 1 GHz in steady state (without transients). This type of RFI emission is governed by BS EN 50121-2 “Emission of the whole railway system to the outside world”. Typically, the magnetic fields are measured in the range of 0.15 MHz to 150 MHz and electric fields between 150 MHz and 1 GHz of radio emission where BS EN 50121-2 specifies limits for both types of radio emission. The initial EMC test and the commissioning EMC test will be dedicated to measure the levels of RFI before and after changes to the railway are introduced.

Fast transients

Fast transients, which are temporary, must be assessed individually in conjunction with the levels of immunity of sensitive equipment installed in the CBC. The main transient events include,

a) Inrush Current

Inrush current caused by pantograph bouncing or passing through APC neutral section or TSC change over. The duration of this event could last up to 3 sec with the first peak of the inrush current may reach up to 1000 A. The inrush current waveform is equivalent to a decaying 50 Hz half-wave signal that disappear in 2 to 3 sec. The FFT of such a signal produces 100 Hz multiples which would result in large magnetic fields in the low order frequency range.

b) Power Switching

Switching of trains’ VCB or feeder station CB tripping/closing. These events produce arcing within the power equipment with RFI emitted in the air. Such events can last for 100 s of m-sec. The effect can be sharp EMI for very short durations. This type of emission must be assessed in conjunction with susceptible equipment on a case-by-case bases.

c) Arcing

Pantograph-contact wire arcing. Such events are typical in cold weather conditions where ice on the contact wire results in bad contact between the pantograph and OLE. This may result in high level of EMI which can last for considerable time. This type of emission must be assessed in conjunction with susceptible equipment on a case-by-case bases.

d) Lightning Strikes

The institutions within the CBC must have their own protection as part of the buildings design.

Arcadis Consulting (UK) Limited

80 Fenchurch Street

London, EC3M 4BY

T: +44 (0) 20 7812 2000

arcadis.com