Report

Estimate of DC losses – Electricity Supply Tariff Area Analysis– CP5 proposal

Network Rail consultation
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Disclaimer

Executive Summary

Train operators who use on-train metering on Network Rail's dc electrification network, are charged on the basis of metered energy consumption. All metered energy consumption is marked-up by a factor to take in to account electrical losses. This total consumption is then multiplied by the electricity price to calculate the metered traction electricity charge. All modelled consumption is included in an annual volume wash-up, which reconciles modelled consumption against actual consumption. Metered consumption is not included in the volume wash-up.

Electrical losses consist of a combination of fixed and variable losses. The fixed losses are a constant and occur all the time the network is energised. The variable losses occur when current is flowing, predominantly as a result of trains drawing traction energy.

Network Rail completed studies in 2011 in partnership with the train operating companies (i.e. Southern & South West Trains) which estimated the average value of electrical losses to be 27% for the dc network; this was expressed as an uplift percentage of power used by the train. It was supported by the industry that the value would be set at 27% for the rest of Control Period 4 (CP4)[1].

As part of Periodic Review 2013 (PR13), Network Rail is reviewing the charges it levies on its customers. All final charges are developed in consultation with the industry and are audited and approved by the Office of Rail Regulation (ORR) as part of its periodic review. The PR13 determination will set out the proposed approach for developing the Electric Current for Traction (EC4T) charging framework for implementation from the start of the next Control Period, (CP5)[2].

This report will support Network Rail's work to develop the EC4T charges framework for CP5.

Since 2011, various studies have been commissioned by Network Rail to further understand the driver(s) of electrical losses on the dc network. It has been established that there are many variables that can contribute to electrical losses which make it difficult to scientifically calculate an absolute figure for losses on the dc network. In a commercial environment we consider that the value of losses should be scientifically based. We also consider that an element of engineering judgement and probability, regarding the many variable factors that can occur, is required to determine the appropriate value of losses. In practice, losses will vary year-on-year, driven by factors such as weather conditions and driver behaviour.

As part of the EC4T charging process, the dc electrical network is divided into two main Electricity Supply Tariff Areas (ESTAs) for billing purposes; the southern dc network captures Kent, Sussex and Wessex areas and the standalone Mersey rail dc network. In addition there are three ESTA areas

[1] This is the regulatory period from 1 April 2009 – 31 March 2014.

[2] This is the regulatory period from 1 April 2014 – 31 March 2019.

which are predominantly ac but include small sections of line with both ac and dc supplies; these dual voltage lines account for under 4% of the total dc network.

We are proposing to apply the same losses mark-up to these sections of line as the losses we will apply in the southern ESTA (set out in Table 4). For modelled operators, we propose no change as losses are embedded in modelled consumption rates.

Network Rail's duty under its licence is to manage the network in an "*efficient and economical*" manner and has provided an indicative electrical average of losses across the dc ESTA networks outlined in Table 4 and 5.

Range (MWh per STK)	DC Area [approx. 3,554 STK]	Average I^2R energy loss [TRx, Con & Return rail loss]	Average Fixed energy loss [Insulator & Iron loss]	HV Distribution Network energy loss	Losses mark-up %
300 – 400	Kent	10	2.76	1	15.57
400 – 500	Sussex		1.92		
300 – 400	Wessex		2.73		

Table 4:- Indicative dc % Losses within southern network - ESTA U

Range (MWh per STK)	DC Area [approx. 221 STK]	Average I^2R energy loss [TRx, Con & Return rail loss]	Average Fixed energy loss [Insulator & Iron loss]	HV Distribution Network energy loss	Losses mark-up %
300 – 400	Mersey Rail	6.3	2.02	1	10.26

Table 5:- Indicative dc % Losses within Mersey Rail - ESTA M

Over the last 22 years the dc network's energy consumption has increased at an annual rate of 1.22%. It is anticipated that this level of growth will continue during CP5 with a consequently greater increase in the level of variable dc losses that will not be directly recovered by the fixed losses uplift.

However, in order to provide certainty to train operators who wish to opt-in for on-train metering and the ability to manage their EC4T bills, Network Rail will propose to set dc average mark-ups of 15.57% for ESTA U, P, R & T and 10.26% for the Mersey Rail - ESTA M, for the whole of CP5.

Capping the average level of dc electrical losses at these percentages for the duration of CP5 will also demonstrate a level of incentive to Network Rail to make the necessary efficiency improvements to match the anticipated level of increase in demand. We consider that there may be merit in allowing the mark-up to be reopened in the light of significant new information becoming availble during the CP5 period.

1. Introduction

Network Rail, the infrastructure operator of the GB railway network, is responsible for managing two different types of electrical traction networks. This report will consider the level of electrical losses on the dc network operating at 650/750V on the third rail system. (The ac networks electrical losses were considered and discussed in separate reports and studies, which were published earlier in 2012. The most recent ac losses report was published for consultation in September 2012[3]).

The extrapolation process of the dc electrification losses has been aligned with the EC4T billing system (which splits the ac and dc networks into ESTAs) to provide individual loss assessments for the two dc networks of southern and Mersey Rail.

The output and analysis of this report supports our supplementary consultation on dc losses. This consultation will include a proposal for setting individual percentage uplifts for dc electrical losses for each dc network to reflect the different nature of their infrastructure, traffic pattern and rolling stock.

1.1 Aim and Purpose

This document is intended to support Network Rail's EC4T consultation. It summarises the methodology used and the output enables the extrapolation of the dc losses across the southern and Mersey Rail dc networks.

1.2 Scope

There are currently 20 ESTAs that capture the entire Network Rail network, of which 18 predominately feed the ac network while the remaining 2 feed the dc network. There is a single ESTA capturing the entire southern dc network (i.e. Sussex, Wessex & Kent) with the other ESTA area encompassing Mersey Rail. This report assesses these two dc networks and will examine the geographic disaggregation of the dc losses across the southern network by separate analysis of the Wessex, Sussex and Kent dc networks. The Mersey Rail dc network will be separately analysed.

1.3 Structure

The structure of the document is summarised below;

Section 1 - Introduction - sets out the aims, objectives and the scope of the document.

Section 2 - Background - contains references to historical descriptions of the network

Section 3 - Assumptions and Methodology - provides a brief outline of the methodology adopted and sets out the key assumptions we have made.

Section 4 - ESTA Analysis – details the extrapolation process across the

[3] Network Rail (Sep 2012), "Estimate of AC losses – electricity supply tariff area analysis" accessible here: http://www.networkrail.co.uk/WorkArea/DownloadAsset.aspx?id=30064783490

present ESTA configuration.

Section 5 - CP5 future electrification – this section discusses the impact of possible ac conversion during CP5 with the southern section of the ‘north south spine’ and parts of the Wessex network and the effects it will have on electrical losses.

Section 6 - Conclusion - outlines the main conclusions of the report.

Section 7- Recommendations - outlines the key recommendations with proposals to support the EC4T consultation.

Section 8 - Definition and abbreviations – lists the main definitions and abbreviations within the report.

Section 9 – References – lists the main references within the report.

2. Background

Train operators who use on-train metering on Network Rail’s dc electrification network, are charged on the basis of metered energy consumption. All metered energy consumption is marked-up by a factor to take in to account electrical losses. This total consumption is then multiplied by the electricity price to calculate the metered traction electricity charge. All modelled consumption is included in an annual volume wash-up, which reconciles modelled consumption against actual consumption. Metered consumption is not included in the volume wash-up.

It is necessary to model the network losses under normal timetable operation to confidently determine the losses uplift that should be applied to the energy metered by the train operators within a particular ESTA.

In addition, Network Rail has a duty under its licence to manage the network in an “*efficient and economical manner*” and therefore an inherent duty to demonstrate that electrical losses occurring on the traction system are reduced where economically viable; this requires Network Rail to accurately quantify electrical losses, the metering method is the only way to quantify losses accurately (as the electricity industry does). However, in the absence of meters on the trains, NR has attempted to model the losses as accurately as possible.

Electrical losses consist of a combination of fixed and variable losses. The fixed losses are constant and occur all the time the network is energised. The variable losses occur when current is flowing predominantly as a result of trains drawing traction energy.

Network Rail operates a number of computer models to calculate the energy consumed by trains operating on the dc system. These models are designed to take into account the variables that influence this energy consumption (e.g. train design, driving style, weather, rail wear, etc) and the consequent variability of losses.

Network Rail has used cross industry support to progress further studies on this subject and to this end has commissioned a project, *“Measurement of*

Electrification System Losses". The objective of this report is to carry out a series of on-track measurements on both the southern dc Network [2, 4, 8 & 9] and Mersey Rail network [11, 12 & 13] for comparison with modelled analysis of a similar network. To validate this modelling, Network Rail contracted with a number of third parties to carry out similar modelling exercises [14, 15 & 16].

This report will conclude on and make recommendations regarding:

a) The improvement of the estimation of losses on the dc system;

b) the extrapolation of dc losses separately for the southern and Mersey rail ESTAs; and

c) the potential economically efficient level of dc losses that could be achieved during CP5.

2.1 Electrification system loss dc network

Network Rail & Southern completed studies earlier in 2011 which calculated the value of losses to be 21% as a percentage of input power for the dc network.

The following table is taken from the Network Rail report [1&14] which concluded that 27% was the best estimate for traction losses based on our understanding at that time of loads and system configurations.

This confirmed that the current loss uplift of 27%, as applied during CP4, was appropriate based on understanding at that time, with any over or under recovery being balanced during the volume wash-up process. The report recommended further studies be undertaken to increase our understanding and determine what the appropriate uplift values should be for CP5.

Source	Uplift	Total	HV	Transformer Rectifier	Con rail	Return rail	Leakage allowance
Booz class 377	26.6%	21%	1%	3%	10%	5%	2%

Table 1 Summary of Booz Results – Southern area

3. Assumptions / Methodology

We have established that EC4T losses are a combination of fixed and variable losses across the ac network.

Variable losses (I^2R) are a multiple of the network impedance and the square of the load current and we have modelled various network configurations over discrete periods using numerous timetables [4, 8 & 9].

The dc network's fixed losses have been established using the annual 2011 energy consumption report and extrapolating the fixed loss across ESTAs U & M [6].

The established relationship between the energy consumed (MWh) and the length of the feeding area (STK) enabled the summation of the variable and fixed losses for each GSP and therefore equated to an average loss per ESTA.

In estimating the extrapolation of the total dc losses across the 2 ESTAs the following key assumptions have been made:-

1. The train simulation modelling package (Vision / Oslo) has been validated during Stage 1 of the project [1]. Due to the variable factors influencing losses [5] it has always been difficult to align real time data with modelled data however the report has not applied any uplift on modelled results to actual results.
2. No stabling loads in depots or sidings have been included in our modelling assumptions.
3. Using the Balancing Settlement Metering Code we have assumed metering accuracy at the Network Rail GSPs will all operate to Code of Practice 2, (CoP). The metering accuracy of +/-1% will have a net effect on losses.
4. All on-train metering data will be within the metering tolerances specified in EN 50463[4]. We have assumed the dc metering accuracy of +/- 2% will have a net effect on losses.
5. The regenerative braking aspect with our simulation model has assumed a zero net impact on electrical losses. This will be discussed further in the consultation. (Note; Regenerated power does reduce overall demand but does not impact on the percentage of reduced demand that is lost).
6. We have not accounted for any error with the On-Train Metering (OTM) system errors.
7. We have assumed all energy consumed with our models is related to traction power.
8. In all areas we have assumed conductor rail support insulators are spaced at 6 metre intervals. It is difficult to quantify the amount of insulators across the network but we believe this assumption may be a conservative estimate.
9. We have assumed a transformer rectifier iron loss of 0.25% of the unit's capacity.
10. The ratio of installed polymeric against ceramic insulators is assumed to be 50%.
11. UK climate is changeable over the 4 seasons. The UK receives a considerable amount of rainfall and precipitation from fog and snow. We have demonstrated via our insulator studies the effects that wet conditions have over leakage losses. Using the data from various sources we have calculated a wet to dry annual ratio of 37% (i.e. in a 24-hour period, the insulators will be wet for 8.88 hours).

[4] Euro norm 50463 sets out the European standards for on-train metering equipment.

4. ESTA analysis

Currently within Network Rail's network there are approximately 123 GSPs; approximately 44 are related to the dc network. The GSP is the location of the transformation of transmission voltages that are required for the power to feed the dc traction network. These GSP locations also house the settlement metering devices that support the EC4T billing process

GSPs are then grouped into the two ESTAs for billing purposes. We have established that electrification traction system losses are made up of a combination of fixed and variable losses across the network. As part of the metered billing process, the energy consumed by the train operators is uplifted to account for the electrification traction system losses.

Each ESTA is designated with an alphabetic code where each GSP traction load feeds a section of railway and has a distance measured in STK, therefore grouping the relevant GSPs to make up the ESTAs.

Of the 5 ESTAs with dc traction supplies, there are 3 which incorporate a billing system for dual voltages (i.e. ac and dc networks). In these 3 ESTAs, identified as ESTAs P, R & T, the proportion of dc load is so small (i.e. less than 4%), that the report will propose to apply the loss analysis from ESTA U to these dc lines.

ESTA U is the dc 3rd rail network which operates at 650V-750V and captures the 3 southern routes Sussex, Wessex and Kent. The analysis has identified that the Sussex region is the most heavily loaded in respect of MWh per STK (i.e. 400 to 500 MWh) but the ESTA U dc network has an average MWh per STK range of 300 to 400.

The self contained, ESTA M - Mersey Rail infrastructure, is maintained by Network Rail and is a 750V dc 3rd rail network. The train service, unlike the southern dc network, is more like a metro system which contains 3 separate lines, two of which are electrified (i.e. Northern and Wirral lines). In respect of MWh per STK the Mersey Rail electrified network just falls within the annual load range of 300 to 400 MWh per STK.

The method and analysis in calculating the variable and fixed losses on the dc networks are illustrated in the following sections 5.1 and 5.2 with the estimated extrapolation of the total dc loss across each ESTA U & M identified in Tables 4 and 5 in section 5.3.

4.1 Extrapolation of DC Variable (I^2R) losses

Various traction modelling has been carried out to determine the level of resistive losses (I^2R) based on various timetables and single train simulations during the discrete timetable periods. The simulations capture each electrically fed section (GSP) that forms discrete parts of the Southern (Kent & Sussex) and Mersey Rail networks. The Wessex region has not been modelled due to the modelling time constraints but the Kent & Sussex models provide a good representation of ESTA U as outlined in Section 4.1.1.

4.1.1 Southern Network - ESTA U (I^2R Losses)

The three main discrete modeling simulations captured over the southern network provide a good representation of the southern dc network in order to conclude an average estimate of the I^2 R losses.

The simulations captured 4, 8 & 12 car single train simulations and illustrate the various infrastructure scenarios and the impact on the dc I^2R losses [4}. The Sussex modeling simulation captures low and high density traffic areas across 3 timetabled scenarios, (2007, 2013 & 2018) [8]. While the final modeling simulation report captures approximately 70% of the total energy consumption and approximately 60% STK of the southern dc network. The report utilised pre-K02 timetable information within the simulation [9].

Using the above 3 reports will enable a more informed judgment / estimate in respect of I^2R losses to be put forward during CP5. Although as expected the percentage of resistive losses varies across the different configuration and scenarios as illustrated in Table 2.

Summary Table - ETST U Modelling Simulations							
ESTA U - Single Train Modelling Variable I^2 R Losses			ESTA U - Sussex Multi-Train Modelling Variable I^2R Losses (06:30 - 09:30)			ESTA U - Mult-Train Modelling Variable I^2R Losses (04:00 - 11:00)	
Configuration	% Range	% Median	Timetable	Low Service Density % loss	High Service Density % Loss	Area	% Loss
4 car	4 to 11	7.5	2007	13.3	10.6	Inner London	9.3
8 car	6 to 16	11	2013	12.8	12.2	Outer Sussex	10.7
12 car	9 to 21	15	2018	12.7	11.32	Outer Kent	7.9
Average % modelling loss		**11.17**	**Average % modelling loss**	**12.93**	**11.37**	**Average % modelling loss**	**9.3**

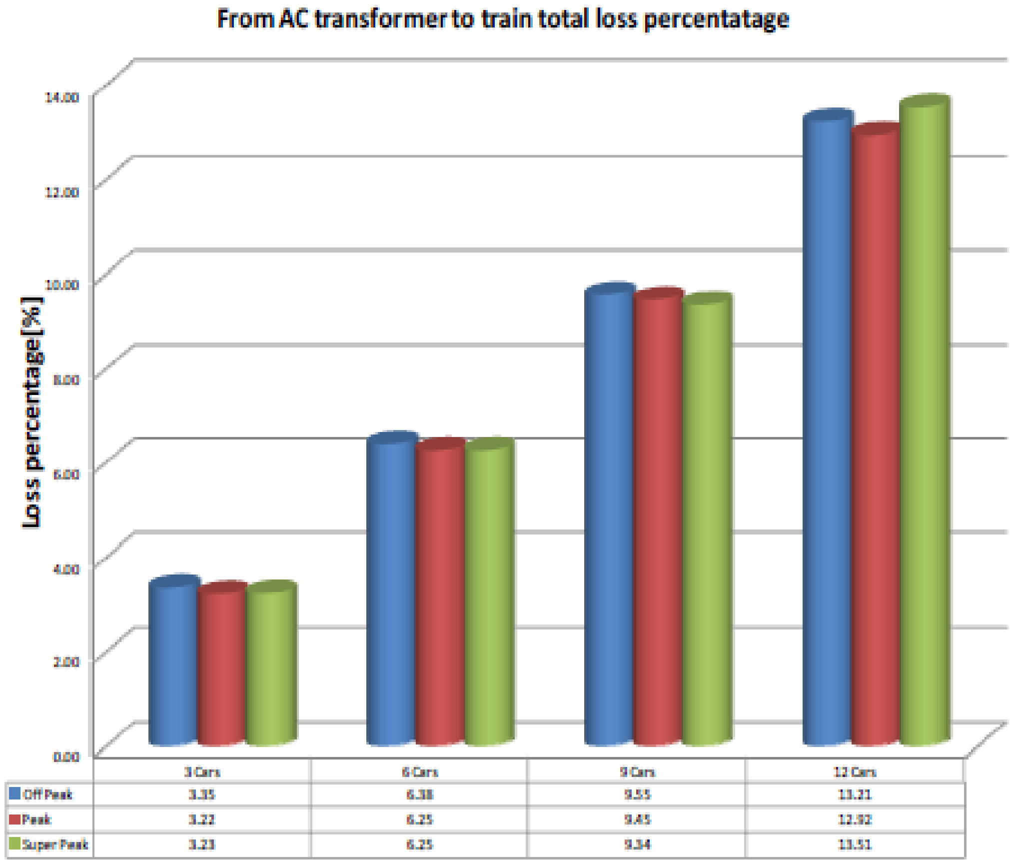
Table 2:- Summary Table – ESTA U Modelling Simulations

In respect of ESTA U, the I^2R average value is based on the average ranges within Table 2. Based on the route knowledge, engineering judgement and probability of the many variable factors it seems that 10% I^2R loss is an appropriate value.

4.1.2 *Mersey Rail - ESTA M (I^2R Losses)*

Network Rail engaged the University of Birmingham to undertake train simulation and transformer rectifier modelling [11,12 & 13]. The final package of works used real time monitoring with support from Network Rail utilising an instrumented infrastructure and train that operated over the Wirral Line under normal traffic.

Analysis of the 3 packages of works from the University of Birmingham provides a good understanding and correlation of the Mersey Rail infrastructure in respect of I^2R losses. Below is an extract graph from the train simulation modelling [12] for different train lengths and timetables on the Mersey Rail dc network. It established that the I^2R losses are proportional to the system load thus increasing the current drawn from the system will increase losses.



In respect of ESTA M, the I^2R average value is based on the average 6 car configurations in addition to the knowledge and engineering judgement and probability of the many variable factors. Therefore, it seems that 6.3% I^2R loss is an appropriate value.

4.2 Extrapolation of DC fixed Losses

Fixed losses on the dc network arise from the current that flows on the network irrespective of the load demand due to primarily transformer/rectifier magnetising and insulator leakage currents.

It is difficult to model and simulate such fixed losses. For this reason, various studies were commissioned in order to calculate each component's electrical loss either via testing or using manufacturer data sheets [6]. From measurement, manufacturer's data and laboratory experiments, the level of loss associated with each of the components of the dc network has been established for both the dc Southern and Mersey Rail ESTAs.

These components are:

1. Transformer rectifier fixed losses
2. Conductor rail support insulator leakage

On both networks the conversion from the ac / dc loss has been captured in the I^2R losses modelling. Therefore, in order to gather the data for each of the components' cumulative electrical losses, a spreadsheet for each GSP was assembled which was supported by the latest infrastructure operational documentation (i.e. Network Rail – five mile diagrams etc). This enabled the correct quantity of components to be assembled per GSP (i.e. quantity of insulators, transformers/rectifiers etc). From this population of components, the fixed loss of each of the two dc ESTA areas has been derived in Sections 4.2.1 & 4.2.2.

4.2.1 Southern Network – ESTA U – Fixed Losses

Using the 2011 electrical energy consumption for each GSP [3], it has been possible to extrapolate an average daily load (kWh) for each Network Rail GSP. By inserting the 2011 average daily loads into the spreadsheet, the estimated 24 hour fixed no load losses for each GSP can be estimated. The average fixed no load loss result for each GSP is then grouped into the respective dc ESTA U and an average fixed no load loss can be estimated below capturing the 3 southern regions.

Sussex Region	
GSP	Fixed Losses %
Ashburton	1.08%
Croydon	0.69%
Dormansland	3.51%
Eastbourne	3.04%
Fishersgate	1.21%
Hunston	2.28%
Three Bridges	1.66%
Average Fixed Loss %	**1.92%**

Wessex Region	
GSP	Fixed Losses %
Aldershot	2.11%
Alton	1.21%
Basingstoke	2.05%
Bournemouth	2.11%
Byfleet	1.38%
Camberley	2.11%
Isle of Wight	11.56%
Leatherhead	2.06%
Reading	2.39%
Southampton	**2.47%**
St Cross	2.82%
Wimbledon	1.10%
Wareham	3.60%
Wymering	1.62%
Redlands	2.01%
Acton (22kV)	3.10%
Average Fixed Loss %	2.73%

Kent Region	
GSP	Fixed Losses %
Ashford	2.64%
Bromley	2.68%
Canterbury	3.88%
Folkestone	3.05%
Hastings	4.43%
Maidstone	5.65%
New Cross	0.90%
Northfleet	1.48%
Sittingbourne	1.72%
Thanet	**2.19%**
Tunbridge wells	1.76%
Queenbourough	Supports Sittingbourne during outage conditions
Average Fixed Loss %	2.76%

4.2.2 Mersey Rail – ESTA M – Fixed Losses

Using the 2011 electrical energy consumption for each GSP [3], it has been possible to extrapolate an average daily load (kWh) for each Network Rail GSP. By inserting the 2011 average daily loads into the spreadsheet, the estimated 24 hour fixed no load losses for each GSP can be estimated. The average fixed no load loss result for each GSP is then grouped into the respective dc ESTA M and can be estimated below in Table 3.

Mersey Rail - ESTA M	
GSP	**Fixed Losses**
Bankhall	1.60%
Bromborough	2.35%
Shore Road	2.11%
Average Fixed Loss %	**2.02%**

Table 3:- Mersey Rail - Average Fixed Losses

4.3 Estimation of Total DC Losses

Due to the many variables that can contribute to electrical losses, it is still not possible to scientifically calculate an absolute figure for a dc traction network loss. In a commercial environment we consider that the value of losses should be based on an element of engineering judgement and probability regarding the many variable factors that can occur [5]. This can aid in determining the appropriate value of losses.

Based on the studies completed to date an average fixed uplift of 15.57% for ESTA U appears a more appropriate value from the earlier work completed in 2011, which was based on the Booz single train runs. Although, under certain parameters, the single train modelling scenarios do coincide with the 2011 values

Furthermore, the dc studies also recognised that it would be appropriate to obtain a stand alone losses uplift for the Mersey Rail network due to its rolling stock and infrastructure configurations. The losses uplift value differs slightly from the southern network and will be proposed at 10.26%.

Network Rail's duty under its licence to manage the network in an "*efficient and economical manner*" has provided an indicative electrical range of losses across the two dc ESTA networks outlined in Tables 4 and 5. The tables have been produced by summating the average range of variable (I^2R) loss and fixed loss with the final column providing a train 'losses mark-up' value for input into the metered billing process.

Range MWh per STK	DC Area [approx. 3,554 STK]	Average I^2R energy loss [TRx, Con & Return rail loss]	Average Fixed energy loss [Insulator & Iron loss]	HV Distribution Network energy loss	Losses mark-up %
300 - 400	Kent	10	2.76	1	15.57
400 - 500	Sussex		1.92		
300 – 400	Wessex		2.73		

Table 4:- Indicative dc % Losses within southern network - ESTA U

Range MWh per STK	DC Area [approx. 221 STK]	Average I^2R energy loss [TRx, Con & Return rail loss]	Average Fixed energy loss [Insulator & Iron loss]	HV Distribution Network energy loss	Losses mark-up %
300 – 400	Mersey Rail	6.3	2.02	1	10.26

Table 5:- Indicative dc % Losses within Mersey Rail - ESTA M

5. CP5 - Future electrification and losses

Under the current electrification enhancement works in CP4 and the proposed CP5 High level Output Specification (HLOS), the electrification network will undergo the greatest expansion of the electric network since the Victorian times.

The HLOS CP5 electrification strategy will impact upon the Southern dc ESTA. The strategy includes the creation of the “Electric Spine”, a high capacity passenger and freight electric corridor running from the South Coast through Oxford, Bedford and via the Midland Main Line to the East Midlands and South Yorkshire, with a link from Oxford to the West Midlands and the North-West. This will create an electrified route linking the core centres of population and economic activity in the Midlands and North with the major container port of Southampton. Notably this will require the ac conversion of the 750V dc line between Southampton Port and Basingstoke.

At this stage, the effect on the dc network losses due to an increased load demand and further electrification is difficult to quantify without the integration of the ESTA configuration network being complete. Although, from the losses work completed to date, a conservative estimate of the dc network’s average losses increasing by 1% throughout CP5 would be a valid assumption.

6. Conclusion

The following can be concluded from this report:-

1. The disaggregation of losses per ESTA outlined in Section 5.3 provides a very useful picture / benchmark on how the losses vary across the dc networks with load.
2. The changes in the ratio of variable losses against fixed losses provides Network Rail with useful information for policy to be reviewed and set to ensure the infrastructure has the minimum set of fixed loss [7].
3. The level of losses on Mersey Rail justifies a separate value of loss uplift.
4. The comparison of loss values between Kent, Sussex and Wessex has shown some variation between areas. However the variation is not sufficient to warrant individual loss uplift values given that in each area there is a similar mix of infrastructure; high current routes, 4 track and 2 track combined with similar traffic densities. The closeness of these comparisons justifies the application of the single loss uplift particularly when it is considered that each operator shares the use of the inner London network which, due to their combined high traffic density, has a high level of losses that cannot be disaggregated between operators.
5. The 3 ESTAs with dual voltage account for a very small percentage (less than 4%) of the overall dc network and are of a similar infrastructure to the Kent, Sussex and Wessex areas. On this basis, this report concludes that the southern dc loss uplift should also be applied in these areas.

7. Recommendations

Recommendations from this report are as follows:-

1. The work undertaken to refine the dc network losses estimates are based on models, testing, component manufacturing data sheets and assumptions. Therefore parts of the analysis may be subjective but Network Rail has used an element of engineering judgement and probability in order to conclude its findings.
2. To provide certainty to train operators who wish to opt-in for on train metering and the ability to manage their EC4T bills, Network Rail will propose to set dc average mark-ups of 15.57% for the Southern area and 10.26% for the Mersey rail area for the whole of CP5.
3. Given that the forecast increase in services will naturally increase the level of loss, Network Rail believes that capping the average level of dc electrical losses at these percentages for the duration of CP5 will also demonstrate a level of incentive to Network Rail to make the necessary efficiency improvements to match such a level of increase in demand. We consider that there may be merit in allowing the mark-up to be reopened for possible reduction in the light of significant new information.

8. Definitions and abbreviations

The following definitions and abbreviations are used within this report.

ac	Alternative current
CoP	Code of practice
CP	Control period
dc	Direct current
DfT	Department for transport
EC4T	Electric current for traction
ECML	East coast main line
ESTA	Electricity supply tariff area
GSP	Grid supply point
HLOS	High level output specification
MWh	Mega watt hours
NR	Network Rail
OTM	On-train metering
ORR	Office of rail regulation
STK	Single track kilometres

9. References

No	Title	Author	Ref	Date
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2	Booz & Company - Quantification of DC Losses :- Report on Class 455 Testing	Wendy Morgan	R01042-007	Sept 2011
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4	Summary of DC System Efficiency – Generic Studies	Michal Taratajcio	TPD-DGN-071-DCEE-REP-0004	2012
5	Factors Causing Variability of EC4T Load and Impact on Losses	Simon Polley	TPD-DGN-LOSS-REP-0007	2012
6	Fixed No Load Loss – ESTA analysis	Kevin Middleton	TPD-DGN-021-LOSS-REP-0008	2012
7	Review of DC Traction Energy Efficiency Proposals	Simon Polley	TPD-xxxxxxxx	2012
8	Network Rail – Electricity Supply Tariff Area	Alan Bullock	Version 2.3	2011
9	DC ESTAs – Resistive Losses Study	Rhoddy Mair	TPD-DGN-021-LOSS-REP-0009	2012
10	Southern DC ESTA – Resistive Energy Losses Study	Michal Taratajcio	TPD-DGN-021-LOSS-REP-0011	2012
11	University of Birmingham Mersey Rail Rectifier Report	Pietro Tricoli, Stuart Hillmansen, Paul Weston.	121025/BCRRE/SH/NR_RECTIFIER_REPORT	2012
12	University of Birmingham Mersey Rail Modelling Report	Stuart Hillmansen, Paul Weston, Shaofeng Lu.	121025/BCRRE/SH/NR_MODELLING_REPORT	2012
13	University of Birmingham Mersey Rail Measurement Report	Stuart Hillmansen, Paul Weston.	121025/BCRRE/SH/NR_MEASUREMENT_REPORT	2012

14	Summary – Measurement of Electrification System Losses – DC Network	Simon Polley	TPD-NST-021-LOSS-REP-0004	2011
15	Electrification System Losses	Chuan Tan	E289-Rw15	Sept 2012
16	DC Traction Power System Losses	A. Denkov	311524/TPN/RCR/00001/A	Sept 2012