DART EXPANSION – RAIL ELECTRIFICATION ASSESSMENT

FINAL REPORT

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1 | INTRODUCTION

1.1 Overview

The National Transport Authority (NTA) and Iarnród Éireann (IE) have commissioned SYSTRA and Jacobs to undertake an assessment of the proposed electrification of the Greater Dublin Area (GDA) rail network, which forms part of the proposed DART Expansion Programme.

This report considers Iarnród Éireann's (IE) strategic objectives around future rail electrification as part of the DART Expansion Programme, which includes the following:

- Developing a short, medium and long-term traction energy strategy both for DART Expansion and the main-line inter-city rail network;
- Establishing a preferred approach for the electrification of rail lines in the Greater Dublin Area for both new and existing electrified lines; and
- Informing the future procurement of long term assets such as rolling stock and infrastructure.

One of the key components of the DART Expansion Programme involves the electrification of existing rail lines as identified in the Government's Project Ireland 2040[1] – National Planning Framework (NPF) and National Development Plan (NDP) 2018-2027 and the NTA's Greater Dublin Area (GDA) 2016-2035 Transport Strategy[2]. This report seeks to identify the issues and solutions associated with the electrification of the GDA rail network with specific consideration given to two electrification options: 1500 V DC and 25kv AC.

There are two principal types of Rail Electrification Systems – the DC (Direct Current) electrification system and the AC (Alternating Current) electrification system. The difference is based on the type of source supply system that is used while powering the electric locomotive systems.

At present, the only part of the Irish rail network that is electrified is the existing DART (Dublin Area Rapid Transit) line. DART consists of a north-south line from Malahide, north County Dublin, to Greystones, County Wicklow with a branch to the peninsula of Howth. A 1500V DC overhead contact system is used to provide electrical energy to the existing DART network. The expansion of the 1500V DC system, therefore, is considered as a viable option for the electrification of the full GDA rail network.

25 kV AC is the most widely used system in new electrification schemes. There are also several instances in Europe and elsewhere where existing DC systems are being replaced with 25 kV AC to accommodate higher levels of heavier rail traffic on urban and interurban networks. Recent examples include announcements in Slovakia and Czech Republic to convert 3kV DC Lines to 25kV AC and the Mumbai project referenced in Chapter 2. The use of 25 kV AC for GDA rail electrification is therefore considered a viable option for the full GDA rail network.

There is currently no overarching policy direction in terms of which is the preferred electrification option, as both options (i.e. 1500 V DC and 25kv AC) provide similar benefits in terms of performance and servicing current and future passenger demand, safety, operational and environmental standards. This report, therefore, seeks to provide information relating to both electrification options in terms of their technical aspects and costs and the consequence of delivering either option in the GDA.

The report is presented in the context of NTA's ongoing Fleet Management Strategy which has implications for any rail electrification strategy chosen.

1 Project Ireland 2040 is the Government's overarching planning policy initiative for development up to 2040. It was published along with its associated documents the National Planning Framework to 2040 and the National Development Plan 2018-2027 in February 2018.

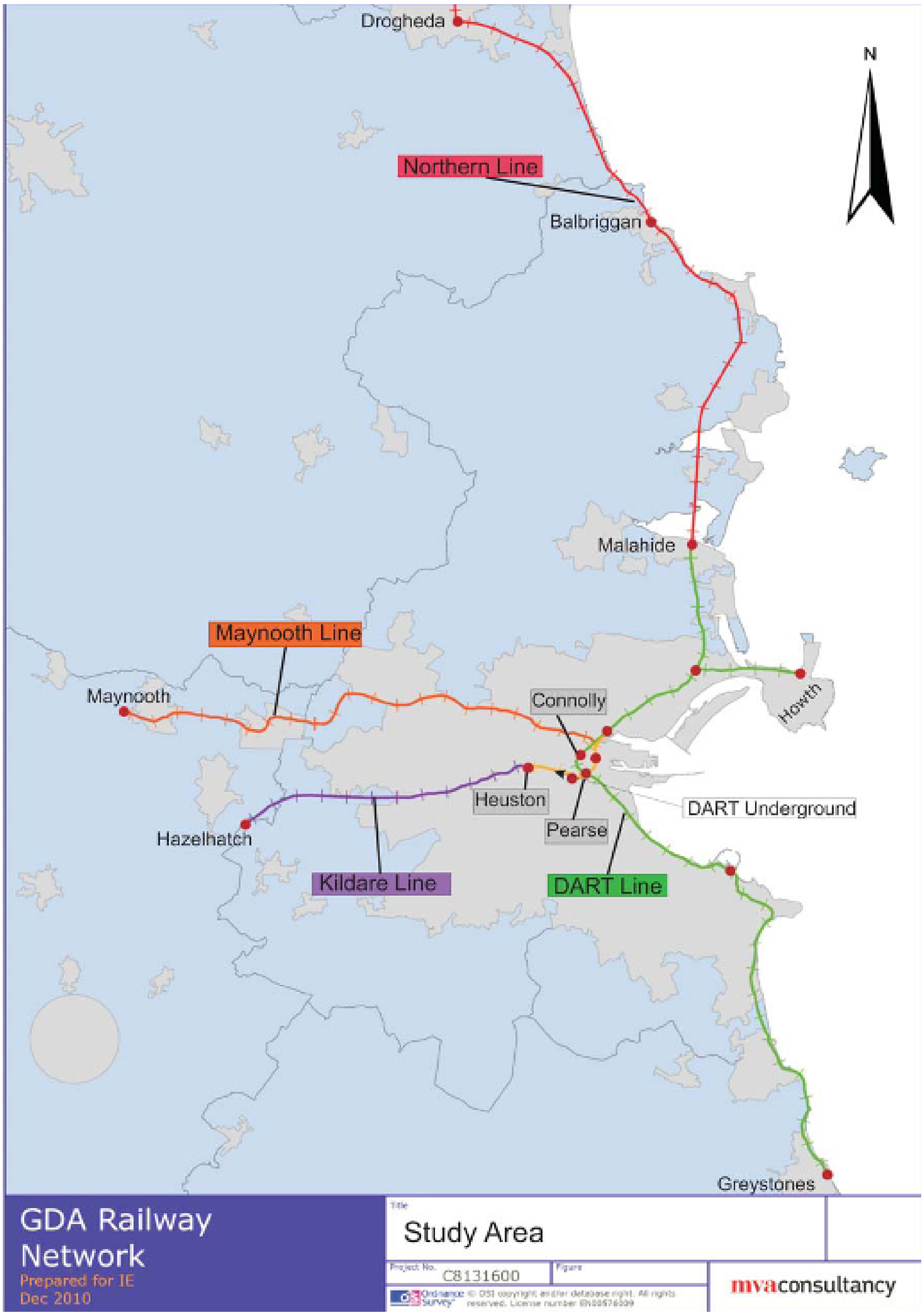
2 The Transport Strategy for the Greater Dublin Area, 2016-2035 was prepared and published by the National Transport Authority in 2016.

1.2 DART Electrification Study 2011

In 2011, a GDA Rail Electrification Study[3] was undertaken to determine a preferred approach for expanding the electrified rail network.

The study was based on the proposed DART Expansion Network at the time which included DART Underground as an integral part of the system, shown below in Figure 1.

Figure 1. 2011 GDA Rail Electrification Network (extracted from 2011 Study)



3 Study on Proposed Electrification in the Greater Dublin Area - Comparison and Ranking of Electrification Options - 2011

This study focussed on the two electrification options of 1500 V DC and 25 kV AC and assessed which option (or combination of these options) would be the most appropriate in the context of the DART Expansion Network.

The simplification of the network into the two segregated corridors (described above) meant that only a limited number of electrified network combinations needed to be considered.

The 2011 Study, therefore, assessed four options:

- Option 1 – 1500V DC system from Hazelhatch to Drogheda (assuming 7.5km DART Underground at 1500V DC) and Connolly to Maynooth was electrified to 1500V DC;
- Option 2A – an 25kV AC system from Hazelhatch to Drogheda (assuming 7.5km DART Underground at 25kV AC), where the current 1500V DC DART line between East Wall Junction and Malahide remained as 1500V DC and Connolly to Maynooth was electrified to 1500V DC).
- Option 2B – the same as Option 2A except that the 1500V DC DART line between East Wall Junction and Malahide was converted to 25kV AC system; and
- Option 3 – the entire Greater Dublin Area (GDA) network was electrified at 25kV (assuming 7.5km DART Underground at 25kV AC).

Options 1 and 3 assumed full electrification of the GDA rail network in either 1500 V DC or 25 kV AC whilst Options 2A and 2B assumed a combination of both electrification options.

Following a detailed technical and cost assessment, the 2011 GDA Rail Electrification Study concluded that:

Option 1, which was an extension of the existing 1500V DC over the whole GDA rail network, was the preferred option from the 2011 GDA Rail Electrification Study.

1.3 Changes since the 2011 GDA Rail Electrification Study

A number of changes have occurred since the 2011 Study which could affect the electrification recommendation outcome from this study. These changes relate to the GDA rail network and to other changes such as advancements in rail electrification technology.

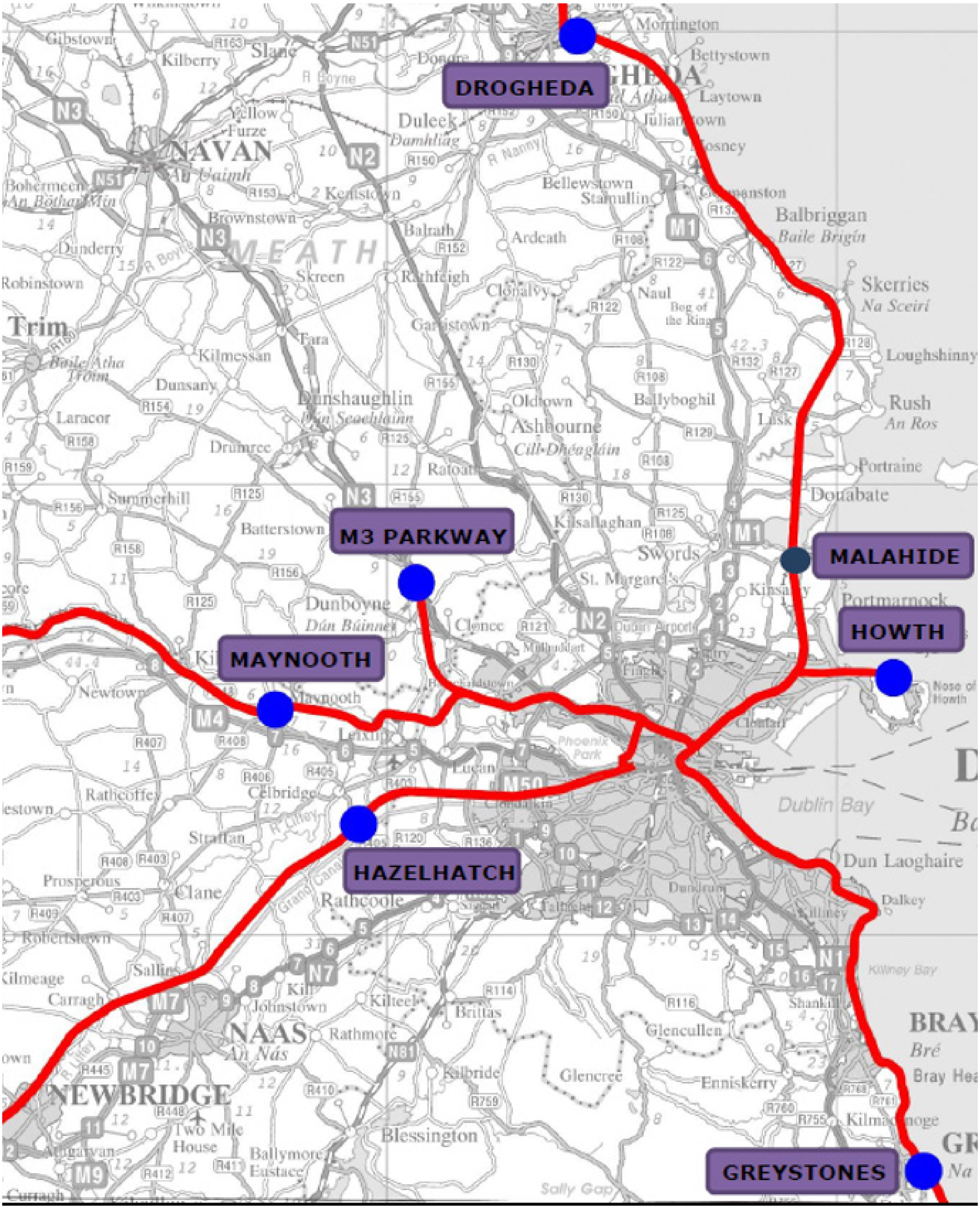
Changes to the GDA Rail Network

The GDA Rail Network has undergone changes since the 2011 Study was undertaken. They include the re-opening of the Phoenix Park Tunnel (described in more detail in Section 1.8) and the M3 Parkway Extension off the Maynooth Line.

The Phoenix Park Tunnel (PPT) is now integrated into the DART Network, with Connolly as the major hub between the lines. The PPT was not part of the rail network that was considered in the 2011 Study. The implication of this is that DART Underground (described below in more detail in Section 1.8) is not a short to medium component of the DART Expansion programme and is not required to be in place to allow GDA electrification to proceed. DART Expansion is to be delivered as a programme of projects which requires potential segmentation of the electrification schemes so that individual lines can be progressed independently, with each line intended to have uniform design and equipment specified throughout.

The proposed network for DART Expansion is shown on Figure 2 below.

Figure 2. 2018 Proposed GDA Rail Electrification Network



The length of rail lines across the GDA Network are given in Table 1 below.

Table 1. Approximate Length of Rail Lines in GDA Network

RAIL LINE	LENGTH (KM)
SE/Greystones	30
Maynooth	40
Hazelhatch	20
Malahide	20
Drogheda	40
TOTAL LENGTH OF NETWORK	150

Other Changes Considered

Other changes that have a bearing on the 2011 electrification recommendation include:

- Advancements in rail technology;
- Advancements in electrical power supply technology;
- Changes in electrical grid supply capacity and availability;
- Life expectancy of the existing electrified sections; and
- IE current rolling stock and future strategy.

This report considers the above changes since the 2011 study, with specific consideration to the effect of:

- Phoenix Park Tunnel integration into the DART Expansion network, with Connolly Station acting as the major hub connecting the lines;
- DART Expansion to be carried out as a programme of projects which requires potential segmentation of the electrification schemes so that individual lines can be progressed independently;
- DART Underground to remain as a future, longer term requirement; and
- Redundancy of power supplies for the revised network.

1.4 Background to the DART Expansion Programme and DART Electrification

The DART Expansion Programme consists of a number of investment projects that will significantly expand the heavy rail capacity, frequency and connectivity in Dublin city centre and throughout the GDA. A number of the key projects are listed below:

- Electrification & Resignalling of the Cork Line to Hazelhatch;
- Completion of 4 tracking from Park West to Inchicore;
- Electrification & Resignalling of the Northern Line to Drogheda;
- Electrification & Resignalling of the Sligo Line to Maynooth, together with the removal of level crossings and re-signalling on this line; and
- Expansion of fleet and depot facilities.

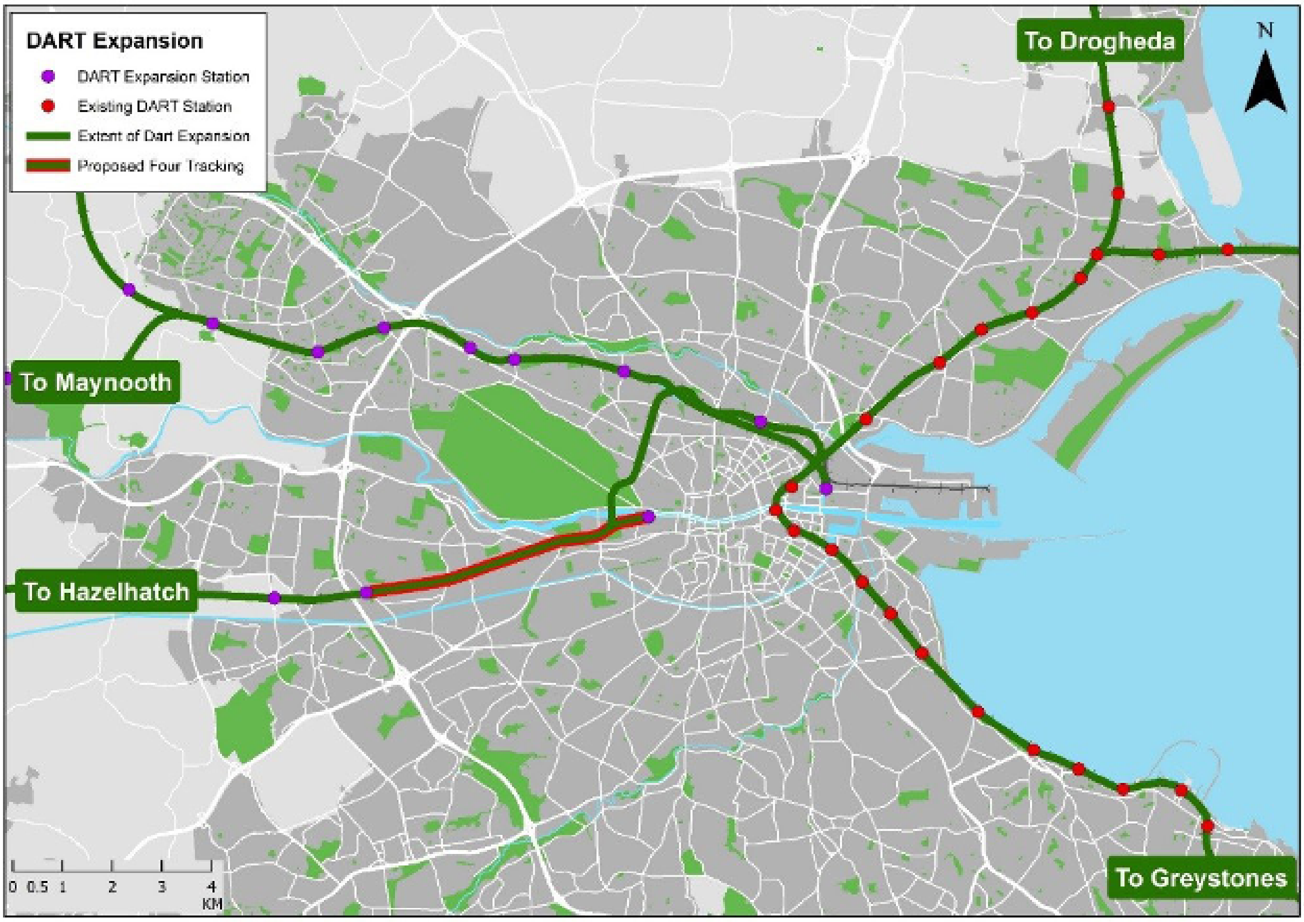
A key part of the DART Expansion Programme is the DART Underground project, which is a rail link proposal consisting of a 7.6km underground tunnel through Dublin city to link the Northern Line to the Cork Line. However, due to the significant cost of the underground tunnel element (DART Underground) and recognising that a lower cost alternative for the tunnel element may be possible, the NTA deferred the tunnel element in the current National Development Plan (NDP) and recommended that the DART Underground Project be re-examined in order to deliver the required rail connectivity in the Dublin with a lower cost technical solution.

The current scheme seeks to maximise the transport benefits of the DART Expansion Programme earlier at a lower cost while retaining the option to add the DART underground tunnel in the future. To this end, a separate study is underway to identify a lower cost DART underground tunnel component and protect the route for possible future implementation.

The DART Expansion Programme has strong policy support at European, national, regional and local level. It is a pre-identified project on the Core Network Corridors in the Connecting Europe Facility (CEF) and a priority project in the Trans-European Transport Network (TEN-T).

Electrification of the GDA rail network offers improved energy efficiency, lower emissions and lower operating and life-cycle costs – while providing quicker, quieter and smoother journeys for passengers. Currently only the Malahide/Howth – Connolly – Greystones DART line is electrified (in 1500 V DC).

Figure 3. Extent of DART Expansion Study



1.5 Project Ireland 2040

Project Ireland 2040 is the overarching policy and planning framework for the social, economic and cultural development of the State. It includes a detailed capital investment plan for the period 2018 to 2027, the National Development Plan 2018-2027, and the 20-year National Planning Framework 2040.

By 2040, an additional one million people will live in Ireland (with an additional half a million homes needed) – with supporting transport infrastructure required to ensure that planned, compact and sustainable growth is delivered in the Greater Dublin Area. One of the ten Strategic Outcomes of *Project Ireland 2040* is Sustainable Mobility.

> "An environmentally sustainable public transport system will enable economic growth and meet significant increases in travel demand while contributing to our national policy of a low-carbon economy. We will see a decisive shift away from polluting and carbon-intensive propulsion systems and investment in public transport will include the Metro Link in Dublin, priority elements of DART expansion, and BusConnects programme..."

The **National Development Plan 2018-2027** (NDP) identifies €8.6 billion public investment in environmentally sustainable public transport systems in major urban areas as one of its Strategic Investment Priorities – delivering compact growth and achieving climate action objectives while improving the choice and experience of the travelling public, connecting people with more places and easing urban congestion.

As part of the NDP, a number of heavy and light rail transport projects will be delivered in the Greater Dublin Area up to 2027, including:

> "Delivery of priority elements of the DART Expansion Programme including investment in new train fleet, new infrastructure and electrification of existing lines."

1.6 NTA Greater Dublin Area (GDA) Transport Strategy 2016-2035

The NTA is tasked with the responsibility of developing the public transport network in the GDA and in 2016 published its future vision for the GDA transport network – *The Transport Strategy for the Greater Dublin Area 2016-2035*. The Strategy provides the framework for the planning and delivery of transport infrastructure and services in the Greater Dublin Area up to 2035. The Strategy was adopted as a statutory document in April 2016, providing a firm basis to all agencies involved in planning for the future development of this region.

Significant investment is planned for the GDA to help increase public transport mode share in the region. The infrastructure schemes recommended as part of this Strategy are:

- DART Expansion Programme;
- Proposed new Metro North and Metro South (referred to as MetroLink);
- Extension of Luas Cross City to Finglas, extension of the Luas Red Line further East to Docklands and a new Lucan Luas line;
- A Bus Rapid Transit (BRT) Network with two cross city lines from Clongriffin to Tallaght and Blanchardstown to UCD, and a further line connecting Swords to the City Centre via Dublin Airport;
- Extension and improvement in cycling infrastructure; and
- Development of strategic rail-based park and ride facilities.

As part of the Strategy, the DART Expansion Programme was again identified as a key public transport intervention required to serve the future transport demand needs of the GDA region.

The GDA Transport Strategy states that:

> "The DART Expansion Programme which is a cornerstone project of the Strategy, will see the DART system expanded, providing fast, high-frequency electrified services to Drogheda on the Northern Line, Hazelhatch on the Kildare Line, Maynooth and M3 Parkway on the Maynooth/ Sligo Line, while continuing to provide DART services on the South-Eastern Line as far south as Greystones".

The Transport Strategy reaffirms the need for the DART Expansion Programme and sets out the parameters and geographical extent of the programme – including the electrification of rail lines to Drogheda, Maynooth and Hazelhatch as well as the continuation of DART services to Greystones.

1.7 DART Expansion Programme

Building on the recently opened connector tunnel under the Phoenix Park, the DART Expansion Programme includes the following projects (listed in indicative sequencing of investment outlined in the National Development Plan).

- Additional rolling stock for the DART network to provide enhanced passenger capacity;
- Measures including re-signalling, junction and station changes to provide expanded services;
- Provision of fast, high-frequency electrified services to:
    - Drogheda on the Northern Line;
    - Celbridge/Hazelhatch on the Kildare Line;
    - Maynooth and M3 Parkway on the Maynooth/Sligo Line (together with the removal of level crossings and re-signalling on this line);
- Completion of 4 tracking from Park West to Heuston;
- New stations to provide interchange with the bus, LUAS and Metro networks; and
- Expansion of fleet and depot facilities.

The indicative DART Expansion Project Management Delivery Framework is indicated in Table 2 below. Underpinning delivery of all of these Work Packages is the determination of the preferred Rail Electrification Strategy for the network.

Table 2. DART Expansion Delivery Framework

WORK PACKAGE	ITEM
1. Rolling Stock	1.1 Procure new fleet
2. City Centre Enhancements	2.1 Connolly reconfiguration 2.2 Docklands location / upgrade 2.3 Junction remodelling including Glasnevin interchange with Metrolink
3. Maynooth Line	3.1 New depot 3.2 Close level crossings 3.3 Electrify Line 3.4 Re-signal 3.5 Overbridge modifications
4. Kildare Line	4.1 Complete 4 tracking 4.2 Electrify line 4.3 Re-signal 4.4 Bridge works 4.5 New stations at Kylemore/Cabra 4.6 Upgrade Phoenix Park Tunnel 4.7 Modifications to track, signalling and station infrastructure
5. Northern Line	5.1 Electrify line 5.2 Re-signal 5.3 Station revisions Clongriffin / Howth Jnct 5.4 Upgrade Drogheda depot 5.5 Re-model Fairview depot
6. Southeast Line	6.1 Address road conflicts restricting capacity 6.2 Provide improved turnback facilities 6.3 Tara Station upgrade
7. DART Underground	7.1 Establish DART Underground route for delivery in longer term 7.2 Protect the Route

The DART Expansion Programme will deliver an improved integrated rail network, providing a core, high-capacity transit system for the Greater Dublin Region and deliver a very substantial increase in peak-hour capacity on all lines from Drogheda, Maynooth, Celbridge/Hazelhatch and Greystones.

1.8 Other Transport Considerations

The public transport landscape in the GDA is evolving, with changes including the completion of a number of rail and Luas schemes and planning regarding MetroLink.

These schemes are outlined below and are considered within the context of the overall DART Expansion & Electrification Programme – in terms of dependencies and / or opportunities for interchange and increased public transport patronage:

- The City Centre Re-signalling Project (CCRP);
- The re-opening of the Phoenix Park Tunnel (PPT);
- DART Underground;
- Luas Cross City;
- MetroLink[4];
- BusConnects[5]; and
- Iarnród Éireann 2030 Rail Network Strategy Review

City Centre Re-signalling Project (CCRP)

One of the key constraints on the existing rail network is the limitation on train paths through the Dublin city centre section between Connolly and Grand Canal Dock stations. In particular, the Loop-line Bridge (LLB) section between Connolly and Tara Street stations was previously restricted to 12 train paths per direction per hour. The City Centre Re-signalling project provides for significant capacity enhancement through this section – by upgrading signalling and turn-back facilities to accommodate up to 8 additional train paths per direction per hour (i.e. up to a total of 20 train paths per direction per hour train paths per direction per hour) in this critical city centre area.

This is a key project aimed at unlocking the existing major bottleneck in the city centre, which will have a positive impact for DART, Commuter and Intercity passengers. It provides the necessary capacity through the city centre to cater for other projects within the Greater Dublin area, including the Phoenix Park Tunnel (PPT) Link. The re-signalling project extends from Howth in the north to Grand Canal Dock in the south. This project sees the installation of a state of the art signalling system together with the construction of required turnback facilities at Grand Canal Dock station – providing significant capacity enhancements and improved journey times for rail passengers through the city centre.

Implications of CCRP on the DART Expansion and Electrification Programme:

- **Improved journey times for rail services via the city centre**
- **Increased train paths through city centre and on the Loop-line bridge**
- **Critical to enabling the future expansion of the DART network.**

Phoenix Park Tunnel (PPT)

The completion of the major signalling works described above, together with other engineering works, has facilitated the commencement of commuter services using the Phoenix Park Tunnel (PPT) Link from the Cork/ Kildare line to Connolly and through to Grand Canal Dock station since November 2016.

Under the previous configuration of the Irish Rail network, rail services entering Dublin City had to terminate in Heuston Station, with passengers wishing to access the commercial core of the city or Connolly required to transfer to bus or Luas Red line from Heuston station. Services accessing Heuston Station include a mix of Intercity trains from Cork, Waterford, Limerick and Galway, as well as commuter services from Kildare, Carlow, Newbridge and Portlaoise. The redevelopment of the PPT now gives rail users travelling into Dublin Heuston greater choice and frequency of services, with the option of travelling on to Drumcondra, Connolly, Tara Street, Pearse and Grand Canal Dock stations.

The PPT is a twin-track line that runs from Islandbridge junction, just west of Heuston Station (Platform 10), to Connolly Station and the North Wall, via the Phoenix Park Tunnel. The line crosses over the River Liffey and passes under the Phoenix Park in a 692-metre-long tunnel (constructed in 1877) and continues northwards through Cabra in cutting. It then runs under the Maynooth line before heading eastwards to Glasnevin Junction, where it joins the Maynooth line. The line then continues eastwards through Drumcondra Station and onwards to Connolly Station. The line can also access the North Wall via the North Strand Junction on existing tracks that are

4 MetroLink is the combined New Metro North and Metro South metro scheme proposed to run from Swords to Sandyford with an anticipated year of opening of 2027

5 BusConnects is a project, run by the NTA, to overhaul the current bus system in the Dublin Region (https://www.busconnects.ie/about/)

currently only used for freight movements.

The PPT line has performed very well since its re-opening in November 2016, with four inbound and three outbound trains operating in the AM period (7am-10am) and the reverse in the PM. This provides a two-way capacity of approximately 2,000 passengers over each peak period, with the trains generally full.

Catering for the increased traffic through the PPT line is one of the challenges under the DART Expansion program.

DART Underground

In Spring 2018, the National Transport Authority (NTA) commissioned SYSTRA and Jacobs to undertake an extensive transport modelling and Options Appraisal to identify and determine preferred options for a lower cost alternative to the proposed DART underground tunnel component of the DART Expansion programme. The Options Appraisal also seeks to maintain similar transport user benefits as the original DART Underground scheme and to maintain all other elements of the DART Expansion Programme. The recommended Option following this Appraisal is 'Scheme Bundle 6 – DART Expansion with Existing Network Enhancement (no underground tunnel)' and includes the following elements:

- New station at Kylemore on the Kildare line;
- Interchange with Metrolink;
- Upgrading of Newcomen Junction to a permanently open junction through the installation of a Canal Drop Lock;
- Re-opening of East Wall Junction and North Strand Junction to commuter and DART services;
- Re-configured Connolly Station;
- New Docklands Station further to the south; and
- A new turnback facility at Dun Laoghaire Station

The implications of the recommended Bundle 6 – DART Expansion with Existing Network Enhancement (no underground tunnel) are considered as part of the appraisal of options for the Electrification Programme.

In terms of electrification, the provisional design for DART Underground is 1500V DC. with passive provisions for future upgrade to 25kV AC.

Luas Cross City (LCC)

The Luas Cross City (LCC) scheme opened in December 2017 and comprises a north / south light rail tram line extending from St. Stephen's Green in the south to Broombridge in Cabra to the north. Luas Cross City connects the Green and Red Luas lines, providing interchange opportunities with the Maynooth heavy rail line at Broombridge in Cabra and the Phoenix Park Tunnel rail commuter services.

Proposed MetroLink

The MetroLink project is the development of a north-south Dublin urban railway service between Swords and Sandyford, connecting key destinations including Dublin Airport and the city centre. It is currently proposed to use a 1500 V DC system. Journey time will be approximately 50 minutes with proposals for 25 stations (including 15 new stations).

The draft Emerging Preferred Route (EPR) identifies stations connecting to the DART system at Tara Street and to the Maynooth and Kildare heavy rail lines at Glasnevin station. The Glasnevin MetroLink station provides a 3-way interchange for the Maynooth and Kildare (via PPT) heavy rail lines with MetroLink – facilitating access from the west of Dublin to the Airport (in the north) and the City Centre (in the south).

Bus Connects

The proposed BusConnects programme aims to overhaul the current bus system in the Greater Dublin Area. BusConnects will provide improved lower carbon bus services, frequency and capacity while supporting multi-modal ticketing and enabling improved interchange opportunities between bus and the heavy rail network.

Iarnród Éireann 2030 Rail Network Strategy Review

The focus of this 2030 Rail Network Strategy Review is on the future development requirements of the Iarnród Éireann InterCity Network (ICN) and the regional services. The strategy acknowledges that competition between InterCity services and GDA commuter services will exist, particularly during the peak periods.

Rail electrification of InterCity lines is considered as part of the strategy review. Dublin to Cork scores best under the cost-benefit appraisal, however, the study concludes that electrification of InterCity lines is seen as a longer term strategic objective. A big factor in this outcome is the long life expectancy of the InterCity Fleet currently used in operations.

It is worth noting that the study was undertaken in 2011 during a time of economic downturn.

1.9 Structure of Report

- **Chapter 2:** This chapter gives an outline of the history of DART electrification in the Greater Dublin Area (GDA) to date, along with the operational context of the existing GDA rail network
- **Chapter 3:** This chapter introduces rail electrification along with an overview of the AC and DC Electrification options and their applications in an international context
- **Chapter 4:** This chapter outlines the evaluation methodology for assessing the electrification options.
- **Chapter 5:** This chapter involves the technical evaluation of the electrification options.
- **Chapter 6:** This chapter involves the cost evaluation of the electrification options.
- **Chapter 7:** This chapter outlines the main considerations associated with 1500 V DC and 25 kV AC options and their pros and cons.

2 | EXISTING RAIL ELECTRIFICATION IN THE GDA

2.1 Dublin Rail Rapid Transit Study (DRRTS)

In 1975, the Dublin Rail Rapid Transit Study (DRRTS) investigated the options of which power supply system to be used for the DART, in terms of safety, capital costs and running costs. The options considered, along with the reasons which helped determine the final electrification system for the DART, were as follows:

- An AC overhead system (25KV) was discounted as trains would have been required to carry a heavy transformer, therefore needing to draw more electrical power to match the performance of a similar DC powered train. This option would have increased running costs in both terms of electricity and maintenance. The initial purchase cost was also higher for suitable rolling stock.
- A 750V DC 3rd rail system was assessed as an option. A third rail is a method of providing electric power to a train via a conductor placed alongside or between the rails of a railway track. As 3rd rail systems are always supplied from direct current electricity, they are typically used in rail corridors segregated from the outside environment. This option was discounted as it required a significant number of substations. It also presented significant safety issues (as there is a lethal live conductor rail which is accessible to the public from a station platform). Ice on the conductor rail was also identified as an issue.
- 1500V DC was chosen as the optimum solution requiring only half the number of substations of the 750V DC 3rd Rail solution, while providing a much safer overhead wire system than 750V DC without the penalty of a heavy and expensive transformer. At the time of the Study, 1500V DC also offered preferential acceleration performance in comparison to the AC option – one factor related to this was due to the suburban nature of the DART line (where stations are in close proximity to each other) compared to a regional rail line (where stations are located further apart).

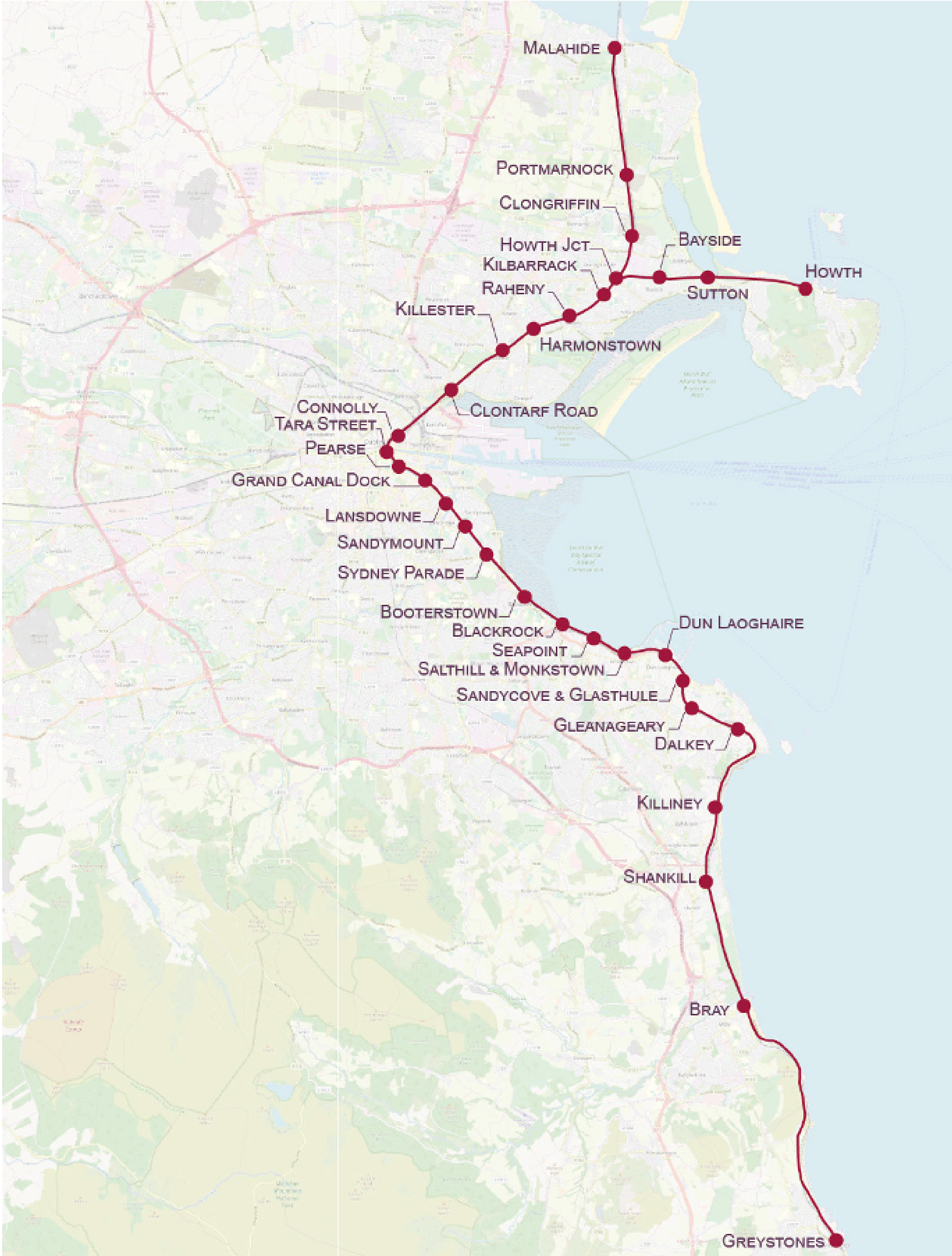
Based on the DRRTS study phase one of the project (the Bray to Howth DART line) was built using 1500V DC power supply.

A brief timeline of the development of DART line is outlined below:

- 23 July 1984: Howth – Bray;
- 10 April 2000: Bray – Greystones;
- 09 Oct 2000: Howth Junction – Malahide;
- 01 Sept 1997: Clontarf Road station added; and
- 22 Jan 2001: Grand Canal Dock station added.

A map of the existing DART is shown in Figure 4 below.

Figure 4. Existing DART Electrification



3 | OVERVIEW OF RAIL ELECTRIFICATION

3.1 An Introduction to Rail Electrification

A railway electrification system supplies electrical energy to railway locomotives and multiple units so that they can operate without having an on-board prime mover. In a diesel locomotive, the prime mover is the diesel engine, whereas an electric locomotive has no prime mover, relying instead on an external power supply.

Compared to diesel engines, electric railways offer substantially better energy efficiency, lower emissions and lower operating costs. Electric trains are more efficient and reliable, offering the following benefits for rail operators and passengers:

- **Lighter and quicker** – rolling stock on electrified lines don't need to carry their own fuel and are therefore lighter than diesel powered trains. They are, therefore, able to accelerate faster and offer quicker, quieter and smoother journeys.
- **More environmentally friendly** – electric traction is efficient and represents a lower cost energy source when compared to diesel. Electric traction will assist in the national transition away from fossil fuels towards a low carbon economy.
- **Lifecycle costs** – the life cycle cost of a diesel train compared to an electric train is significantly greater as total cost of ownership (i.e. maintenance costs of both the rolling stock and the line) are much greater. Rolling stock maintenance costs were estimated to be 30-35% lower for electric trains and line maintenance costs were identified as approximately 60-65% lower in the DART Expansion Options Assessment Study.

Reflecting the trend towards electric mobility in rail transport, and the gradual move away from diesel power, railway electrification has increased steadily in the past decades. Of around 1.3million km of rail lines worldwide, around 344,000 km are electrified, i.e. just over a quarter. The degree of electrification varies from 1 percent (North America) to 57 percent (Western Europe). Electrification in Asia has risen substantially in the last few years – in 2013 it was 34 percent, but by 2017 it had reached 47 percent – driven by investments in the rail network in China and India[6].

There are two principal types of Rail Electrification Systems – the DC (Direct Current) electrification system and the AC (Alternating Current) electrification system. The difference is based on the type of source supply system that is used while powering the electric locomotive systems – please see Section 3.2 for further details.

At present, the only part of the Irish rail network that is electrified is the existing DART (Dublin Area Rapid Transit) line. DART consists of a north-south line from Malahide, north County Dublin, to Greystones, County Wicklow with a branch to the peninsula of Howth – as illustrated in Chapter 2. A 1500V DC overhead contact system is used to provide electrical energy to the existing DART network.

3.2 Rail Electrification Systems - Alternating Current (AC) and Direct Current (DC)

A rail electrification system consists of a traction power supply system, traction power distribution system, and traction power return system.

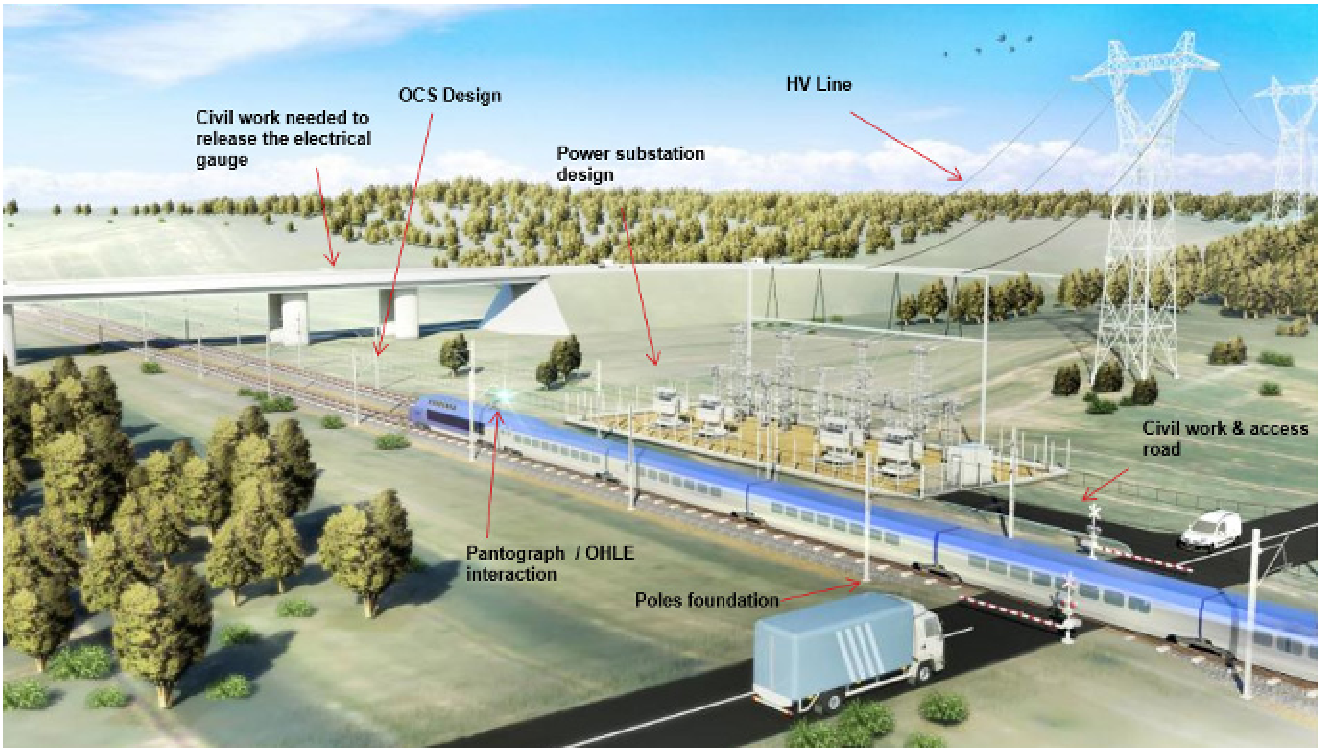
6 https://www.masstransitmag.com/press_release/12408644/new-study-railway-electrification-continues-to-grow-global-market-development-2018

The traction power supply system delivers power to the distribution system. The trains collect their propulsion power from the distribution system by means of pantographs and return the power to the substations via the rails and the traction power return system.

The power required to run a rail electrification system is supplied from an external source, by ESB/EirGrid in Ireland's case.

A high-level schematic of the various components making up a rail electrification system is provided in Figure 5 below.

Figure 5. Rail Electrification System



It is important to note that control and protection systems exist which are separate to the rail electrification system. These systems ensure the safe and effective operation of the electrified rail network. Compatibility is required between each of the systems. Examples of such systems include:

- Supervisory control and data acquisition (SCADA) for signalling
- Train Protection System (TPS) to facilitate automatic control of train movements and provide automatic early warnings
- Telecoms Systems for all voice, video & data requirements trackside and at stations.

External Power Supply System

The external power supply system is the National Grid, operated by ESB/EirGrid in Ireland. Power is generated at an electricity generating source and then transmitted via transformers into overhead transmission lines at high voltage. The supply is alternating current (AC). Higher voltage is more economical and practical to transmit over long distances than direct current because it suffers from smaller losses.

This external power is fed into the rail electrification system via the traction power supply system.

Traction Power Supply System

A traction power network is an electricity grid for the supply of electrified rail networks. The system includes traction power substations located along the route at predetermined locations.

Substation spacing depends on the rolling stock power demand, train size, train operation characteristics and the electrification system design. Their siting is also dependant on the availability of power supply within the external power supply system.

In AC powered systems, the power is supplied by the substations directly without rectification. This takes place at relatively high voltage necessitating further transformation on-board of the rolling stock for the voltage to be suitable for use by the vehicle propulsion equipment.

In DC powered systems, each substation includes transformers and rectifiers. These components condition the power to relatively low voltage suitable for direct use by the vehicle propulsion equipment. It is noted that rectifiers are used for the conversion of AC to DC.

There are components available to increase substation spacings for both AC and DC systems:

- DC powered systems - track paralleling huts and voltage controlled rectifiers.
- AC powered systems – autotransformers and booster fed systems.

Track paralleling huts are also used on DC systems to connect to the traction power supply adjacent to the system in times of degraded conditions. They contain 1500 V DC circuit breakers for the traction power supply. They will also contain auxiliary equipment such as SCADA RTU, Pilot Box, Marshalling cubicle, Battery/charger unit, Substation LV ac board (domestic) and Dial Telephone on Secure Network.

Traction Power Distribution System

The main component of the traction power distribution system is the overhead line equipment system (OHLE). The OHLE system can also be referred to as the Overhead Contact or Catenary System (OCS).

Both AC and DC Systems use masts and gantries to the overhead wire carrying the power – the contact wire. The power is transmitted from the contact wire to the train by a sprung 'pantograph', which is attached to the roof of the moving train. In the train, the current is used to drive the motors with the aid of on-board controllers.

A typical OHLE cross section for an AC system is shown on Figures 6 and 7 below and consists of console, stay, registration arm, arm steady and suspension of conductors. The system mainly consists of the following equipment:

- One messenger wire Bz65, auto-tensioned @10kN;
- One contact wire Cu107, auto-tensioned @10kN;
- One negative feeder (in case of 2x25kV) iron-aluminium 288mm² @9kN at medium temperature range. This feeder cable could be installed on the internal or the external part of the pole (also on the top);
- One earthing cable iron-aluminium 93mm² @4kN at medium temperature range.

Figure 6. Typical 1 x 25kv AC OHLE cross Section (with or without feeder)

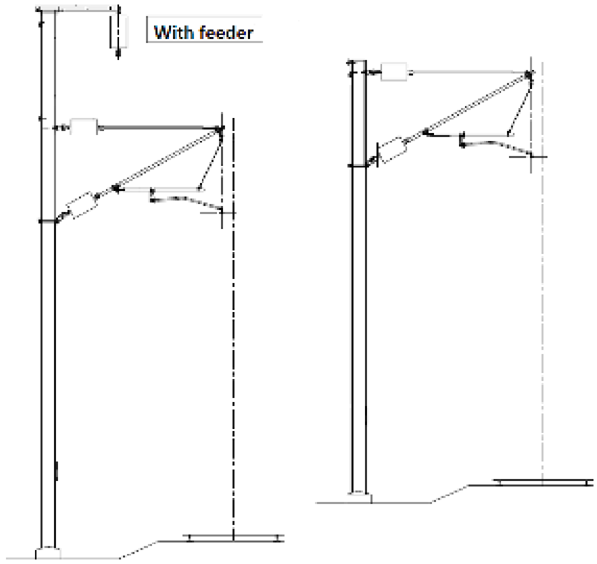


Figure 7. Example of 1x25kV OHLE (Niort-La Rochelle, France)

A typical OHLE cross section for a 1500 V DC system is shown on Figures 8 and 9 below and mainly consists of:

- One messenger wire, auto-tensioned;
- One contact wire, auto-tensioned;
- Messenger wire held by a delta cable. This delta cable is running on a pulley, attached to an insulator; and
- Single 1500VDC insulation.

Figure 8. Typical 1500 V DC OHLE cross section

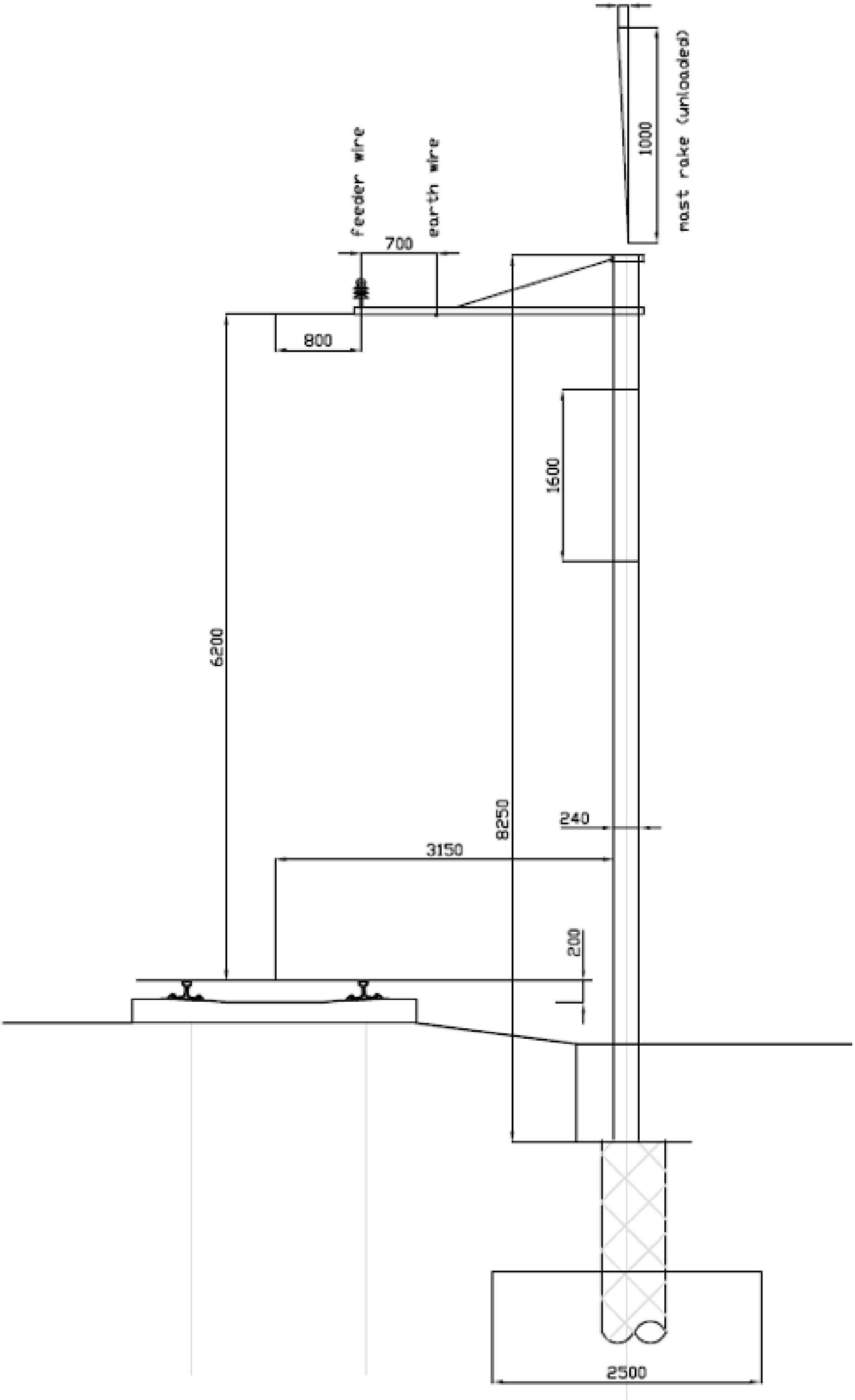
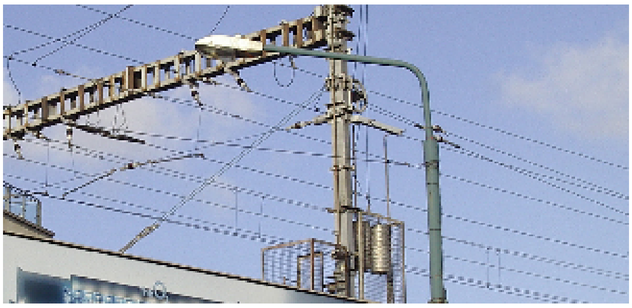


Figure 9. Existing 1500VDC OHLE with gantry on DART network



Conductors (wires) are used to carry electric current. The high voltage of AC Systems means that smaller wires are needed to transmit electricity than DC systems. This is because low voltage DC systems need high currents to transmit the same power, increasing the size of conductor wires.

Insulators are used where the masts and cantilevers meet, to separate the electrically live parts of the OLE from other structural elements and the earth. Insulators are larger for AC systems due to the higher voltages and polymeric Insulators (composite) are often used to minimise loading on the support structures.

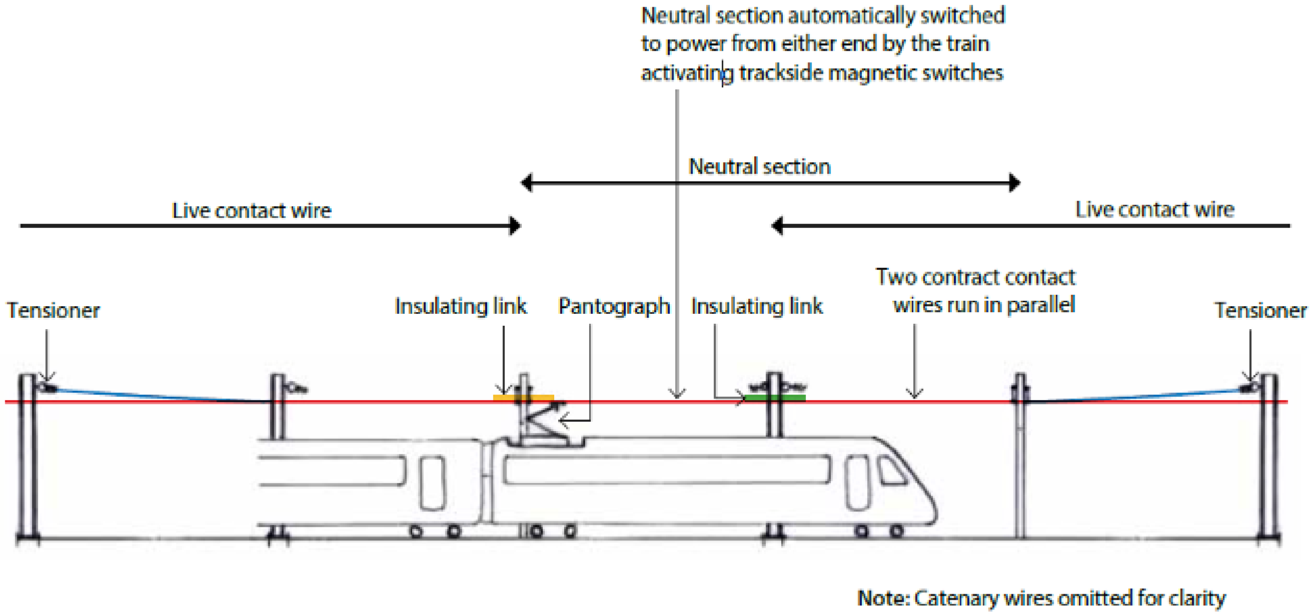
Section breaks are used to allow maintenance to sections of the overhead line without having to turn off the system. This allows the overhead line system to be broken into electrically separated portion known as sections.

Track sectioning rooms or cabinets are used to isolate individual sections of the 1500V DC or 25 kV AC OHL system. They contain isolators for the traction power supply system and auxiliary equipment such as SCADA units and secure communications equipment. Both AC and DC Systems require track sectioning rooms/cabinets.

Neutral zones are required for AC Systems. In neutral zones, the catenary has breaks called neutral sections in its electrical continuity at points where successive live sections are connected to different substations. This prevents power from inadvertently passing between grids via the OHLE. Warning boards before the neutral section are provided and pantographs are usually dropped on all the locomotives of a train or power car of a multiple unit trains, to avoid the possibility of short-circuiting adjacent sections of the catenary. This could also be automatically sequenced. On the RER B in Paris, a neutral section is in place in Gare du Nord between the 1500 V DC in central Paris and the 25 kV AC (up to Charles de Gaulle airport). This neutral section is 300m long. It may be possible to reduce this to a 120m long neutral section, depending on gradients, curve and signalling. Furthermore, rolling stock units are all equipped with an onboard automatic switching device which enables the 1500 VDC pantograph to lower (after automatically closing the circuit-breaker) and the 25 kV AC pantograph to rise (and vice versa).

A schematic of a neutral zone is shown in Figure 10 below.

Figure 10. Neutral Zones for AC System[7]



7 Network Rail Guide to Overhead Electrification 132787-ALB-GUN-EOH-000001 / February 2015 Rev 10

In the case of unexpected stopping within the neutral section, the catenary spans the neutral section overlaps with both the DC and AC catenary in order to be connected to either the DC or the AC power supply. In the case of incorrect line supply, most EMUs have protection (fuse). Without this, the motor can be severely damaged.

In the case of a pantograph not lowered when the locomotive enters the dead zone, the EMU loses power and grinds to a halt once it loses its momentum. There is usually no problem as the master circuit breaker of the EMU has been switched off. If not, there is a possibility of sparking or transient disturbances, which can trip protective circuits in the locomotive and bring the train to a halt. An automatic switch is standard for modern EMUs and does not increase the level of risk.

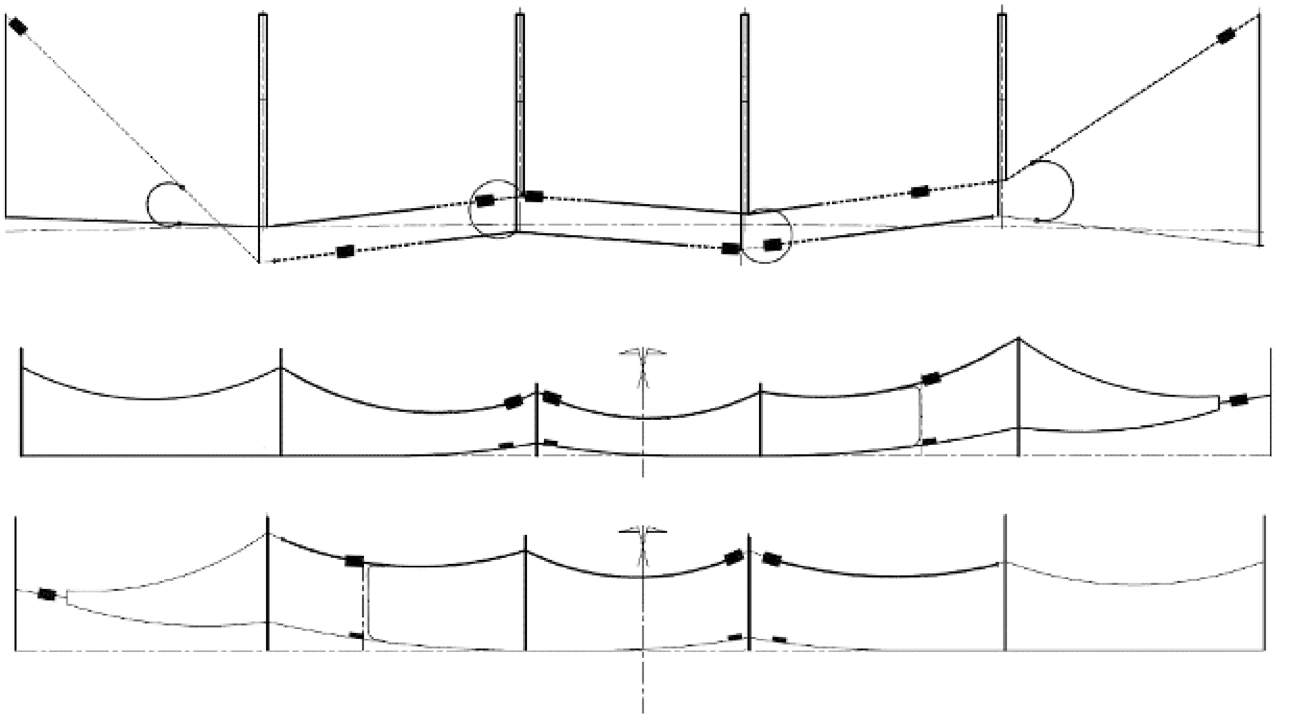
There are two types of neutral zones:

- A Phase separation section
- A 1500 V DC / 25 kV AC system separation section.

A Phase separation section

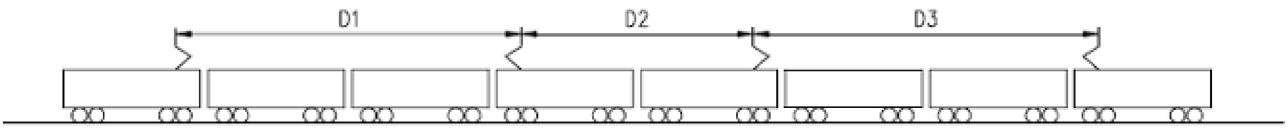
- Phase separation section (first kind of neutral section) extends on a range around 200m or 220yards;
- Figure 11 below reveals a typical arrangement for one track in straight alignment (trains running from the left to the right);
- Circuit breakers are opened when a train is running through a phase separation section.

Figure 11. 25kV phase separation section



- The distance from pantographs compatible with such an arrangement are as follows:
  - One or two pantographs: no specific requirement;
  - Three pantographs: D1+D2 shall be greater than 143m;
  - Four pantographs: D1+D2 shall be greater than 143m and D2+D3 shall be greater than 143m.

Figure 12. Distances between pantographs

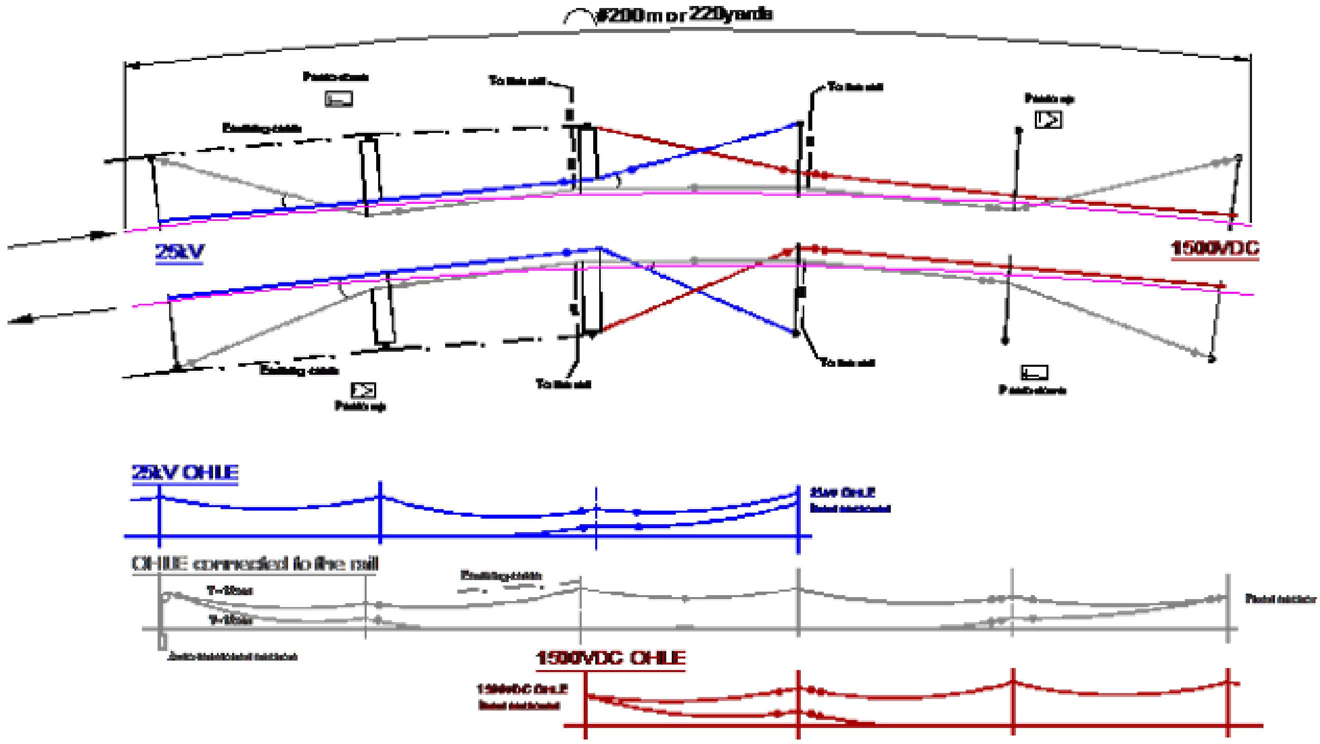


- Such a phase separation section is installed in an area where a flat track vertical alignment covers a 600m distance from each side. In case of declivity, it is necessary to check whether trains can move on their own (in coasting mode) across the phase separation section.

A 1500V DC / 25kV AC system separation section (second type of neutral section)

- Made of one intermediate OHLE, connected to the rail and two consecutive insulated overlaps. System separation section extends on a range around 200m or 220yards.
- Pantographs are lowered when passing by system separation section.
- Such a 1500V DC / 25kV AC separation section is installed in area where a flat track vertical alignment covers a 600m distance from each side. In case of declivity, it is necessary to check whether trains can move on their own across the 1500V DC / 25kV AC separation section.
- A schematic of a system separation section is shown in Figure 13 below.

Figure 13. System separation section principle



Switching stations are required for AC Systems. They contain circuit breakers or switchgear line up used for switching section of distribution system during substation outage conditions and for paralleling distribution system circuits.

Clearance to structures is required for both AC and DC OHLE Systems. Generally, clearance requirements for an AC system is greater than a DC system due to higher voltages characteristics.

Traction Power Return Systems

A Traction Power Return System comprises the running rails, impedance bonds, and cross-bonds. In addition, AC electrification systems also use the ground (earth) itself as a part of the return system and are also equipped with static wires and grounding connections.

There are different Earthing rules for each system. In a 25 kV AC system, the rail return is earthed. Bonds to the overhead line masts connect the rails to the ground by leakage through the foundations, effectively earthing the rails.

The use of AC and DC systems in close proximity needs to be carefully managed due to the differing earthing and bonding systems used. In AC, earthing plays a vital role whereas DC systems should be kept earth free (or at least only a local equipment earth) so as to prevent high traction return currents using Signalling and Telecoms cables as a return path.

Main issues associated with an AC powered system

Impact of unbalanced load on National Grid – an unbalance appears due to the connection of a traction on only two of the three phases of the HV network. Additional equipment may be required in the traction substation to overcome this issue, such as an unbalance-compensators or Static VAR Compensators.

EMC Impact it is necessary to eliminate electromagnetic induced voltages (due to single phase, 50 HZ, AC electrification) in the vicinity of the railway lines as well as around stations, to avoid any malfunctioning of telecoms, signalling systems, or hospital or university equipment.

Main issues associated with a DC powered system

Impact of harmonics on National Grid – The connection of an electric installation of non-linear type (the rectifier of a DC substation) on a power distribution network will generate harmonic currents. These harmonic currents are themselves also generating harmonic voltages. There is risk that these harmonics may be brought back into the National Grid so it is imperative that all new installations follow the National Grid regulations. However, Iarnród Éireann advised that they are being successfully managed on the existing 1500 V DC DART System without issue.

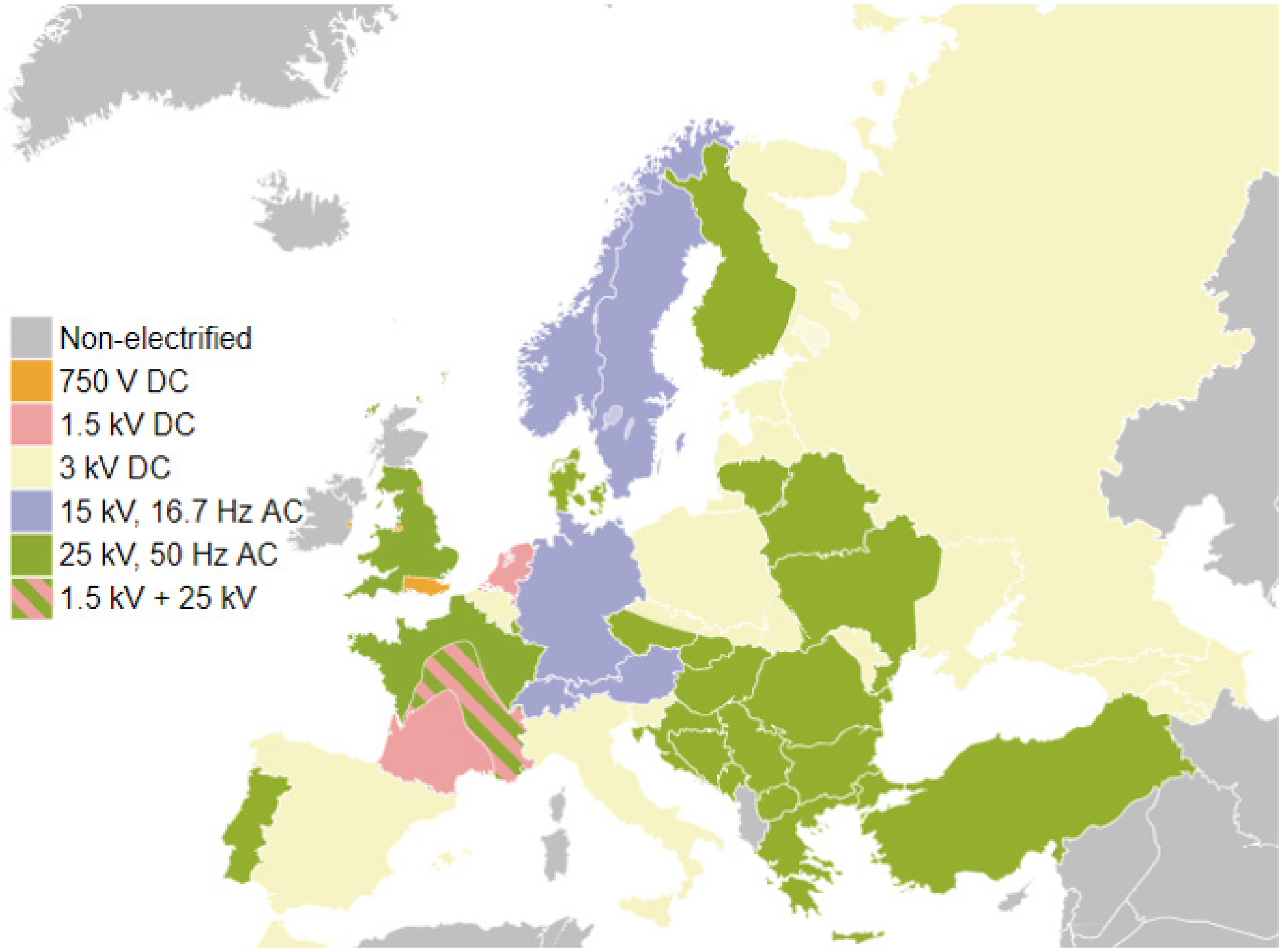
Stray currents – in DC railway electrical systems, rails are used to return the electrical current towards the substations. The voltage drops in the rails which can generate potential differences between the rails and the ground and leakage currents into the ground can occur. These extraneous currents flowing through soil and/or water, known as "stray currents", cause electrochemical corrosion damage to metal structures, or reinforcement in contact with, or below ground. Low resistance between the traction return rails and the ground can allow part of the return current to leak into the ground. Preventive and/ or corrective action can be taken to protect assets against the dangers of corrosion created by stray currents.

3.3 Use of AC and DC systems

Rail electrification systems first appeared in the late 19th and early 20th centuries. Initially low voltage DC powered systems (i.e. 600, 750 and 1,500 V) were the systems of choice, linked to the choice of traction motor and its control. Electric motors were fed directly from the traction supply and were controlled using a combination of resistors and relays that connected the motors in parallel or series.

Railway electrification systems have evolved considerable since then in line with technological advancements, particularly around electrical grid infrastructure and electric motors. Different countries have opted for different rail electrification systems, often due to particular historical contexts and operating conditions at the time of option selection. Several different types of electrification are now being used in Europe alone, as shown in Figure 14 below.

Figure 14. Map of Rail Electrification in Europe[8]



The most common types of rail electrification system include:

- 750 V DC (third rail)
- 1500 V DC
- 3000 V DC
- 15 kV AC, 16.7 Hz
- 25 kV AC, 50 Hz and 60 Hz (based on different standards).

750 V DC is most commonly found on tram networks including the Luas in Dublin. It is also used in the South of England where there is a substantial network of electrified lines that use a "third rail" energised at 750V DC.

1500 V DC is used in Ireland on the existing DART Network. It can be found on Dutch Railways and parts of the French, Australian, Chinese, Japanese and other rail networks. It is also commonly used on segregated metro systems.

3000 V DC is used in several European countries including Belgium, Italy, Spain, Poland, Czech Republic, Slovakia, Slovenia, Estonia and Latvia.

15 kV AC, 16.7 Hz is predominantly used on rail networks in Germany, Austria, Sweden, Norway and Switzerland.

25 kV AC, 50Hz is used in the UK, parts of France, Bulgaria, Greece, Finland, Portugal, Romania, Australia and parts of Japan. In Europe, and globally, 25 kV AC, is the preferred standard for high speed rail.

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3.4 Use of AC and DC Systems for DART Expansion

Potentially there are a number of the electrification systems (described above) that could be used for the expanded DART Network.

The Energy Technical Specification for Interoperability 2014 (ENE TSI), Commission Regulation (EU) No. 1301/2014 provides guidance[9] on electrification systems for use on conventional and high-speed rail.

Using the ENE TSI as a guide, there are four electrification systems which could be considered viable for DART Expansion, as follows:

- **1500 V DC** – is already installed on the existing DART Network and has been working effectively for over 40 years. This system allows for the expansion of DART using the existing rail electrification system and rolling stock. Therefore, 1500 V DC is recommended as a viable option for DART Expansion given that the current DART network is powered by this electrified system.
- **3000 V DC** – is not directly compatible with the existing DART electrification system and would require a new type of rail electrification system and rolling stock. 3000 V DC is being phased out by several countries across Europe in favour of 25 kV AC. For example, Slovakia has announced plans to convert its remaining 3000 V DC lines to 25 kV AC and other central European countries are planning the same. Therefore, 3000 V DC is not recommended as a viable option for DART Expansion.
- **15 kV AC** – is not directly compatible with the existing DART electrification system and would require a new type of rail electrification system and rolling stock. This system is generally confined to a handful of countries and is not widely used in new rail electrification systems. 15 kV AC, therefore, is not recommended as a viable option for DART Expansion given its limited use in Europe and globally.
- **25 kV AC** – is not directly compatible with the existing DART electrification system and would require a new type of rail electrification system and rolling stock. It should be noted that 25 kV AC is the most widely used in new rail electrification systems. 25 kV AC is recommended as a viable option given that, for new lines, it is the most widely used electrified system and therefore should be considered for DART Expansion.

1500 V DC and 25 kV AC are considered the most applicable electrification options for DART Expansion

3.5 25 kV AC and 1500 V DC System comparisons

There are inherent differences associated with utilising 25 kV AC and 1500V DC rail electrification systems.

The Société Nationale des Chemins de fer Français (SNCF), France's national state-owned railway company, outlined the key differences between the two systems as part of a comparative study[10] in 2016. The study's findings are provided in Table 3 below.

It is important to note that SNCF operate an extensive electrified rail network consisting of both 25 kV AC and 1500 V DC systems.

9 https://Energy TSI No.1301/2014
10 Rail Power Supply - Direct Current, a future under which conditions?', SNCF

Table 3. **SNCF DC and AC summary comparison – system components and interactions**

COMPONENTS AND INTERACTIONS	25KV AC	1500V DC
Power supply / main grid	Unbalance on the main grid	No unbalance on the main grid
	Strong electrical connections necessary	Possible connection to 'weak' parts of the mains
	Low number of connection to the mains / simpler connection	High and expensive number of connections to the mains
Traction Power Supply and Substations	Substations circa every 20-50km (or up to 80km with 2 x 25kV AC): lower investment, maintenance and operational costs	Substations every 2 – 6 km: higher investment, maintenance and operational costs
	GIS Substation equipment size circa 1,000m2, overall site compound size circa 3,000m2.	Compact substation equipment size circa 150-300m2, overall site compound size circa 1,000m2.
	Simple circuit breakers and switch gears	Complex circuit breakers and switch gears. Need of rectifiers.
	Simple detection of faults in the traction circuit	Complex detection of faults in the traction circuit
	Losses in traction system circa 4 – 5% (due to high voltage)	Losses in traction system circa 14 – 16% (due to low voltage)
Substation interactions	Complex power supply diagram: requirement for phase separation systems	Simple power supply diagram: no phase separation sections
	Complex power supply: less flexibility to operate in case of incident on one substation	Substations in parallel – easier to operate in case of incidence on one substation
Currents sent back to main grid	Use of basic transformers to send back current to overhead power line	voltage inverters needed, with harmonics generated
Overhead Line Equipment & Feeders Current Transport	Greater clearances to structures required	Less clearance to structures required
	Higher isolation distances: difficult implementation in urban areas and tunnels	Lower insulation distances: easier to implement in urban areas and tunnels
	Complex impedance, and therefore inductive voltage drops due to the jL□-part of the impedance	No jL□-part of the impedance, and therefore, no inductive voltage drops
	Low losses of 4 to 5 % in the traction circuit, due to high voltage.	More losses of 14 to16 % in the traction circuit due to low voltage.
	Light overhead line enabling high speeds: lower investment	Heavy overhead contact lines due to high strength of current: higher investment
	Low wear of the contact wire	Heavy wear of contact wires, maintenance work
	One contact wire	Two contact wires
Current collection	Low wear of the pantograph contact strips due to low strength of current	Heavy wear of the pantograph contact strips due to high strength of current
	Light overhead line enabling high speeds	Limited speed due to heavy overhead line
	Better current collection in case of ice on the overhead line	Risk of contact wire fusion due to high strength of current, especially at standstill

COMPONENTS AND INTERACTIONS	25KV AC	1500V DC
Rolling stock	Heavy and space consuming transformers on board	No transformer on board, therefore lighter rolling stock
	Requirement for rectifiers on board	No rectifier on board (inverter directly connected to the overhead contact line), therefore lighter, more reliable rolling stock
	Simple circuit breakers	Complex circuit breakers
Regenerative breaking (sent back to overhead line)	Necessity to adjust the phase of the current with the overhead line current	High levels of current returning to the substations due to low voltage
Current Returns	Low levels of current returning to the substations due to low voltage	High levels of current returning to the substations due to low voltage
Interactions with Signalling Systems	Interactions when power electronics are used	Interactions when power electronics are used
Leaks and corrosions	Low risk of corrosion due to low strength of current leaks	Higher risk of corrosion due to high strength of current leaks

3.6 Converting 1500 V DC to 25 KV AC

A consequence of going with the 25 kV AC option is that the existing 1500 V DC Line would need to be converted to 25 kV AC at some stage in the future.

Similar to the Paris Region in France, it is feasible to have 1500 V DC and 25 kV AC in operation on the same network. For the GDA Network , this means an interim phase is feasible where 25kV AC and 1500 V DC co-exist. This could be where newly electrified lines are in 25 kV AC and the existing DART Line is retained in 1500 V DC.

There are a number of options available for the existing DART if 25kV AC is introduced onto the GDA network:

- Postpone the conversion of DART until a more suitable time in the future;
- Carry out conversion works to DART on a gradual basis to minimise disruption to existing services;
- Retain existing DART at 1500 V DC and have 25kV AC and 1500 V DC co-existing on the network in the longer-term.

The main technical issues associated with a conversion include:

- New power supply network requirements;
- Increased electrical clearance requirements;
- New OHLE infrastructure requirements;
- Fleet Management;
- Signalling and communications equipment;
- General protective measures.

These technical issues are described in further detail in this Chapter.

New power supply network requirements

Power supply network requirements include the need to provide new power supply feeds, traction power supply substations, and associated infrastructure. The number of substations will depend on the extent of the rail network and capacity requirements for train services.

Increased electrical clearance requirements

A 25 kV AC systems requires increased electrical clearances to bridges, tunnels, station platforms, road crossings and trackside vegetation.

The need to maintain traffic over bridges, whether road, or pedestrian, will extend both the scope and the programme for delivering the completed structures. This may require temporary structures, realignment, or delivery of the works in a piecemeal fashion to allow single carriageway operation.

There are likely to be services beneath, or within bridge decks and the works to divert, or support these pipes and ducts – with the associated approvals potentially having a significant impact on the programme.

Works to demolish structures and construct replacement bridges will be more difficult to achieve where existing 1500V DC OHLE must be protected and removed within the possession regime. In particular, Bray Tunnels with existing 1500 V DC OHLE may difficult to convert if there is limited space to insulate 25kV AC from the tunnel ceiling and walls.

New OHLE infrastructure requirements

Insulator ratings are different for 25 kV AC and 1500 V DC systems. 25 kV AC systems need larger insulators which means all existing insulators need replacement as part of a conversion. It may be possible to retain masts and some of the other catenary equipment depending on the type installed and suitability for 25 kV equipment.

The installation of new masts involves major cost. Existing mast installations are in a good state but there is a need to assess the suitability of each installation for 25kv AC including mast heights for clearances.

Conductor wires could initially be retained as they are suitable for the current flowing in 25kV AC systems.

25kV AC Systems require the introduction of neutral zones as discussed earlier in this Chapter. Neutral zones can either be system separation sections between 1500 V DC and 25 kV AC or phase separation sections.

Fleet management

The approach to fleet management is heavily dependent on the proposed phasing for converting an electrified system.

Existing electric multiple units (EMUs), or rolling stock, used for a 1500 V DC system are not compatible for a 25 kV AC system. There is an option to modify or replace existing EMUs before the end of their lifecycle, however, this may not be feasible if existing units are necessary to meet current and growing passenger demand.

Modification depends on the rolling stock in question and can be prohibitively expensive, potentially reaching the cost equivalent of a new unit. Alternatively, units could be replaced with dual voltage or bi-mode trains to continue using the existing line as it progressively gets upgraded without full transfer to 25 kV AC. Dual voltage trains have the capacity to use either 1500 V DC or 25 kV systems while bi-mode trains can use diesel or battery power through the non-compatible electrified sections. There are cost differentials associated with each type of rolling stock, therefore this needs careful consideration.

In addition, Depots need to have compatible electrified systems in order to maintain EMUs. This means depots need to be suitably sited to provide access for all types of EMU being retained on the network.

Signalling and communications equipment

Existing signalling and communication equipment needs to be upgraded and protective measures put in place as part of a conversion from 1500 V DC to 25 kV AC.

25 kV AC can result in unwanted electric currents interfering with signalling, telecoms, lineside power supplies and other equipment. Each piece of equipment is screened against electromagnetic currents (EMCs) to understand if protective measures are required. The process for protecting equipment against EMCs is commonly known as immunisation.

Examples of such equipment includes signal boxes, cabling, Hot Box detector systems (rail mounted), DC Power Systems, CCTV & lighting installed, Track Side Radio Bases/towers/Radio frequency cabling on masts (Analogue and GSMR), Public Address Systems and equipment in Car Parks and Depots/Yards.

Track circuits for train detection and the Automatic Train Protection (ATP) system must also be assessed for interference associated with a 25 kV AC system.

General protective measures

Third party assets such as utility cables may require immunisation against EMCs. While utility cables are currently insulated against 1500 V DC EMCs, the additional EMC impact associated with 25kV AC may require further protective measures.

The design of earthing and bonding is an important part of the 25 kV AC system. The details of the earthing arrangement are stated in the EN50122-1 standard. In a 25 kV system, the rail return is earthed. Bonds to the overhead line masts connect the rails to the ground by leakage through the foundations, effectively earthing the rails. Earthing and bonding systems are also used to protect against insulator failures.

25 kV AC systems may require additional earthing and bonding of existing lineside structures. For example, metallic structures such as metal bridges over or under the track, station structures, signal posts and the earths of electrical distribution systems will need to be bonded to the rail.

The conversion results in the need for alterations to existing safety measures such as lineside signage and fencing.

Disruption to existing services

Works required to address the technical issues listed above are likely to result in disruption to existing services. In particular, works to increase clearances at existing structures may require lengthy possessions of the railway line. The impact of any line possessions needs to be carefully considered when train services are affected. Some key considerations include:

- Extent of delays associated with options involving continued service
- Possibilities for maintaining peak hour or weekday service while shutting down the service at other times
- Alternative services available to passengers in a given corridor
- Number of customer-trips at risk of delays if service is reduced
- Increased travel times resulting from shutdowns
- Speed, reliability, and attractiveness of different alternatives, e.g. rail replacement buses.

The phasing of works associated with a conversion is crucial in ensuring disruption is minimised and there is a smooth changeover of operations. The general steps taken as part of a conversion works programme include:

- Address clearance requirements for existing structures
- Roll out programme for fitting redesigned insulators
- Roll out programme for re-wiring, signalling, and communications upgrades
- Install new AC traction power supply system
- Depot works to facilitate new rolling stock
- Ensure all necessary equipment, including third party assets, are protected against EMCs.

3.7 International Case Studies

When considering conversion from existing 1500 V DC to 25 kV AC, it is useful to identify rail electrification strategies that other countries have adopted and considered based on their own context and requirements. The following three examples highlight electrification strategies internationally. This study will draw on these learnings from international experience as part of the appraisal process.

Spain

The Polytechnic University of Catalonia undertook a 'comparative study between an alternating current (AC) and a direct current (DC) electrification of an urban railway a railway' in 2015. The Barcelona – Vallès line operated by Ferrocarrils de la Generalitat de Catalunya (FGC) was used as case study. The line is currently electrified in 1500 V DC and a possible implementation of 25 kV AC was evaluated.

The study outlined the different technical factors which can affect the cost of 1500 V DC and 25 kV AC electrification systems[11]. A table from this study is replicated below in Table 4.

11 Polytechnic University of Catalonia 'comparative study between an alternating current (AC) and a direct current (DC) electrification of an urban railway a direct current (DC) electrification of an urban railway'

Table 4. **Comparison of cost factor between 1500 V DC and 25 kv AC System (Polytech Barcelona)**

FACTOR	1500 V Dc	25 kV AC	COMMENTS
Overhead line	1 MW load is equivalent to 666 Amps (unity power factor)	1 MW load is equivalent to 40 Amps (unity power factor)	Less cooper cross-section required for a 25 kV system. Fewer Amps imply lower Joule Effect losses.
Traction Power Substations	Close feeder station spacing (4 - 6 km) requires more TPSS and electric supply connections.	Typical spacing between TPSS is around 20-50 km. Less electric supply connections.	25 kV system is cheaper for long routes. Less civil works and land affordability required.
Support Insulators	Simplified insulation arrangements and greater design choice.	Substantially larger and heavier insulators required.	Simpler and cheaper insulators for a 1500 V system, though modern polymeric materials enable lighter and more compact 25 kV designs.
Support Structures	Simple support arrangements at over bridges and tunnels.	More complex support arrangements at over bridges and tunnels.	Simpler and cheaper support arrangements for 1500 V system.
Electrical Clearance	Small electrical clearance more easily accommodated by existing infrastructure.	Larger electrical clearance can require civil works to bridges and tunnels.	25 kV systems may incur in substantial additional costs where tight clearance structures feature on the route.
Power Supply Imbalance	Rectifiers operate from three phase supply for equal loading in all phases.	25 kV transformers operate from a single phase with potential to cause supply imbalance. Higher connection costs.	25 kV feed would require additional consultation with the Distribution Network Operator to establish most economical means of supply provision.
Power Supply Harmonics	Substation harmonics may affect supply.	Problems with harmonics less likely.	Need for harmonic filters and may affect connection costs for 1500 Vdc configuration.
Electromagnetic compatibility	Low affectation to adjacent track circuits or signalling systems. Some mitigation measures may be needed.	Higher affectation. Mitigation measures must be implemented.	Potential higher cost for the 25 kV system. Booster transformer may be required to comply with mandated EMC emission limits.
Traction return	Running rails required to have a good isolation from earth to reduce DC leakage current.	AC leakage current less of an issue and standard of rail - earth insulation not as high.	Cathodic protection of buried services may be required for 1500 V system.

Some key conclusions taken **directly** from the Barcelona – Vallès line study are provided below.

- The 1500 V DC voltage system had an average of 69% more current demand in normal operation conditions than the 25 kV AC configuration. The higher voltage drop in the catenary of the DC voltage system means the distance between traction substations (TPSS) is reduced. This results in more traction substations being required;
- The line was scenario tested for increased train numbers. There were two scenarios where the existing 1500 V DC substations could not handle the operational constraints imposed, namely, when traction substations of Les Fonts or Sant Cugat were out of service;
- The Joule losses with the 25 kV AC configuration are a 0.26% of the total power demanded in the traction substation and for the 1500 Vdc configuration they suppose a 5.1%. Losses in the line (Joule losses) play

an important role regarding efficiency;

- The energetic analysis showed the same global energy consumption for both configurations. However, the study noted the two systems could not be compared directly because rolling stocks had similar technical characteristics but different passenger capacities. A comparison was undertaken with an energy ratio to include the capacity of the trains (kWh/(km·seat)), widely used in railway projects. Using this approach, a lower energy demand for the 25 kV AC of 40% was evident;
- The economic analysis included the catenary system and the traction power substations. The high currents demanded in the DC configuration implied the need for high cross section catenaries and a higher number of traction substations. The global economic cost for the 1500 V DC system was found to be 33% more expensive than 25 kV AC system when 25 kV AC traction substations were taken to be around 55% more expensive than 1500 V DC substations;
- 25 kV AC traction substation configurations require more space than 1500 V DC configurations (but less location points). Feeding points for connections to the grid are more complicated for 25 kV AC than for 1500 V DC connections; and
- Historic use of DC technologies for the railways with similar characteristics as the Barcelona – Vallês meant that less rolling stock models were available for 25 kV AC configurations that could fit with the operational constraints required for the line studied.

The Netherlands

There is approximately 2,000km of rail electrified to 1500 V DC in the Netherlands. Netherlands Railways has been experiencing power supply capacity issues across large parts of this network. Many trains encounter voltage drop problems during incidents where several trains are drawing power simultaneously. This affects their current train services and restricts their ability to expand on existing services. It is noted that system demands in the Netherlands are higher than in the GDA due to increased train size and loading and the extensive use of freight services across the network.

In 1997, the Netherlands government, the passenger and freight business units, and the railway's operating and planning organisations all agreed that conversion to a 25kV AC system would be optimal, not only for international rail services but also for domestic lines. 25 kV AC was considered optimal due to its capacity to facilitate more trains which are heavier and accelerate faster to higher speeds, its perceived improvements in terms of reliability and maintenance costs, as well as the benefits arising from standardisation with the systems of neighbouring countries. However, there were also concerns identified in relation to changing the system to 25kV AC, mainly focusing on the heavy investment and retrofit of current rolling stock required for this conversion.

They assessed converting the network under fast and slow conditions:

- **Fast scenario** means that most of the existing rolling stock would be converted to dual-voltage capability. New stock would be introduced as dual-voltage or 25 kV AC only, and a line could be converted as soon as the rolling stock using it was suitable. Conversion could then be undertaken between 2005 and 2017.
- **Slow scenario** meant no existing rolling stock would be converted with dual-voltage capability. New trains would be introduced as dual-voltage, and conversion of lines to 25kV AC would commence as soon as sufficient dual-voltage trains became available.

A decision was made to opt for the slow scenario in order to stage investment. A major contributing factor to this decision was the lifespan of existing rolling stock. Based on the current view of the lifespan of rolling stock, conversion of the infrastructure could take place from 2022 to 2032.

In tandem with the decision to convert existing lines to 25 kV AC, Netherlands Railways has opted to electrify new lines in 25kV AC. Currently the High-Speed Line HSL-Zuid (125km, high-speed rail line) and Betuweroute (159km, double track freight railway) are electrified in the 25kV AC 50 Hz system. This provides the following benefits:

- capacity to facilitate more trains which are heavier and accelerate faster to higher speeds, important for HSL and Freight Lines
- conformance with Technical Specification for Interoperability (TSI) Energy objectives for High Speed Rail
- improvements in terms of reliability and maintenance costs
- standardisation with the systems of neighbouring countries.

Mumbai Rail

Electric traction in suburban areas of Mumbai started with 1500 V DC supply in 1925 and the system now runs with 25 kV AC supply in three different regions of Mumbai.

One factor in this conversion was the recognition that it was not economical or practical to continue to manage the heavy load and costs of numerous DC traction substations. In addition, loading requirements were increasing due to heavier and more frequent train services. Capacity was enhanced by increasing voltage and reducing current using a 25 kV AC traction system.

Initially (up to 2013), dual voltage Electric Multiple Units

(EMU) rolling stock was introduced that could operate on both 1500 V DC and 25 kV AC systems.

The major benefits of this conversion included seamless operation on 25kV AC electric traction, energy efficiency associated with the AC traction system, and staff savings. The conversion of the DC system to 25 kV AC systems had the following advantages in the Mumbai context:

- Significant saving in energy cost due to the introduction of the higher power electric locomotive and EMUs.
- Introduction of higher power locomotives – the WAG7 locomotives need less maintenance, are more reliable and generate higher tractive effort than DC locomotives. This results in smoother operation in sections at higher speeds and much lower traction current handling (16 times lesser than DC).
- Reduction in maximum power demand for the same level of traffic.
- Reduction in the number of required substation from 73 to 18, leading to higher reliability and lower maintenance costs.
- Energy savings due to reduced lighting load in the traction substations.
- Increase life of contact wire due to lower traction current handling in AC locomotives.
- Higher voltage insulation level in 25 kV AC system to with stand surges with greater reliability.
- Lesser maintenance requirements on rail bonding in the AC system.
- Reduction in transmission and distribution losses as the current in the AC system is lower compared to the DC system.

In summary, the choice of an optimum rail electrification system involves weighing up complex, interrelated issues. Both 1500 V DC and 25 kV AC systems are viable options for electrification of the GDA rail network.

1500 V DC systems require more substations which are small in size relative to 25 kV AC substations. 1500 V DC systems are typically more expensive to install and maintain for new lines when compared to 25 kV AC systems. Less electrical clearance is generally required for 1500 V DC systems, which is advantageous in a dense urban setting with stations located in close proximity on a line.

25 kV AC systems require less substations which are large in size relative to 1500 V DC. Individual traction substations involve much higher connection costs. The system is optimal choice for longer distance intercity travel or where heavy loading exists on the system such as freight traffic.

Both systems have specific technical aspects which can be challenging, but are manageable.

Conversion from an existing 1500 V DC system to 25kV AC depends on local circumstances and multiple factors.

4 | EVALUATION METHODOLOGY

4.1 Introduction

The previous chapter outlined the various electrification options for powering the DART Expansion network. Two options have been identified as appropriate rail electrification for the GDA, namely:

- 1500 V DC; and
- 25 kV AC.

4.2 Key Considerations underpinning Evaluation

To deliver rail electrification in 1500 V DC means the continuation and expansion of the existing electrified network.

To deliver a 25 kV AC electrification network will be more complex and will require electrifying the unelectrified lines in AC first, and then converting the existing 1500 V DC DART line to 25 kV AC over time. The implication of this electrified rail network in the GDA with 1500 V DC and 25 kV AC co-existing for a period of time.

As noted previously, the Malahide/Howth – Connolly – Greystones DART line is already electrified in 1500 V DC. This, therefore, has a material impact on the electrification of existing unelectrified rail lines due to the interaction of rail lines, particularly around Connolly Station for example, where the Maynooth, Kildare (via the PPT) and northern rail lines all converge. These interaction effects only become an issue if 25 kV AC is the chosen electrification system for the GDA, as two electrified systems would need to co-exist until the existing 1500 V DC DART line is converted to 25 kV AC. The technical issues associated with using 1500 V DC in combination with 25 kV AC and the conversion of the existing 1500 V DC Line to 25 kV AC are key considerations and are evaluated as part of this assessment.

There is the potential to retain both the 1500 V DC and 25 kV AC systems on the network in the long term. However, the conversion of the existing 1500 V DC Line to 25 kV AC is also considered in the event that a full 25 kV AC network is the desired outcome. The conversion of the existing DART to 25 kV AC has been evaluated as part of this assessment.

It should also be noted that the choice to electrify with either 1500 V DC or 25 kV AC (or combination of the two) does not have a material impact on the train service capacity of the GDA Rail Network. The electrification options are considered in the context of predetermined train service capacities and patterns which were assessed as part of the DART Expansion Programme Options Assessment Study[12].

It is assumed that infrastructure projects proposed under DART Expansion Programme, which have not commenced construction, will be compatible with either 1500 V DC or 25 kV AC systems. For example, bridge alterations proposed as part of the 'Kildare Line Four Tracking Study' will provide sufficient electrical clearances for both 1500 V DC and 25 kV AC electrified rail systems.

In terms of the evaluation of costs associated with delivering either 1500 V DC or 25 kV AC, both capital costs and operational and maintenance costs are considered. Capital costs include the costs associated with delivering the infrastructure and rolling stock for 1500 V DC or 25 kV AC electrification systems. Operational and maintenance costs include costs associated with running the 1500 V DC or 25 kV AC electrified systems.

12 The DART Expansion Programme Options Assessment Study involved the modelling assessment of an alternative DART Expansion Programme with the deferral of the DART Underground and an enhancement of the existing network (including Phoenix Park Tunnel). A number of scheme bundle options were assessed and a recommended option was put forward as part of the study.

4.3 Evaluation Methodology

The evaluation approach involves the assessment of technical and cost considerations for both options under several criteria headings. Each criterion is evaluated and summarised to allow a direct comparison between 1500 V DC and 25 kV AC.

Following the evaluation of each electrification option with regard to technical and cost considerations, further key issues and recommendations are presented to provide the basis for decision making on rail electrification in the context of the wider DART Expansion Programme.

It is important to reaffirm that both 1500 V DC and 25 kV AC are suitable options for rail electrification in the GDA.

4.4 Technical Evaluation

The technical issues highlighted in Chapter 3 are used as a basis for the technical evaluation of the impact of delivering either 1500 V DC or 25 KV AC across the GDA rail network.

Table 5 below outlines the criteria used for the technical evaluation.

Table 5. Technical Evaluation Criteria

TECHNICAL CRITERIA	DESCRIPTION
TC1 Power Supply	Power supply requirements needed for 1500 V DC and 25 KV AC Systems. The issues associated with delivering an indicative power supply network for both options are assessed.
TC2 OHLE Infrastructure	OHLE requirements needed to introduce 1500 V DC and 25 kV AC Systems. Neutral Zones associated with introduction of 25kV AC System are considered.
TC3 Fleet and Depot Management	The impact of 1500 V DC and 25kV AC electrification on fleet and depot management strategies is assessed.
TC4 Electrical Clearances	1500 V DC and 25 kV AC Systems have different electrical clearance tolerances. Works requirements to provide sufficient clearance at existing overhead structures are assessed.
TC5 Signalling, Communication and Protection	The impact of the two systems on signalling, communications and third party infrastructure and associated protective requirements
TC6 Installation and Phasing	Issues associated with implementation of 1500 V DC and 25kV AC Systems are considered. Particular focus is given to the phasing in of an AC system and conversion of the existing DC line to AC.
TC7 Future Proofing	Consideration is given to impact 1500 V DC and 25 kV AC Systems have on longer term rail projects

The technical evaluation is summarised by highlighting the key considerations associated with implementing both 1500 V DC and 25 kV AC Systems.

4.5 Cost Evaluation

This chapter evaluates 1500 V DC and 25kV AC Systems in terms of cost.

Capital Cost and Operational and Maintenance Costs are broken down into sub-criteria and evaluated separately. The cost criteria were selected in order to as closely align to the technical evaluation criteria as possible.

Table 6 below outlines the criteria used for the cost evaluation.

Table 6. Cost Evaluation Criteria

COST CRITERIA	SUB-CRITERIA
CC1 Capital Cost (infrastructure)	CC1.1 Electrical Clearances CC1.2 Power Supply CC1.3 OHLE CC1.4 Depots
CC2 Capital Cost (Rolling Stock)	CC2.1 Rolling Stock
CC3 Operational and Maintenance Cost	CC3.1 Substations CC3.2 OHLE CC3.3 Rolling stock CC3.4 Usage charges for electricity

5 | TECHNICAL EVALUATION OF 1500V DC AND 25KV AC

5.1 Introduction

In line with the evaluation methodology described previously in Chapter 4, the 1500 V DC and 25 kV AC rail electrification options have undergone a technical evaluation. The technical criteria are as follows:

- TC1 - Power Supply;
- TC2 - OHLE Infrastructure;
- TC3 - Fleet and Depot Management;
- TC4 - Electrical Clearances;
- TC5 - Signalling, Communication and Protection;
- TC6 - Installation and Phasing; and
- TC7 - Future Proofing.

Schematics for 1500 V DC and 25 kV AC systems are provided in Figures 15 and 16 below respectively. The schematics include the following details:

- extent of the future DART Network with existing rail stations;
- locations of existing DART traction substations are shown on the 1500 V DC schematic; and
- potential traction substation locations for both electrification options.

Figure 15. Schematic of 1500 V DC SYSTEM

Figure 16. Schematic of 25kV AC SYSTEM

5.2 TC1 - Power Supply

NOTE REGARDING POWER SUPPLY:

The power supply network required to support rail electrification largely depends on the type of system chosen (i.e. AC or DC). 25kV AC systems require a smaller number of traction substations than 1500 V DC systems whereas 1500 V DC traction substations require a lower demand for electricity than 25 kV AC traction substations.

This assessment made assumptions with regard to the estimation of power supply required for both 1500 V DC and 25 kV AC and for traction substation locations. To accurately determine the level of power supply needed to operate a rail electrification system, the optimum location for traction substations, and the energy efficiency of the system, a traction supply simulation modelling is required.

The assumptions made for this assessment differ for 1500 V DC and 25 KV AC, and include the following;

- **1500 V DC, future power demand estimates are extrapolated from the existing system demand based on historic usage & projected increased capacity / frequency loadings.**
- **25 kV AC System, future power demands are extrapolated from the existing system demand based on historic usage & projected increased capacity / frequency loadings. MIC estimates are based on a comparison with a 25 KV AC system in Glasgow.**

It should be noted that the approach used for 25 kV AC is less accurate than that used for 1500 V DC system and relies on professional judgement underpinned from experiences in the use of 25 kV AC systems in other countries.

In Ireland, ESB is the Distribution System Operator (DSO) (power network up to 38kv) and EirGrid is the Transmission System Operator (TSO) (power network 110kv and above). For individual load enquiries above 4MVA the DSO engages with TSO to determine if loads require direct connection to the Transmission system.

The power supply demand is based on the Maximum Import Capacity (MIC). The MIC of a connection is important for several reasons:

- This is the capacity which ESB Networks makes available at the connection point;
- It is a major determinant of the connection method and charges;
- It is a determinant of Public Service Obligation Charges (for customers where the MIC equals or exceeds 30kVA); and
- It affects the charge that ESB Networks makes on the electricity supplier in respect of the electricity used at your connection (known as Distribution Use of System, or DUoS charges). Additional charges may be applied if the energy usage is higher, or lower, than the MIC agreed with ESB.

The availability of power supply from ESB is an important consideration. Power supply in the GDA is constrained in many areas and ESB/EirGrid are currently undertaking a strategic study with a view to reinforcing their grid network.

ESB/EirGrid have the potential to supply electricity in 220 kV, 110 kV, 38 kV and 20 kV subject to availability. Based on SYSTRA's experience internationally, it should be feasible for ESB / EirGrid to connect both 1500 V DC and 25kV AC traction supply systems.

To determine the availability of supply, ESB / EirGrid review their network to identify a suitable location to provide a new connection. Their preferred location for a grid connection may not be the ideal location from the rail operators perspective due to the fact that the rail operator's objective is to locate traction substations in such way to optimise the performance of electrified rail services.

For cost and installation reasons, it is preferable to locate both 25 kV AC and 1500 V DC traction substations in close proximity to the existing ESB Network Grid. This reduces cost and risks associated with providing overhead or underground connections between the two sets of infrastructures. In both cases, ESB and EirGrid are required to identify the Least Cost Chargeable (LCC) connection.

An estimation was made of the MIC demands to provide an indication of level of power supply required. SYSTRA

13 Simulation modelling includes N-1 contingency scenario testing. This tests the ability of a traction supply system to operate satisfactorily, within prescribed limit conditions, when a substation within the system is under failure.

applied their knowledge of traction supply systems to approximate the number, and location, of traction substations required to meet the estimated level of demand. This included consideration of power supply and voltage drop requirements for the traction system, as well as an understanding of the power grid[14].

For the purpose of this assessment, 1500 V DC and 25 kV AC systems are assumed to use the same quantity of power to operate the same train services pattern. This power consumption is measured in kilowatt hours (kwh) or megawatt hours (MWh).

Each traction substation is proposed to contain two transformers and two supply feeds for redundancy purposes. Further information is required from ESBN on reliability and redundancy of their feed to 110 kV and 220 kV substations. 100% redundancy is envisaged within the traction power supply arrangements and equipment including supply feeds and transformers

1500 V DC Power supply network

The existing 1500 V DC DART consists of 13 traction substations for a network length of approximately 50km. 11 substations are fed directly from ESB's 38kV Network with 2 substations sub-fed; Blackrock is sub-fed via Sandymount and Bray is sub-fed via Shankill. Renewal works are expected at several substations in the coming years, unrelated to this study.

Existing DART traction substations are generally fed with 2 x 3000kVA feeds with one feed used for redundancy purposes.

The voltage is lowered and rectified into 1500 kV through a 12-pulse rectifier. DART substations are mainly composed of:

- HV (38 kV) incoming cells and HV protection cells. This equipment is in a separate room and connected to the ESB network in cut-off mode;
- Two oil-type transformers with power of 3,000 kW. They are located outside of the substation building and protected by means of a fence; and
- A room with two 12-pulse rectifiers, connected to High Speed circuit breakers and various switches and isolators.

1500 V DC traction substations involve:

- complex circuit breakers and switch gears; and
- Complex detection of faults in the traction circuit.

Based on 1500 V DC direct feed substations recently installed in France, a typical substation footprint is about 150m² to 300m² if compact equipment including harmonics filters, auxiliary transformers and flickers filters are used. The overall site compound including the access road is likely to be 1,000m². Substations on a new electrified line could be located every 2 to 6 km depending on the profile, train operation and type of trains, in particular due to voltage drop (The line voltage should not drop under 1000 V to be in accordance with IEC 60850 standard).

It is preferred to direct feed 1500 V DC system from ESB's 38 kV or 20 kV Network.

It is also possible to connect using 110kV Network but this requires large stepdown transformers and other auxiliary equipment which are expensive to deliver when compared to direct feeds. This approach is only considered likely on the 'Malahide to Drogheda' section of the network where existing 38 kV and 20 kV lines are limited.

Existing and proposed MICs for existing DART traction substations are provided in Table 7 below.

Table 7. MICs for existing 1500 V DC DART Substations

SUB STATION	EXISTING MIC (KVA)	MIC PROPOSED (KVA)
Greystones	758	850
Bray	Sub-fed from Shankill	Sub-fed from Shankill
Shankill	1733	2820
Dalkey	904	1470
Dun Laoghaire	1175	2500
Blackrock	Sub-fed from Sandymount	Sub-fed from Sandymount
Sandymount	2007	4270
Pearse	806	2250
Fairview	1328	2820
Raheny	1254	2670
Portmarnock	836	2610
Malahide	407	1000
Bayside	1821	2050

As evident from the table above, proposed MICs reflect an increase in power demand as a result of more frequent train services. New MIC agreements should be

14 MIC estimates and indicative substation locations were then provided to ESB Networks. ESB use this information to undertake a high-level capacity assessment of available power supply on their network. This can be used to provide advice on suitable substation locations. This advice is non-contractual. The results from this assessment by ESB Planners were outstanding at the time of writing this report.

sought with ESB to reflect the new demand. This prevents penalty charges being incurred as a result of MICs being exceeded.

The proposed MIC at Sandymount is estimated at 4,270 kVA. This is above the existing installed capacity of the 3000 kVA Feed. Connection upgrade works may be required or Sandymount substation may need upgrading to facilitate this increased demand. For example, substation works may consist of busbar extension and installation of new circuit breakers.

Newly electrified Hazelhatch, Maynooth and Malahide to Drogheda lines are proposed to contain traction substations spaced every 4-6km. Their exact spacing depends on track profile, train operation and type of trains, as well as the availability of ESB supply in these areas.

MICs for 1500 V DC traction substations proposed on newly electrified lines are listed in Table 8 below.

Table 8. Proposed 1500 V DC Substations on new lines

NETWORK SECTION	SUB STATION	MIC PROPOSED kVA
Malahide to Drogheda	Donabate	1900
	Rusk & Lusk	1900
	Skerries	1900
	Ardgillan Castle	1900
	Balbriggan	1900
	Gormanstown	1900
	Draycott	1900
	Drogheda	1900
Maynooth	Ashtown	2050
	Coolmine	2050
	Dunboyne	2050
	Leixlip (Louisa)	2030
	Maynooth	2030
Maynooth and Hazelhatch	Glasnevin	3520
Hazelhatch	Inchicore	2200
	Cherry Orchard	2200
	Balgaddy	2200
	Hazelhatch	2200

The traction substation locations are based on use of ESB 38 kV connections. However, the extent of 38 kV Network is limited on the Malahide to Drogheda Line. In the event that a direct 38kV connection is not available on this section, potential options may include:

- Use a direct feed off the 20 kV network if available; and
- Install a 110kV/38kV traction substation at Balbriggan to feed in 38 kV the eight traction substations required.

Connections between the ESB Network Grid and traction substation may involve overhead wires or underground cables with trenching works. The routing of connections can be challenging and costly if ESB infrastructure with available capacity is not in close proximity to the desired traction substation location. Indicative costs associated with making these connections are outlined in '**ESB Networks DAC Statement of Charges 01/10/2018**' with further details provided as part of the cost evaluation.

For a 1500V DC System, there is usually greater flexibility to deal with N-1 degraded conditions in case an incident at a substation.

Iarnród Éireann advised that they are not experiencing difficulties with Harmonics on the current DART system.

The main power supply considerations for a 1500 V DC system are outlined in Table 9 below.

Table 9. 1500 V DC Power Supply Considerations

1500 V DC POWER SUPPLY CONSIDERATIONS
18 new tractions substations are required bringing the total number of substations to 31 including two sub-fed stations.
The overall site compound including access road for a 1500 V DC traction substation is likely to be 1000m².
Iarnród Éireann has developed significant in-house experience in operating and maintaining 1500 V DC power supply systems.
Commissioning a large number of substations in a short period of time may pose a challenge for initialising the electrification system. It is important to set out a commissioning programme as early as possible with ESB to overcome this issue.
Iarnród Éireann advised that Harmonics are not considered an issue based on their experience of the existing DART at 1500 V DC.
1500 V DC traction substations consist of complex circuit breakers and switch gears.
1500 V DC Systems tend to provide greater flexibility when dealing with N-1 Scenarios with degraded conditions at a substation, however, this needs to be determined through traction simulation modelling.
1500 V DC Systems involve complex detection of faults in the traction circuit.

25 kV AC Power supply network

For 25kV AC, a new traction power supply system is required for newly electrified lines and for the converted section of 1500 V DC.

A 25 kV feeder AC system could either consist of a 1 x 25kV AC System or a 2 x 25kV AC Autotransformer System.

A line fed in 1 x 25 kV is mainly composed of:

- substations, located in sections of approximately 20 to 50 km (the spacing is depending on the headway between trains, their operation and their mean power); and
- sectioning posts between two substations, in order to avoid having two different phases mixed together (ESB phases used for traction purpose could be different from one substation to another).

A 1 x 25kV AC system will consist of traction supply substations being fed from ESB's 110 kV or 220 kV system. A 25 kV AC substation shall be equipped with:

- A set of 220 kV or 110 kV (depending on the ESB network and/or substation availability) switches, circuit-breaker and isolators in order to allow power to be fed properly from ESB in direct mode (with dedicated HV cables) or in cut-off mode;
- A minimum of two main traction transformers (110 kV/25 kV) for redundancy purposes. It could be Oil Natural Air Natural (ONAN) at first with the opportunity to become Oil Natural Air Force (ONAF) in case of rising of the power needed; and
- A set of traction equipment (switches, circuit-breakers and isolators).

25kV AC systems contain simple circuit breaker and switch gear arrangements. They allow for a simple detection of faults in the traction circuit.

A 2 x 25kV AC Autotransformer system has substations with a similar operating mode to 1 x 25 kV. The transformers output voltage is 50 kV, with its balance point connected to the rail on the secondary side. The substation could be composed of 2 power transformers of about 40 MVA each. Voltage drops will be lowered, thus allowing substations every 60 to even 80 km, depending on the timetable, the type of trains and the profile.

A combination of 1x25 kV and 2x25 kV can also be considered.

The proposed traction substations for 1 x 25kV AC are listed in Table 10 below.

Table 10. Indicative traction substation for 25 kV AC Network

TRACTION SUB STATION	MIC ESTIMATE (KVA)
Balbriggan (2 x 10 MVA)	7425
Grange (2 x 10 MVA)	7425
Blackrock (2 x 10 MVA)	7425
***[15]Leixlip (2 x 10 MVA)**	7425
Inchicore (2 x 23 MVA)	17325

2 x 25 kV system involves two traction substations at Inchicore (2 x 30MVA) and Balbriggan (2 x 23 MVA). A mixed solution with 1x25 kV and 2x25 kV on some parts of the network could also be considered.

GIS (Gas Insulated Substation) substations are recommended given the relatively dense urban / suburban environment of the rail network. GIS substations are assumed to be 1000m², at 20-50km spacings, and fed from ESB's 110 kV network or possibly 220 kV network in very restricted circumstances. They are housed indoors using portal frame type structures. The overall site compound including the access road is likely to be 3,000m².

AIS (Air insulated Substations) substations require a footprint of about 9,000 to 10,000 m² not including the site compound or access roads. This option is not proposed in an urban or suburban environment due to the extent of land required.

Land availability for 25 kV AC GIS substation infrastructure is an important consideration.

It is difficult to extend GIS substations if sufficient space has not been provided in the building from the outset. The GIS Building should be large enough and an appropriate number of bays should be installed to accommodate future expansion.

For a 25kV AC System, there is usually less flexibility to deal with N-1 degraded conditions in case of incident at a substation. This is particularly an issue for 2 x 25 kV AC Systems on a network consisting of short distances.

Based on two traction substations being required for a 2 x 25 kV AC System, there is no capacity for N-1 redundancy unless all newly electrified lines are commissioned at the same time. The new 25kV AC system will require a connection between the two traction substations to provide for N-1 degraded conditions.

15 *The Leixlip substation is shown in case potential voltage drops issues between Inchicore substation and the end of Maynooth line (about 26.4 km + for depot) cannot be overcome. A SVC (Static Var Compensator) could also be used to overcome this issue which does not need any ESB connections.

The impact of unbalanced load requires further consultation with ESB/EirGrid once a common understanding of power demand requirements is in place. The use of static VAR compensators can be used to manage unbalanced loads.

The main power supply considerations for a 25 kV AC System are outlined in Table 11 below.

Table 11. 25 kV AC Power Supply Considerations

25 kV DC Power Supply Considerations
Four or five new tractions substations are required for a 1 x 25 kV AC system. Two traction substations are required for a 2 x 25 kV AC system.
GIS substations are recommended given the relatively dense urban / suburban environment of the rail network. The overall site compound including roads for a 25 kV AC traction substation is likely to be 3000m2 .The availability of sites of this size to provide a substation is a concern in areas such as Blackrock.
Iarnród Éireann has no in-house experience in operating and maintaining 25 kV DC power supply systems.
The impact of unbalanced loads associated with 25 kV AC Systems requires further consultation with ESB.
25 kV AC traction substations consist of simple circuit breakers and switch gears
25 kV AC systems tend to provide less flexibility when dealing with N-1 Scenarios with degraded conditions at a substation.
Two traction substations are estimated for a 2 x 25 kV AC system. This provides no capacity for N-1 redundancy unless all newly electrified lines are commissioned at the same time. The new 25kV AC system will require a connection between the two traction substations to provide for N-1 degraded conditions.

Mix of 1500 V DC and 25 kV AC Power supply network

There will be a mix of 1500 V DC and 25 kV AC power supplies in two scenarios;

- Temporarily during the phasing-in of 25 kV AC on newly electrified lines for the all 25 kV AC option; and
- In the long term, if 1500 V DC is retained on the existing DART Line to co-exist with 25 kV AC on the other lines.

The 13 existing DART substations are retained in both scenarios.

The main power supply considerations for newly electrified lines at 25 kV AC are outlined in Table 12 below.

Table 12. 25 kV AC Power Supply Considerations for newly electrified lines

Traction Sub Station	MIC Estimate (kVA)
Balbriggan (2 x 10 MVA)	7425
***[16]Leixlip (2 x 10 MVA)**	7425
Inchicore (2 x 23 MVA)	17325

5.3 TC2 - OHLE Infrastructure

The installation and use of 1500 V DC and 25 kV AC OHLE systems are assessed under TC2.

On newly installed OHLE infrastructure the issues associated with each system tend to balance each other out. For example, a negative of the 1500 V DC system is that overhead lines require larger conductors. This can be offset by the fact that 25 kV AC systems require larger and generally heavier insulators.

Notwithstanding the difference listed above, the OHLE aspect of both systems is largely similar.

The installation of OHLE Equipment on newly electrified lines involves a similar process for both 1500 V DC and 25 kV AC systems, based on information received from Contractors.

16 *The Leixlip substation is shown in case potential voltage drops issues between Inchicore substation and the end of Maynooth line (about 26.4 km + for depot) cannot be overcome. A SVC (Static Var Compensator) could also be used to overcome this issue which does not need any ESB connections.

Support structures are available, and economical, which are commonly used for both 1500 V DC and 25 kV AC systems. They could be used as part of upcoming works packages to ensure flexibility is retained within the system.

1500 V DC OHLE

Existing 1500 V DC OHLE on DART Network is made up of:

- One messenger wire, auto-tensioned;
- One contact wire, auto-tensioned;
- Messenger wire held by a delta cable. This delta cable is running on a pulley, attached to an insulator; and
- Single 1500V DC insulation.

Main considerations for a 1500 V DC System are outlined in Table 13 below.

Table 13. 1500 V DC OHLE Considerations

1500 V DC OHLE CONSIDERATIONS
Iarnród Éireann is familiar with 1500 V DC OHLE equipment so no issues are envisaged with expanding the existing system.
Installation requirements and scheduling of a new 1500 V DC OHLE systems is similar to that for a 25kV AC

25 KV AC OHLE

25 kV AC OHLE is made up of:

- One messenger wire Bz65, auto-tensioned @10kN;
- One contact wire Cu107, auto-tensioned @10kN;
- One negative feeder (in case of 2x25kV) Iron-aluminium 288mm² @9kN at medium temperature range. This feeder cable could be installed on the internal or the external part of the pole (also on the top);
- One earthing cable iron-aluminium 93mm² @4kN at medium temperature range.

Cantilever insulators are either made of glass, or synthetic. Synthetic is mandatory nearby tunnels or overbridges. Creepage distance is 1200m

The introduction of 25 kV AC will require it to co-exist with the current 1500 V DC system until the DC system is converted to AC. This will, therefore, require the use of two types of neutral zones, as follows:

- A Phase separation section (first kind of neutral section) extends on a range around 200m or 220 yards. Circuit breakers shall be opened when the train is running through the phased separation section. Such a phase separation section shall be installed in an area where a flat track vertical alignment covers a 600m distance apart from each side.
- A 1500 V DC / 25 kV AC system separation section (second type of neutral section) is made of one intermediate OHLE, connected to the rail and two consecutive insulated overlaps. Pantographs shall be lowered when passing by the system separation section. Such a 1500 V DC / 25 kV AC separation section shall be installed in an area where a flat track vertical alignment covers a 600m distance apart from each side.

Three 1500 V DC / 25 kV AC system separation sections will be required if 25 kV AC is proposed. These neutral zones are required on a temporary basis to allow the phased introduction of 25kV AC across the entire network. The introduction of different voltages on the same network needs careful consideration to address safety and risk management issues.

In the event that a 25 kV AC system is chosen, local maintenance teams should be actively involved in the construction activities during conversion/ installation as this will allow them to become familiar with the proposed systems prior to it being formally handed over by the project team.

The conversion of 1500 V DC to 25 kV AC will result in the need to replace approximately 2,500 insulators across the existing DART system. It may be possible to re-use some of the existing supports structures such as foundations, masts and gantries. Re-use of existing supports needs to be confirmed by more detailed assessments including site investigations.

Main considerations for a 25 kV AC System are outlined in Table 14 below.

Table 14. 25 kV AC OHLE Considerations

25 KV AC OHLE CONSIDERATIONS
25 kV AC involve the use of 'phase' neutral zones.
It is feasible to undertake the conversion of existing 1500 V DC DART Lines to 25kV AC on a gradual basis, over a number of years. This results in 1500 V DC and 25 kV AC co-existing on the network prior to the conversion. This requires the introduction of three 'interface' neutral sections.
Local maintenance teams should be actively involved in the installation of a 25kV AC system to allow familiarisation prior to handover.
Staff need appropriately training around the use of a 25 kV OHLE System, particularly around the operation of neutral zones.

5.4 TC3 - Fleet and Depot Management

Fleet

A 'Fleet Management Strategy', separate to this study, is ongoing to determine the type and number of rolling stock units needed under the DART Expansion Programme. The exact number of fleet to be procured, their type, and the associated procurement strategy were not finalised at the time of writing this report. In addition, the cascading of fleet between newly electrified lines is yet to be determined.

Rail electrification has an impact on the Fleet Management Strategy. For example, a network consisting of both 1500 V DC and 25kV AC systems will result in the need for new EMUs that are either dual voltage or bi-mode to ensure interoperability between the two systems.

Bi-mode rolling stock can be diesel or battery. Battery units (BEMUs) will need to be compatible with 1500 V DC if they are introduced in advance of electrification to enable charging from the existing DART system.

The Fleet Management Strategy does not consider dual voltage BEMUs to be a feasible option for the GDA. This means the existing 1500 V DC DART Network should continue in operation until the new BEMUs reach the end of their expected asset life cycle.

There is an existing fleet of 144 1500 V DC EMUs in operation on the DART network. This is made up of two types of rolling stock unit as follows:

- 76 Class 8100 units due for retirement from 2025 onwards; and
- 68 Class 8500 units due for retirement from 2035 onwards.

The availability of replacement rolling stock is an issue due to the lead times involved in procuring new fleet. Therefore, these units need to be retained for as long as possible. This is considered as part of fleet management proposals.

Iarnród Éireann advised that modification of existing 1500 V DC EMUs to 25 kV AC is not a cost effective solution as the costs involves are similar to the cost of procuring new units. They also advised that existing units have minimal re-sale value.

Depot

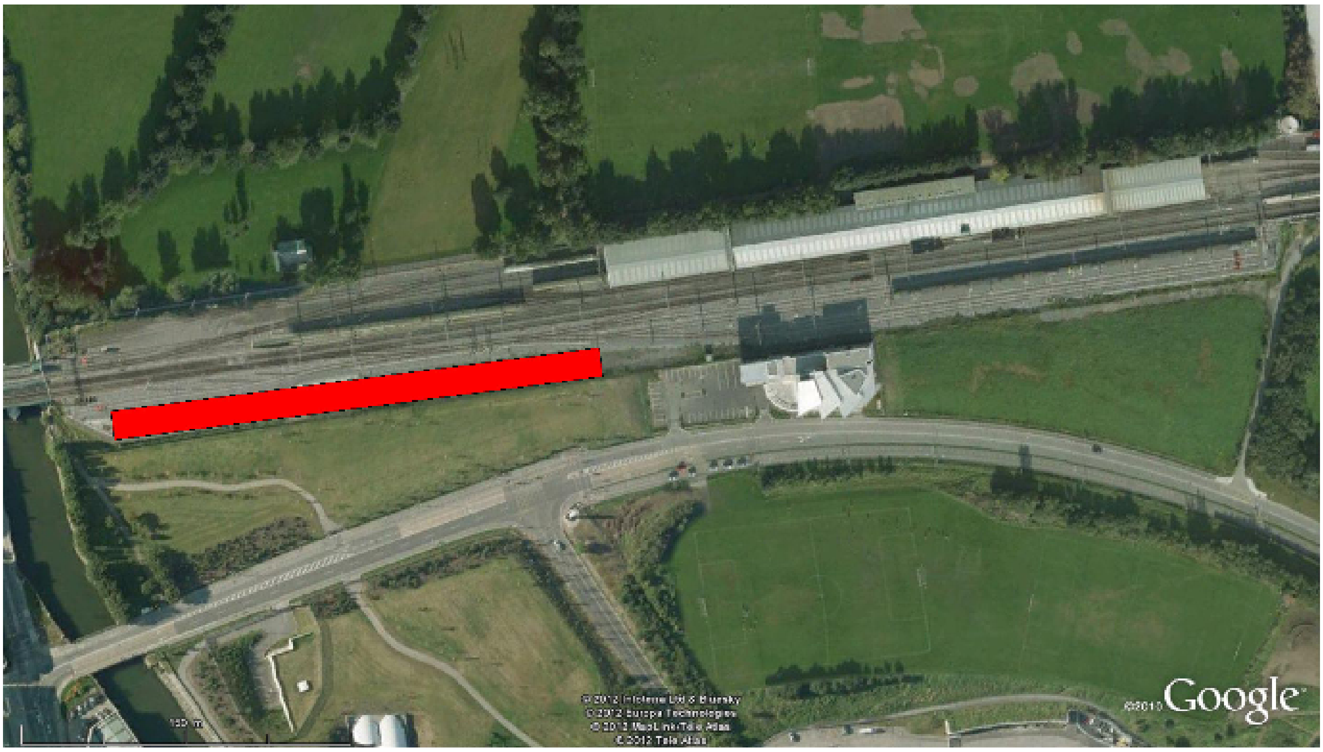
The existing EMU fleet is serviced at Fairview while heavy maintenance (mainly wheel lathe) is carried out at Inchicore.

Maynooth is identified as a future main and light maintenance depot location.

A depot at Drogheda is also under consideration to provide sufficient capacity and flexibility for maintenance of an expanded fleet.

In both 1500 V DC and 25 kV AC options, an extension to Fairview is proposed for continued low level maintenance on a long term basis. The possibility to extend the Fairview area in order to add some maintenance tracks and some sheds to maintain additional units was considered as part of the previous 2011 study. It identified that a new shed can be added on the up side before Clontarf Road station to provide two 220m pit tracks to receive eight carriages, as illustrated in Figure 17 below.

Figure 17. Fairview Depot Extension



For both 1500 V DC and 25 kV AC options, sidings and minor maintenance (cleaning etc.) will be kept at Bray, Greystones, Inchicore, Fairview and Drogheda in the future.

1500 V DC Fleet and Depot

Existing and new EMUs have the flexibility to operate across the expanded GDA rail network. This will provide full interoperability of units.

Maynooth main depot and an additional Drogheda depot are expected to cater for long-term fleet maintenance requirements.

The introduction of the Maynooth Depot would be undertaken in parallel with the use of the existing Fairview depot. Unless implementation of the new depot is late, there will be no major issue during changeover, as all the fleet is energised to 1500V DC.

Fairview Depot is to be phased out for main maintenance works as Maynooth Depot becomes fully operational.

The main considerations for a 1500 V DC System are outlined in Table 15 below.

Table 15. 1500 V DC Fleet and Depot Considerations

1500 V DC FLEET AND DEPOT CONSIDERATIONS
Existing fleet and new rolling stock units are able to operate and be maintained with flexibility across the DART Network
Depots at Maynooth and Drogheda are expected to cater for long-term fleet maintenance requirements.

25 kV AC Fleet and Depot

New rolling stock will either be dual voltage or bi-mode to ensure interoperability across the GDA rail network

New depots at Maynooth and Drogheda are equipped to maintain the new dual voltage or bi-mode rolling stock.

The preferred approach for the existing 1500 V DC fleet is to retain them on the system until they reach obsolescence from 2035 onwards. This creates a challenge as newly electrified lines and depots are designed for 25 kV AC system.

A mitigation measure is required whereby Fairview Depot is retained for existing 1500 V DC fleet until 2035 minimum. This allows the existing to continue operation on the system until the end of their life expectancy.

The main considerations for a 25 kV AC System are outlined in Table 16 below.

Table 16. 25 kV Fleet and Depot Considerations

25 KV AC FLEET AND DEPOT CONSIDERATIONS
Introduction of a 25KV AC system requires the addition of new dual voltage or bi-mode rolling stock units to ensure interoperability across the existing and newly electrified sections of the network.
Existing 1500 V DC EMUs are being retained on the existing DART Network until they reach the end of their life expectancy. This requires a mitigation measure whereby Fairview Depot is maintained in operation until existing 1500 V DC Fleet becomes obsolete from 2035 onwards.
If dual voltage units are proposed, electrification of depots at Maynooth and Drogheda need to accommodate dual voltage rolling stock or bi-mode rolling stock.

5.5 TC4 - Electrical clearances

Iarnród Éireann has several categories of electrical clearances including Enhanced, Normal, Reduced and Special Reduced, in order of decreasing height. Existing clearance categories are outlined in Table 17 below.

Table 17. Electrical Clearances

CLEARANCE CATEGORY	1500V DC (MM)	25KV AC (MM)	COMMENT/CONSIDERATIONS
Enhanced	5300	5600	Not a major consideration at existing structures
Minimum Normal (free running)	4830	4830	Should be minimum target
Minimum Normal (fitted)	4690	4690	Measures at bridge to control flash over, higher maintenance and monitoring on OHLE, minimum tamping lifts
Reduced	4564	4564	Measures at bridge to control flash over, possible line speed restriction, higher maintenance and monitoring on OHLE, absolute minimum tamping lifts
Special Reduced	4343	4489	Exceptional circumstances, suits masonry, brick, concrete bridges only, measures at bridge to control flash over, line speed restriction, higher maintenance and monitoring on OHLE, no tamping lifts

The minimum normal (free running) clearance outlined in the table above may not be readily available at existing structures. Each low structure needs to be reviewed on a case by case basis to determine the best solution to address sub-optimal clearances.

Maintenance issues and speed restrictions associated with the introduction of minimum clearances also need to be evaluated on a case by case basis. For example, there are currently speed restrictions on the existing DART from Dun Laoghaire to Sandycove due to sub-optimal clearances.

Solutions to consider for sub-optimal clearances could range from tolerating the reduced clearance (noting potential maintenance and speed restriction issues), track lowering/realignment, bridge deck jacking, bridge deck renewal, or some combination of these.

The form of structure and construction methodology should be chosen to minimise the works needed during possessions and maximise the works that can be achieved during normal operational hours. This optimises the overall programme and can be achieved through the following:

- Taking full advantage of pre-fabrication where possible;
- Using craneage to lift units into place during the possession periods;
- Provide protection to the live railway to allow works to proceed at other times; and
- Phasing of the work will reflect the need to maintain traffic or limit road closures.

The key issues around delivery of the replacement structures concerns additional works that may be required to facilitate construction, such as:

- The need to maintain traffic over bridges, whether road, or pedestrian, will extend both the scope and the programme for delivering the completed structures. This may require temporary structures, realignment, or delivery of the works in a piecemeal fashion to allow single carriageway operation;
- There are likely to be undertakers services beneath, or within the bridge decks and the works to divert, or support these pipes and ducts with the associated approvals could have a significant impact on the programme; and
- Works to demolish structures and construct replacement bridges will be more difficult to achieve where existing 1500V DC OHLE has to be protected and removed within the possession regime.

Structural clearance requirements between Hazelhatch and Phoenix Park Tunnel are being addressed as part of Kildare Line 4 Tracking Study which forms part of DART Expansion Programme.

The alteration of structures along the existing DART Line to address sub-optimal clearances is not envisaged if 1500 V DC is being retained. There are derogations already in place for use of existing clearances.

The 2011 Rail Electrification Study assessed electrical clearances at the 17 existing level crossings for both 1500 V DC and 25 kV AC Scenarios. The study concluded that:

> 'The level crossings have been assessed for the potential impacts of electrification considering the necessary clearances and the proximity of adjacent bridges. This study has concluded that neither removal of the level crossing, nor changes to the bridges would be required as a result of future electrification work'.

1500 V DC electrical clearances

Table 17 below provide the number of structures affected when 1500 V DC electrical clearance categories are considered for the GDA rail network. Further details of the affected structures, including name, location, type and clearance tolerances are included in an Appendix.

Table 18. Electrical Clearances for 1500 V DC System

CATEGORY	MAYNOOTH	HAZELHATCH	MALAHIDE TO DROGHEDA	DART NORTH	DART SOUTH	OVERALL	OVERALL NOT INCLUDING DART
	STRUCTURES AFFECTED						
Minimum Normal (Free Running)	8	6	11	-	-	**25**	**25**
Minimum Normal (Fitted)	7	6	6	-	-	**19**	**19**
Reduced	3	6	4	-	-	**13**	**13**
Special Reduced	0	0	2	-	-	**2**	**2**

Structures below the clearance thresholds on the existing DART Network are not included because a derogation already exists for these clearances.

Each of the affected structures needs to be reviewed on a case by case basis to determine the best solution to address sub-optimal clearances.

25 kV AC electrical clearances

Table 18 below provide the number of structures affected when 25kV AC electrical clearance categories are considered for the GDA rail network. Further details of the affected structures, including name, location, type and clearance tolerances are included in an Appendix.

Table 19. Electrical Clearances for 25 kV AC System

CATEGORY	MAYNOOTH	HAZELHATCH	MALAHIDE TO DROGHEDA	DART NORTH	DART SOUTH	OVERALL	OVERALL NOT INCLUDING DART
	STRUCTURES AFFECTED						
Minimum Normal (Free Running)	8	6	11	9	28	**62**	**25**
Minimum Normal (Fitted)	7	6	6	4	16	**39**	**19**
Reduced	3	6	4	2	5	**20**	**13**
Special Reduced	2	5	2	2	4	**15**	**2**

Each of the affected structures needs to be reviewed on a case by case basis to determine the best solution to address sub-optimal clearances.

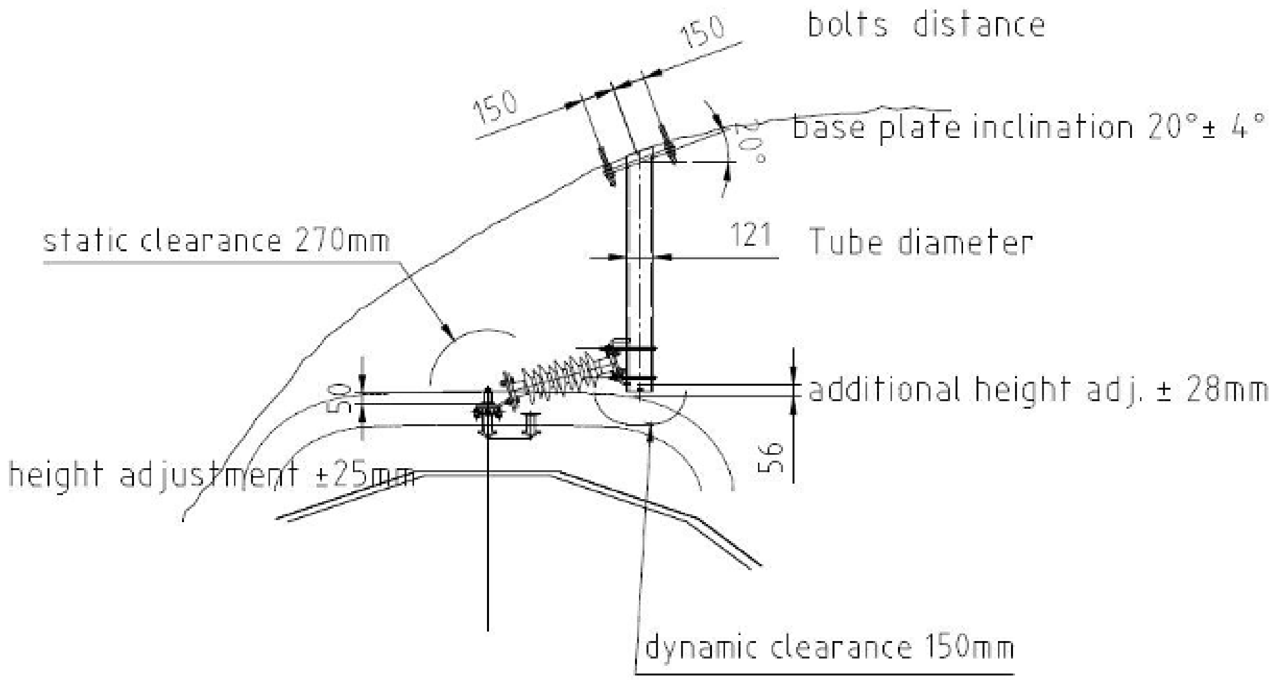
Existing DART Line – Increasing clearances along the existing DART Network is likely to be the most challenging aspect of this option, including:

- Dun Laoghaire to Sandycove - Cutting at DLRCC has speed restriction due to clearances issues;
- Bray Tunnels; and
- OBR86A, a reinforced concrete station structure and OBR103, a reinforced concrete road bridge are likely to be difficult to reconstruct. For OBR86A, the station building, is likely to it has been assumed that the additional mm required can be accommodated by track lowering rather than altering the structure.

Bray tunnels are challenging for AC electrification, particularly Tunnel 1 and 4, as a soffit of 4.451 is quoted. Close to 100mm is required to achieve adequate clearance. Although the full extent of the clearance works for the tunnels has not been established, a lowering of the track bed is both difficult and time consuming. Within the assumed possession regime it is likely to take considerably longer than the 9 months currently allocated for electrification works unless the reduced clearance is very localised.

A potential solution to overcome clearance issues at the Bray Tunnels is use of a conductor beam. This technical feasibility of using a conductor beam needs to be fully investigated. This has the benefit of removing the catenary wire and restricting pantograph uplift and removes additional interface with tunnel walls within arched tunnels. A typical cross for a conductor beam is shown below in Figure 18.

Figure 18. Typical cross section for a conductor beam



Bray tunnels have the benefit of a larger track gauge which means the pantograph is automatically farther from the tunnel wall.

At station platforms, the intention is to position the new AC Overhead Lines at a dimension of 3.5m from the platform surface to comply with current European Standards. This is not an issue for the conductors but is a problem for the pantograph. A potential solution to overcome this issue is to specify a TSI pantograph with insulating horns. This also has benefits within tunnels and on arch bridges but does constrain the overhead ad line conductors as positional tolerances are required to be tighter. The technical considerations associated with use this equipment need careful consideration by Iarnród Éireann.

TC4 electrical clearances summary

Electrical clearances are considered with respect to Iarnród Éireann categories including Normal, Reduced and Special Reduced, in order of decreasing height.

Low structures need to be reviewed on a case by case basis to determine the best solution to address sub-optimal clearances.

Solutions to consider for sub-optimal clearances can range from tolerating the reduced clearance (noting potential maintenance and speed restriction issues), track lowering/realignment, bridge deck jacking, bridge deck renewal, or some combination of these.

A comparative assessment of electrical clearances for 1500 V DC and 25 kV AC are outlined in Table 20 below.

Table 20. 1500 V DC and 25 kV AC Electrical Clearance Considerations

1500 V DC AND 25 KV AC ELECTRICAL CLEARANCES				
	1500 V DC		25 KV AC	
CATEGORY	Including DART lines	Not including DART lines	Including DART lines	Not including DART lines
minimum Normal (Free Running)	25	25	62	25
Minimum Normal (Fitted)	19	19	39	19
Reduced	13	13	20	13
Special Reduced	2	2	15	9

5.6 TC5 - Signalling, communications and protection of Equipment

1500 V DC and 25 kV AC systems both have the potential to interfere with signalling and communications equipment.

Iarnród Éireann advised that re-signalling works are expected on Hazelhatch, Maynooth and Drogheda Lines. Resignalling works will involve the replacement of existing signalling equipment and associated lineside cabling. Protective measures should be included to future-proof equipment against rail electrification as part of re-signalling works.

Works as part of Connolly and Docklands reconfigurations should be pre-emptive with protective measures installed to future proof against 1500 V DC or 25 kV AC as required.

A new joint assessment is required to assess the impact of both 25kV AC and 1,500 V DC on the existing Luas Depot at Broombridge, electrified at 750 V DC.

Iarnród Éireann is currently undertaking a Train Protection System (TPS) Study. 25 kV AC systems have the potential to affect TPS. It may be the case that trains can be switched manually to 83.3hz to avoid interference, however, the immunisation of lineside equipment (belize) is a factor. The impact of a 25kV AC system on the TPS needs to be fully investigated.

While Iarnród Éireann are familiar with the management of EMCs associated with 1500 V DC Systems, interference associated with 25kV AC Systems is greater and their impact is not known to Iarnród Éireann. The effect of 25kV AC on the existing DART Corridor is an important consideration of the EMC interference study.

25kV AC Systems require an EMC interference study to be undertaken including a full survey of lineside cables. The impact of 25 kV AC System on the Train Protection System (TPS) and on the existing DART Corridor are important aspects of this. Immunisation of circuits not on the railway corridor will require assessment, interference levels calculated and background levels monitored prior to works starting. The levels will then need to be monitored on completion of works. Particular areas of concern will be hospitals, recording studios and areas with installed hearing aid loops (nursing homes etc).

Stray currents due to 1500 V DC electrification can be problematic. They have the potential to flow through soil and/or water and cause electrochemical corrosion damage to metal structures, or reinforcement in contact with, or below ground. It is noted that Iarnród Éireann are familiar with managing stray currents through their DART experience.

TC5 Signalling, communications and protection Summary

The main considerations for a 1500 V DC System are outlined in Table 21 below.

Table 21. 1500 V DC Signalling, Communications and Protection Considerations

1500 V DC SIGNALLING, COMMUNICATIONS AND PROTECTION
Re-signalling works are expected on Hazelhatch, Maynooth and Drogheda Lines. Protective measures should be included to future-proof equipment against rail electrification as part of re-signalling works
Stray currents need to be assessed for newly electrified lines. Iarnród Éireann is familiar with these requirements due to experience of the existing 1500 V DART Network.

Main considerations for a 25 kV AC System are outlined in Table 22 below.

Table 22. 25kV AC Signalling, Communications and Protection Considerations

25 KV AC SIGNALLING, COMMUNICATIONS AND PROTECTION
Re-signalling works are expected on Hazelhatch, Maynooth and Drogheda Lines. Protective measures should be included to future-proof equipment against rail electrification as part of re-signalling works
The impact of interference associated with 25 kV AC Systems is not known to Iarnród Éireann. An EMC interference study to assess this impact. The impact of 25 kV AC System on the Train Protection System (TPS) and on the existing DART Corridor are important aspects of the interference study. It should include a full survey of all lineside cables.

5.7 TC6 - Phasing and installation

The phasing of the electrification programme will have significant impacts on existing rail operations. Works that involve possession of the existing rail lines have the potential to be particularly disruptive.

The study assumes that procurement of rolling stock and electrification of the lines are undertaken in tandem.

Enabling works are recommended to address clearance issues at structures. This will allow the OHLE team to have a 'clear run' when installing the overhead contact system installation.

The construction of traction power supply systems can largely be undertaken by a preferred contractor however connection works to the grid, and commissioning and energisation of substations must be undertaken by ESB representatives. The availability of outages for commissioning and energisation of new traction substations are important to consider as they can have a big effect on works programmes.

Battery units (BEMUs) will need to be compatible with 1500 V DC if they are introduced in advance of electrification to enable charging from the existing DART system. The existing 1500 V DC DART Network should continue to operate until the new BEMUs reach the end of their expected asset life cycle.

Installation overhead contact system

Mechanisation of the installation, replacement and the maintenance of catenary is an important contribution to achieving maximum availability of the overhead lines for electric train operations as well as providing the most economical solution. Reduced worksites and possession times are essential in managing the high usage of the line. With the use of plant and equipment in good condition operated by skilled staff and delivered through continuous and rapid production will permit the installation of the catenary with final cable tension in one track possession.

Full possessions are normally for four hours per night. However, if possible, six hour possessions would offer tangible improvements in productivity and cost effectiveness. It is assumed that most of the work will be done in a mixture of possessions over midweek nights (4 hours), Saturday nights (8 hour), 28-hour weekends and occasional longer 52-hour holiday weekends in order to allow uninterrupted daily operations and for last train services not to be replaced. Additional blockades will be required for transfer between phases, as well as for testing and commissioning when necessary.

Phasing and installation of 1500 V DC

The Maynooth line is expected to be electrified first so that a new Maynooth depot can become operational. Hazelhatch will be electrified next and then finally the Drogheda extension.

The introduction of new fleet should be straight forward provided sufficient capacity is made available in existing or new depots for maintenance requirements.

The construction and commissioning of new traction substations is the most challenging aspect of the newly electrified 1500 V DC lines. 18 new traction substations are anticipated and this may create scheduling issues for connection, commissioning and energisation works carried out by ESB.

The main considerations for a 1500 V DC System are outlined in Table 23 below.

Table 23. 1500 V DC Installation and Phasing Considerations

INSTALLATION AND PHASING OF 1500 V DC SYSTEM
Iarnród Éireann is familiar with the existing 1500 V DC network so expansion of the same system should not create technical issues unknown to them.
Maynooth line is expected to be electrified first with a new depot at Maynooth, followed by Hazelhatch and lastly the Northern Line Drogheda extension.
Disruption to the existing DART Network should be minimal as the lines are being retained 'as is'.
The construction and commissioning of new traction substations is the most challenging aspect of the newly electrified 1500 V DC system. 18 new traction substations are anticipated and this may create scheduling issues for connection, commissioning and energisation works carried out by ESB. Early engagement with ESB Network on programming is recommended.
Existing and new EMUs have the flexibility to operate across the expanded GDA rail network providing full interoperability.

Phasing and Installation of 25 kV AC

The method of phasing 25kV AC across the entire network is heavily interdependent with the fleet strategy because two types of rolling stock are introduced onto the network.

A phasing strategy for the implementation of 25kV AC is provided below.

- Phase 1: Install 25kV AC on new lines – Maynooth, Hazelhatch and then Drogheda and facilitate co-existence of 1500 V DC and 25kV AC on the network
- Phase 2: Convert Existing DART lines to 25 kV AC

Further consideration is given to 25 kV AC/1500 V DC systems interfaces for each phase later in this chapter.

It is possible to meet required passenger demands without full conversion to 25kV AC through the use of dual voltage or bi-mode rolling stock.

There is the potential for Maynooth and Hazelhatch Lines to be electrified using a single traction substation at Inchicore. This would have major benefits for the electrification programme.

Construction and commissioning of up to five new traction substations is required along with the corresponding ESB infrastructure.

Two traction substations are estimated for a 2 x 25 kV AC system. This provides no capacity for N-1 redundancy unless all newly electrified lines are commissioned at the same time. The new 25kV AC system will require a connection between the two traction substations at Inchicore and Balbriggan to provide for N-1 degraded conditions. This is not considered a feasible option due to the need for all lines to be electrified simultaneously.

Phase 1: Install 25kV AC on new lines and

The first phase of 25 kV AC System involves a staged introduction of 25 kV AC across the newly electrified lines.

New 25kV AC lines co-exist with the existing 1500 V DC DART network.

Dual voltage or bi-mode rolling stock allow new fleet to operate on the newly electrified and existing DART lines. Depots to be located at Maynooth and potentially Drogheda.

Existing 1500 V DC EMUs are retained on the existing DART line. A mitigation measure is required where existing fleet continue to be maintained at Fairview Depot. This measure is retained until the existing fleet become ready for scrappage from 2035 onwards.

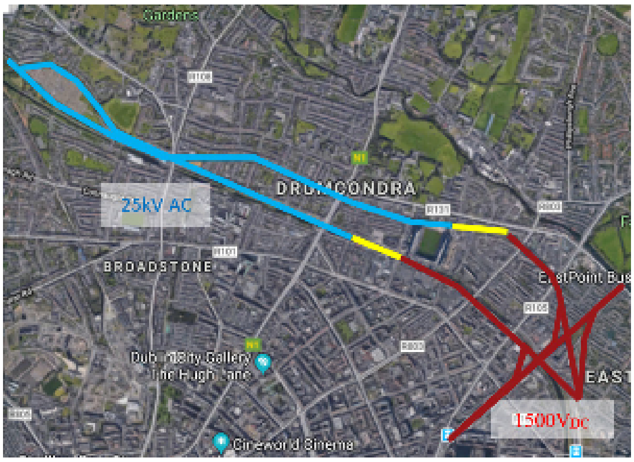
The interface between 25kV AC (red) and 1500 V DC (orange) is shown in Figure 19 below.

Figure 19. Phase 1: Install 25 kV AC on new lines

A 1500 V DC / 25 kV AC system separation section (neutral section) is required where 1500 V DC and 25 KV AC interface. This is made of one intermediate OHLE, connected to the rail and two consecutive insulated overlaps. They are installed in areas where a flat track vertical alignment covers a 600m distance apart from each side. Pantographs are lowered when passing by system separation section.

The system separation section neutral zones for Hazelhatch and Maynooth Lines are shown on Figure 20 below. The existing DART Lines and Connolly Station electrified in 1500 V DC.

Figure 20. Phase 1: Install 25kV AC on new lines AC - Neutral Zone for Hazelhatch and Maynooth Lines



The system separation section neutral zones for Malahide to Drogheda Line is shown on Figure 21 below. One neutral section is proposed on the bridge north of Malahide station and the existing DART is still retained in 1500 V DC.

Figure 21. Phase 1: Install 25kV AC on new lines AC - Neutral Zone for Malahide to Drogheda Lines

It is necessary to undertake a more detailed design to provide further information on the position of the neutral zones as this requires consideration of detailed information regarding track alignment, infrastructure and rolling stock.

Phase 2: Convert Existing DART lines to 25 kV AC if a full 25 kV AC network is desired

The existing DART Lines could be converted to 25 kV AC to enable a full 25 kV AC network. This could coincide with existing 1500 V DC EMUs reaching the end of their life expectancy from 2035 onwards. This conversion could be assessed as a separate scheme based on its own merits.

Works will integrate the replacement of the existing type 1500 V DC insulators with 25 kV AC insulators. There may also be a need for regularisation of the OCS wire runs.

The conversion of the existing DART line could be undertaken in a short period of several month or more gradually as part of a long- term conversion plan. In both scenarios, the support structures and conductors should be retained where possible. The following steps for conversion are required:

- Undertake Electrical Clearance Works;
- Install catenary wire and/or insulated catenary at all bridges;
- Replace OHLE and Lineside Equipment such as cantilevers, droppers, switches;
- Install new 25 kV AC feeders to substations from ESB;
- Install new AC traction substations (railway);
- Install new HV traction cables;
- Install bonding connections to masts;
- Retain existing earth wire;
- Convert Bray tunnels to conductor beam if feasible; and
- Raise level crossings contact wire (if not impacted by bridge).

The main considerations for a 25 kV AC System are outlined in Table 24 below.

Table 24. 25 kV AC Installation and Phasing Considerations

INSTALLATION AND PHASING OF 25KV AC SYSTEM
The system could be introduced in two phases: • Phase 1: Install 25kV AC on new lines – Maynooth, Hazelhatch and then Drogheda and facilitate co-existence between 1500 V DC and 25 kV AC; • Phase 2: Convert Existing DART Line to 25kv AC if a full 25 kV AC network is desired.
The approach to phasing 25kV AC across the entire network is heavily interdependent with the fleet strategy because two types of rolling stock are introduced onto the network – existing 1500 V DC EMUs and new dual voltage or bi-mode EMUs.
Phase 1 requires both 1500 V DC and 25 kV AC systems in operation on the network for an interim period. This requires the inclusion of three 1500 V DC/ 25kV AC neutral zone interfaces.
Phase 1 includes the retention of existing 1500 V DC EMUs on the existing DART line. A mitigation measure is required where existing fleet continue to be maintained at Fairview Depot. This measure is retained until the existing fleet become ready for scrappage from 2035 onwards.
Phase 2 – if a full 25 kV AC network is required the Conversion of 1500 V DC to 25 kV AC could be planned to coincide with scrappage of existing 1500 V DC EMUs. There is potential to undertake conversion works on a gradual basis to minimise disruption to existing DART services.
Iarnród Éireann are not familiar with 25 kV AC systems. The introduction of a new system may present new technical issues that need to be resolved.
Two traction substations are estimated for a 2 x 25 kV AC system. This provides no capacity for N-1 redundancy unless all newly electrified lines are commissioned at the same time. The new 25kV AC system will require a connection between the two traction substations at Inchicore and Balbriggan to provide for N-1 degraded conditions. This is not considered a feasible option due to the need for all lines to be electrified simultaneously.

5.8 TC7 - Future Proofing

It is assumed that electrification of the GDA network will be introduced as a first step, followed by the possible electrification of the InterCity network, including services from Dublin to Cork and Belfast. It is important to define a long term electrification strategy for the GDA and InterCity to optimise investment and not jeopardise future countrywide electrification due to the electrification method chosen for the GDA.

DART Underground and Cork - Dublin - Belfast Intercity Electrification both feature in the National Planning Framework 2040. Funding was not provided for these schemes under the 10-year National Development Plan (NDP), however it is vital integration of these schemes is considered as part of this study. DART Underground and Intercity Electrification are both intended to integrate with the Hazelhatch/Kildare Line and Northern corridors.

25 kV AC has become the international standard for intercity electrification. 1500 V DC is not considered for this purpose because it is too costly to implement due to substation spacings. 25 kV AC is therefore anticipated for electrification of the Cork – Dublin - Belfast InterCity corridors.

The use of 25 kV AC in the GDA is preferred for intercity future proofing as it will lead to a global electrified system in 25 kV AC. This removes the need for eith dual voltage rolling stock, parallel running or interface neutral zones depending on the approach used.

The use of 1500 V DC on Hazelhatch/Kildare Line and Northern Line, or at Connolly Station, means that intercity rolling stock units need to be dual voltage. Based on current fleet estimates, this could involve up to 7 EMU units on the Cork – Dublin service using the Kildare Line and 4 EMU units on the Dublin-Belfast service using the Northern Line.

On the Hazelhatch/Kildare Line, the Dublin-Cork InterCity service is not proposed to share the electrified 'slow' commuter lines east of Hazelhatch and requires the electrification of the two 'fast lines'. It is possible to electrify the parallel 'slow' and 'fast' lines in different voltages but it does creates operational issues and safety risks for maintenance personnel so should be avoided where possible. Electrifying the 'slow lines' in 1500 V DC creates this issue if the 'fast lines' for intercity are electrified in 25 kV AC.

The DART Underground (DU) scheme is designed to accommodate either 1500V DC or 25kv AC electrification. Ideally the type of electrification used on Hazelhatch/ Kildare Line and Northern Lines approaching DU is consistent to eliminate the need for interface neutral zones as part of future works and dual voltage or bi-mode rolling stock.

In the 1500 V DC scenario for DART Underground, new 110 kV substations are required to supply the tunnel.

In the 25 kV AC scenario for DART Underground, there is the potential to utilise existing 110 kV substations at Inchicore and Grange.

Delivery of further extensions to the electrified GDA network is anticipated to be more straight forward in 25 kV AC. For example, an extension from Hazelhatch to Sallins in Co. Kildare will require a minimum of two additional substations using 1500 V DC based on approx. 5km spacings and a distance of 12km. The need for additional substations is not expected under the 25kV AC scenario.

TC7 Future Proofing Summary

The main future proofing considerations for 1500 V DC and 25 kV AC Systems are outlined in Table 25 below.

Table 25. 1500 V DC and 25 kV AC Future Proofing Considerations

FUTURE PROOFING CONSIDERATIONS	1500V DC	25 kV AC
Dublin – Belfast InterCity Rolling Stock	Parallel running or dual voltage rolling stock required	25 kV AC rolling stock required
Dublin – Cork InterCity Rolling Stock	Parallel running or dual voltage rolling stock required	25 kV AC rolling stock required
DART Underground	110 kV will be required to feed DART Underground	Potential to utilise existing substation at Inchicore and Grange
Electrification to Sallins, Newbridge and Kildare	Additional 1500 V DC substations required	Potential to utilise existing substation at Inchicore
Global System	Mix of 1500 V DC for GDA and 25 kV AC for InterCity	25kV AC for Global System

5.9 Overall Summary of Technical Evaluation

A summary of technical considerations is provided in this section under the following technical criteria headings:

- TC1 - Power Supply;
- TC2 - OHLE Infrastructure;
- TC3 - Fleet and Depot Management;
- TC4 - Electrical Clearances;
- TC5 - Signalling, Communication and Protection;
- TC6 - Installation and Phasing; and
- TC7 - Future Proofing.

TC1 Power Supply

TC1 POWER SUPPY CONSIDERATIONS	
1500 V DC CONSIDERATIONS	**25KV AC CONSIDERATIONS**
18 new tractions substations are estimated bringing the total number of substations to 31 including two sub-fed stations.	Four or five new tractions substations are estimated for a 1 x 25 kV AC system. Two traction substations are estimated for a 2 x 25 kV AC system.
The overall site compound including access road for a 1500 V DC traction substation is likely to be 1000m² .	GIS substations are recommended given the relatively dense urban / suburban environment of the rail network. The overall site compound including roads for a 25 kV AC traction substation is likely to be 3000m².The availability of sites of this size to provide a substation is a concern in areas such as Blackrock.
Iarnród Éireann has developed significant in-house experience in operating and maintaining 1500 V DC power supply systems.	Iarnród Éireann has no in-house experience in operating and maintaining 25 kV DC power supply systems.
Iarnród Éireann advised that Harmonics are not considered an issue based on their experience of the existing DART at 1500 V DC.	The impact of unbalanced loads associated with 25 kV AC Systems requires further consultation with ESB.
1500 V DC Systems tend to provide greater flexibility when dealing with N-1 Scenarios with degraded conditions at a substation, however, this needs to be determined through traction simulation modelling.	1 x 25 kV AC systems tend to provide less flexibility when dealing with N-1 Scenarios with degraded conditions at a substation.
	Two traction substations are estimated for a 2 x 25 kV AC system. This provides no capacity for N-1 redundancy unless all newly electrified lines are commissioned at the same time. The new 25kV AC system will require a connection between the two traction substations to provide for N-1 degraded conditions.
In the event that all newly electrified lines are in 1 x 25 kV AC and the existing DART is retained at 1500 V DC; thirteen 1500 V DC tractions substations and three 25 kV AC Traction substations are estimated.	

TC2 OHLE

TC2 OHLE CONSIDERATIONS	
1500 V DC	**25KV AC**
Iarnród Éireann is familiar with 1500 V DC OHLE equipment so no issues are envisaged with expanding the existing system.	The OHLE aspect of 25kV AC is similar to that of 1500 VDC OHLE. However, 25 kV AC involve the use of 'phase' neutral sections.
Installation requirements and scheduling of a new 1500 V DC OHLE systems is similar to that for a 25kV AC system.	It is feasible to undertake the conversion of existing 1500 V DC DART Lines to 25kV AC on a gradual basis, over a number of years. This results in 1500 V DC and 25 kV AC co-existing on the network prior to the conversion. This requires the introduction of three 'interface' neutral sections.
	Local maintenance teams should be actively involved in the installation of a 25kV AC system to allow familiarisation prior to handover.
	Staff need appropriate training around the use of a 25 kV OHLE System, particularly around the operation of neutral zones.

TC3 Fleet and Depot

TC3 FLEET AND DEPOT MANAGEMENT CONSIDERATIONS	
1500 V DC	25KV AC
Existing fleet and new rolling stock units are able to operate and be maintained with flexibility across the DART Network	Introduction of a 25KV AC system requires the addition of new dual voltage or bi-mode rolling stock units to ensure interoperability across the existing and newly electrified sections of the network.
Depots at Maynooth and Drogheda are expected to cater for long-term fleet maintenance requirements.	Existing 1500 V DC EMUs are being retained on the existing DART Network until they reach the end of their life expectancy. This requires a mitigation measure whereby Fairview Depot is maintained in operation until existing 1500 V DC Fleet becomes obsolete from 2035 onwards.
	If dual voltage units are proposed, electrification of depots at Maynooth and Drogheda need to accommodate dual voltage rolling stock or bi-mode rolling stock.

TC4 Electrical Clearances

TC4 ELECTRICAL CLEARANCES CONSIDERATIONS		
CATEGORY	1500 V DC AFFECTED STRUCTURES	25 KV AC AFFECTED STRUCTURES
Minimum Normal (Free Running)	25	62
Minimum Normal (Fitted)	19	39
Reduced	13	20
Special Reduced	2	15

TC5 Signalling, Communications and Protection of Equipment

TC5 SIGNALLING, COMMUNICATIONS AND PROTECTION OF EQUIPMENT	
1500 V DC	25KV AC
Re-signalling works are expected on Hazelhatch, Maynooth and Drogheda Lines. Protective measures should be included to future-proof equipment against rail electrification as part of re-signalling works	Re-signalling works are expected on Hazelhatch, Maynooth and Drogheda Lines. Protective measures should be included to future-proof equipment against rail electrification as part of re-signalling works
Stray currents need to be assessed for newly electrified lines. Iarnród Éireann is familiar with these requirements due to experience of the existing 1500 V DART Network.	The impact of interference associated with 25 kV AC Systems is not known to Iarnród Éireann. An EMC interference study to assess this impact. The impact of 25 kV AC System on the Train Protection System (TPS) and on the existing DART Corridor are important aspects of the interference study. It should include a full survey of all lineside cables..

TC6 Phasing and installation

TC6 PHASING AND INSTALLATION	
1500 V DC	**25KV AC**
Iarnród Éireann is familiar with the existing 1500 V DC network so expansion of the same system should not create technical issues unknown to them.	Iarnród Éireann are not familiar with 25 kV AC systems. The introduction of a new system may result in technical issues that were previously unknown.
Maynooth line is expected to be electrified first with a new depot at Maynooth, followed by Hazelhatch and lastly the Northern Line Drogheda extension.	The system could be introduced in two main phases: Phase 1: Install 25kV AC on new lines – Maynooth, Hazelhatch and then Drogheda and facilitate co-existence between 1500 V DC and 25 kV AC; Phase 2: Convert Existing DART Lines to 25kV AC if a single 25 kV AC System is desired.
Disruption to the existing DART Network should be minimal as the lines are being retained 'as is'.	The approach to phasing 25kV AC across the entire network is heavily interdependent with the fleet strategy because two types of rolling stock are introduced onto the network – existing 1500 V DC EMUs and new dual voltage or bi-mode EMUs.
The construction and commissioning of new traction substations is the most challenging aspect of the newly electrified 1500 V DC system. 18 new traction substations are anticipated and this may create scheduling issues for connection, commissioning and energisation works carried out by ESB. Early engagement with ESB Network on programming is recommended.	Phase 1 requires both 1500 V DC and 25 kV AC systems in operation on the network. This requires the inclusion of three 1500 V DC/ 25kV AC neutral zone interfaces.
	Phase 1 includes the retention of existing 1500 V DC EMUs on the existing DART line. A mitigation measure is required where existing fleet continue to be maintained at Fairview Depot. This measure is retained until the existing fleet become ready for scrappage from 2035 onwards.
	Phase 2 -- If a single 25 kV AC System is desired, the conversion of 1500 V DC to 25 kV AC could be planned to coincide with scrappage of existing 1500 V DC EMUs. There is potential to undertake conversion works on a gradual basis to minimise disruption to existing DART services.
	The availability of suitable sites for 3000m² traction substation compounds in Dublin suburbs may present an issue.
	Two traction substations are estimated for a 2 x 25 kV AC system. This provides no capacity for N-1 redundancy unless all newly electrified lines are commissioned at the same time. The new 25kV AC system will require a connection between the two traction substations at Inchicore and Balbriggan to provide for N-1 degraded conditions. This is not considered a feasible option due to the need for all lines to be electrified simultaneously.

TC7 Future Proofing

TC6 FUTURE PROOFING CONSIDERATIONS		
FUTURE SCHEME	1500V DC	25 AC
Dublin – Belfast InterCity Electrification	Dual voltage rolling stock required	25 kV AC rolling stock required
Dublin – Cork InterCity InterCity Electrification	Dual Voltage rolling stock required or parallel running	25 kV AC rolling stock required
DART Underground	110 kV will be required to feed DART Underground	Potential to utilise existing 110 kV substation at Inchicore
Electrification to Sallins, Newbridge and Kildare	Additional substations required	Potential to utilise existing substation at Inchicore
Global Electrified System – GDA and Intercity	Mix of 1500 V DC for GDA and 25 kV AC for InterCity	25kV AC for Global System

6 | COST EVALUATION

6.1 Introduction

Chapter 6 involves an evaluation of costs for 1500 V DC and 25 kV AC systems.

The costs in this chapter are provided for comparative purposes and are not intended to inform final scheme cost estimates. The costs are based on the most accurate cost information available during the study.

A summary of the cost criteria used for the evaluation is provided in Table 26 below, along with details of sources for cost information.

Table 26. Cost Evaluation Criteria

COST CRITERIA	SUB CRITERIA	SOURCES FOR COSTING INFORMATION
CC1 Capital Cost (infrastructure)	CC1.1 Power Supply	DART Underground Report, 2011 Rail Electrification Study, CER 2015 Standard Transmission, Distribution and Operation and Maintenance Charges, ESB DAC Connection Charges, Jacobs – industry sourced[17]
	CC1.2 OHLE	Contractor estimate, 2011 Rail Electrification Study
	CC1.3 Depots	2010 Depot Study, Dart Expansion Programme Options Assessment Study
	CC1.4 Electrical Clearances	2011 Rail Electrification Study
CC2 Capital Cost (Rolling Stock)	CC2.1 Rolling Stock	Provisional costs obtained from NTA Fleet Management Strategy
CC3 Operational and Maintenance Cost	CC3,1 Substations	CER 2015 Standard Transmission, Distribution and Operation and Maintenance Charges Jacobs – industry sourced
	CC3.2 OHLE	CER 2015 Standard Transmission, Distribution and Operation and Maintenance Charges, Jacobs – industry sourced
	CC3.3 Rolling stock	Dart Expansion Programme Options Assessment Study, 2011 Rail Electrification Study
	CC3.4 Usage Charges for electricity	ESB Networks DAC Statement of Charges, EirGrid Statement of Charges, CRU Pass through charges for businesses, DART Billing

Costs have not been assessed for mitigation against EMCs and stray currents on newly electrified lines.

It was advised that re-signalling works formed part of separate works packages under the DART Expansion Programme. As a result, re-signalling costs have not been assessed as part of this study.

The 2 x 25 kV AC System has not been costed. This is because the system was identified as been undeliverable in the current GDA context. The commissioning of all newly electrified newly lines simultaneously is not considered realistic.

17 Jacobs Engineering Ltd sourced from Morgan Sindall, Balfour Beatty, Laboratoire d'intermodalitē des transports et de la planification (LITEP), Ēcole Polytechnique Fēdērale de Lausanne (EPFL).

6.2 CC1 Capital Cost (Infrastructure)

CC1.1 Power Supply Costs

Power supply costs consist of 'ESB and Connection Costs' and 'Traction Substation Costs' for the purpose of this evaluation.

It is difficult to quantify ESB and Connection costs due to uncertainty around proposed traction substation locations and availability of power supply and land. There can be major cost implications if reinforcements works are required to the power supply grid to facilitate a connection.

ESB Substation and connection costs are based on costings in the 2011 Rail Electrification Study, DART Underground substation costs and 'ESB Networks DAC Statement of Charges 01/10/2018'.

It should be noted that for MICs above 5MVA, any new 38kV/110kV network is chargeable as a capital contribution at 50% of Attributable Costs helping reduce the overall cost. The Attributable Cost of the 38kV/110kV network is determined as a proportion of the firm capacity of the station taken up by the customer. If the customer was taking up 60% of the station then the customer would be charged 50% of 60% of the cost of the 38kV/110kV lines / cable.

The cost for any 110kV connection is subject to uncertainties surrounding the project including;

- pricing and connection policy at the time;
- the substation site being suitable and made available to ESB when required;
- the routing of the 110kV cable; and
- connection requirements at traction substation locations on completion of HV designs.

Connection costs to 110 kV network include €1.25m per km for a 110 kV cable underground and €375,000 per km for overhead lines.

The cost for direct feeds using 38 kV and 20 kV connections are provided in 'ESB Networks DAC Statement of Charges 01/10/2018'.

For newly installed systems, CAPEX costs taken from several sources including:

- DART Underground Study[18]
- 2011 Rail Electrification Study
- Jacobs - industry sourced[19]

In addition to newly installed substation, upgrade works are assumed for two of the existing DART substations. This assumption is based on supply input increasing above the existing 3000 kVA feed capacity. For example, Sandymount has an estimated MIC requirements of 4270 kVA. Upgrade works are costed at approximately €0.5m per substation to extend the existing busbar and install new circuit breakers.

Power Supply costs are provided in Table 27, 28 and 29 below.

18 Referring to DART Underground Study to ensure the figures are relatively consistent and suitable for comparative purposes, while taking into consideration potential differences in material and labour costs.

19 Jacobs Engineering Ltd sourced from Morgan Sindall, Balfour Beatty, Laboratoire d'intermodalité des transports et de la planification (LITEP), École Polytechnique Fédérale de Lausanne (EPFL).

Table 27. 1500 V DC Power Supply Costs

ASSET	ASSET COMPONENT	COST PER UNIT (€M)	QUANTITY OF UNITS	1500 V DC COST (€M)
New ESB Connections for 1500 V DC	Existing connection Upgrades	0.019 average costs	11	0.2
	New 3000 kVA & 4500 kVA connections	0.035 average cost	18	0.63
	38kV Additional Connection Works Assumed 50% overhead line (5km) and 50% underground cabling (2km)	0.045 (5km overhead)	9	0.4
		0.070 (2km of cable)	9	0.63
1500 V DC Substation	New Substation	1.75	18	31.5
	Substation Upgrade	0.5	2	1
	Civils	0.15	18	2.7
TOTAL COST				37

Table 28. 25 kV AC Phase 1 Scenario Power Supply Costs

ASSET	ASSET COMPONENT	COST PER UNIT (€M)	QUANTITY OF UNITS	1500 V DC COST (€M)
New ESB 110 kV Substation for 25kV AC System	New 110kV Substation including civil works, ESB connection	6.9	3	20.7
25kV AC Substation[20]	New Substation	4.3	3	12.9
	Civils	1	3	3
New ESB Connections for 1500 V DC	Existing connection Upgrades	0.019 average costs	11	0.2
	New 3000 kVA & 4500 kVA connections	0.035 average cost	2	0.07
	Substation Upgrade	0.5	2	1
TOTAL COST				37.9

Table 29. 25 kV AC Phase 2 Scenario Power Supply Costs

ASSET	ASSET COMPONENT	COST PER UNIT (€M)	QUANTITY OF UNITS	25 KV AC COST (€M)
New ESB 110 kV Substation for 25kV AC System	New 110kV Substation including civil works, ESB connection	6.9	5	34.5
25kV AC Substation[21]	New Substation	4.3	5	21.5
	Civils	1	5	5
1500 V DC	Substation Upgrade	0.5	2	1
TOTAL COST				62

20 25 kV AC Option is costed for five traction substations, however, it may be feasible to provide four substations to meet the estimated level of demand. The specific requirements can only be determined by through traction supply simulation modelling.

21 25 kV AC Option is costed for five traction substations, however, it may be feasible to provide four substations to meet the estimated level of demand. The specific requirements can only be determined by through traction supply simulation modelling.

Land valuations costs were considered separately to substation costs. The costs are based on high level estimates provided by Iarnród Éireann for property prices per acre.

It is the intention to site substations on land already owned by CIE where possible. However, in the interest of a fair comparison it is assumed that all substation sites need to be purchased.

Overall site compounds including access roads are likely to be 1,000m² for 1500 V DC substations and 3,000m² for 25kV AC substations.

Land purchase costs for 1500 V DC and 25 kV AC Phase 2 Scenario are provided in Table 30, 31 and 32 below.

Table 30. 1500 V DC Land Purchase Costs

ASSET	SITE LOCATION	QUANTITY OF 1500 V DC SITES	COST PER ACRE (€M)	1500 V DC COST @1000M2 (€M)
Land Purchase	City centre	0	25	0
	Outer city centre	3	6	4.5
	Dublin County	9	2	4.4
	Kildare/Louth	6	1.5	2.2
TOTAL		18	-	11.1

Table 31. 25 kV AC Phase 1 Scenario Land Purchase Costs

ASSET	SITE LOCATION	QUANTITY OF 25 KV AC SITES	COST PER ACRE (€M)	25 KV AC COST @3000M2 (€M)
Land Purchase	City centre	0	25	0
	Outer city centre	1	6	4.5
	Dublin County	1	2	1.5
	Kildare/Louth	1	1.5	1.1
TOTAL		3	-	7.1

Table 32. 25 kV AC Phase 2 Scenario Land Purchase Costs

ASSET	SITE LOCATION	QUANTITY OF 25 KV AC SITES	COST PER ACRE (€M)	25 KV AC COST @3000M² (€M)
Land Purchase	City centre	0	25	0
	Outer city centre	3	6	13.3
	Dublin County	1	2	1.5
	Kildare/Louth	1	1.5	1.1
TOTAL		5	-	15.9

Overall power supply costs are provided in Table 33 below.

Table 33. Total Power Supply Costs

COST	1500 V DC (€M)	25 KV AC PHASE 1 (€M)	25 KV AC PHASE 2 (€M)
Substation Costs	37	37.9	62
Land Costs	11.1	7.1	15.9
TOTAL COST	48.1	45	77.9

CC1.2 OHLE

Indicative costs were provided by a Contractor for design and construction of both newly installed 1500 V DC and 25 kV AC Systems.

The 2011 Rail Electrification Study included a cost for converting 1500 V DC to 25 KV AC. The conversion cost equated to 45% of newly installed 25kV AC OHLE. The reduced cost was on the basis that a large number of existing foundations and supports structures could be re-used, and polymeric insulators were installed to minimise loading on the support structures.

A conversion cost of 50% of newly installed 25kV AC OHLE is assumed for the purpose of this study. It is also assumed that 1500 V DC to 25 KV AC conversion works can take place gradually over several years.

Immunisation costs for a 'per km' of 25kV AC System are taken from the 2011 Rail Electrification Study and are factored up by 20% for the purpose of this study.

A cost is added to the 25 kV AC scenario for additional clearance requirements on the existing DART Line to cover vegetation, fencing etc. A specific cost is not available so a cost of €0.05M / km is assumed.

A Summary of OHLE and Lineside Costs are provided in Table 34 below.

Table 34. Summary OHLE and Lineside Costs

ASSET	CAPEX (INVESTMENT)	INSTALLED	1500 V DC COST (€M)	25 KV AC PHASE 1 (€M)	25 KV AC PHASE 2 COST (€M)
1500V DC Catenary System	€0.9M / km	100km	90	-	0
25 kV AC Catenary System	€0.9M / km	100km	0	90	90
1500 V DC / 25 kV AC Interface Neutral Zones	€0.6M per neutral zone	3	0	1.8	1.8
1500 V DC to 25 kV AC Conversion	€0.45M / km	50km	0	-	22.5
Additional Clearance for 1500 V DC to 25 kV AC Conversion	€0.05M / km	50km	0	-	2.5
Immunisation of DART Line equipment	€0.05M / km	50km	0	-	2.5
TOTAL COSTS			90	91.8	119.3

No allowance is made for costs incurred to address existing OHLE constraint issues on the DART Network. It is assumed that any costs incurred are the same for both options due to the phasing of the conversion for the 25kV AC Scenario.

Track sectioning cabinets and track paralleling huts are not included within per km costs for both 1500 V DC and 25 kV AC Systems.

CC1.3 Depot Facilities

New depot costs are based on the DART Expansion Options Assessment Study which included a provision for depot improvements. Costs are based on the following improvements:

- New depot at Maynooth 250 Units
- Electrified depot at Drogheda 200 Units
- Fairview Light maintenance

The 25 kV AC Scenario requires new depots to be suitable for dual voltage trains. An additional 6% cost is applied to cover this requirement, similar to that applied in the 2011 Rail Electrification Study.

There is uncertainty around future depot requirements until a total fleet number is confirmed as part of the Fleet Management Strategy.

Maintenance of the existing 1500 V DC EMUs is to be transferred to Maynooth under the 1500 V DC option. They will continue to be maintained at Fairview depot until they become ready for scrappage from 2035 onwards under the 25kV AC scenario. No cost has been attributed to this difference between the 1500 V DC and 25 kV AC options.

Depot costs for 1500 V DC and 25 kV AC are provided in Table 35 below.

Table 35. Depot Costs

DEPOT	1500 V DC COST (€M)	25 KV AC COST PHASE 1 AND 2 (€M)
Maynooth (+6% Dual)	135	143
Drogheda (+6% Dual)	25	26.5
Fairview Light	5	5.3
TOTAL	165	174.8

CC1.4 Clearance to Existing Structures

Reduce minimum fitted clearances to 4.343m for 1500 V DC systems and 4.534m for 25 kV AC systems were used for costing purposes. This is similar to the approach used in the 2011 Rail Electrification Study.

The complexity of works to existing structures makes it difficult to cost. To develop a comparative cost for the works the following assumptions have been made:

- Each of the overbridges with sub-standard clearances is to be replaced rather than adopting other measures such as track lowering, or raising the deck. These options may be investigated under more detailed studies to provide an optimum solution;
- Where the abutment is independent of the deck it is structurally adequate to support a new deck and any required increase in load capacity;
- Road levels may be increased, or deck thicknesses reduced to maintain the same profile;
- All footbridges will be completely replaced if clearance is insufficient;
- The impact on services on bridges is unknown at this stage and this could potentially increase or decrease costs and the programme for the works;
- The programme for the works will be heavily dependent on the availability of possessions on the railway;
- The obligation to maintain road traffic on bridges during the works will significantly increase the cost of the works. Full closure with diversionary routes would provide significant savings. Alternatively, if sufficient space exists, a requirement to provide a temporary bridge with associated supports, or whether the structure could be demolished in two halves to maintain traffic could be considered. Constructing the bridge on a new alignment may also be worth investigating;
- In the two tunnels affected in 25kV AC Option it has been assumed that the track can be lowered to achieve the additional 100mm clearance required. It may be possible to install rigid conductor bars, but this solution would need to be investigated as part of an optioneering exercise;
- Most of the work will be done in a mixture of possessions over midweek nights (4 hours from 11.00 PM to 5.00 AM), Saturday nights (8 hours from 12:00 PM to 08:00 AM), 28 hour weekends and occasional longer 54 hour holiday weekends. Costs of possessions are excluded from the estimates; and
- It is assumed that some of the parapets will need to be raised.

The costs include design, procurement, an allowance for service diversions and traffic management and demolition. Costs are taken from the 2011 Rail Electrification Study with a 20% increase applied to be more reflective of present day costs.

V DC Clearances

Indicative costs for structural works to address clearances for a 1500 V DC system are shown in Table 36 below.

The indicative costs are based on structural works proposed under the 2011 Rail Electrification Study with an additional 20% cost applied to be more reflective of present day costs.

Table 36. 1500 V DC Electrical clearance costs

CATEGORY	MAYNOOTH	HAZELHATCH	MALAHIDE TO DROGHEDA	DART NORTH	DART SOUTH	OVERALL
	APPROXIMATE COST (€M)					
Minimum Normal (Free Running)	8.2	10.8	8.9	-	-	27.9
Minimum Normal (Fitted)	7.2	10.8	3.8	-	-	21.8
Reduced	3.1	10.8	1.8	-	-	15.7
Special Reduced	0	0	0.9	-	-	0.9

25kV AC Clearances

Indicative costs for structural works to address clearances for Phase 1 and Phase 2 of 25 kV AC system are shown in Table 37 and Table 38 below.

The indicative costs are based on structural works proposed under the 2011 Rail Electrification Study with an additional 20% cost applied to be more reflective of present day costs.

Table 37. 25kV AC Phase 1 Electrical Clearance Costs

CATEGORY	MAYNOOTH	HAZELHATCH	MALAHIDE TO DROGHEDA	DART NORTH	DART SOUTH	OVERALL
	APPROXIMATE COST (€M)					
Minimum Normal (Free Running)	8.2	10.8	8.9			27.9
Minimum Normal (Fitted)	7.2	10.8	3.8			21.8
Reduced	3.1	10.8	1.8			15.7
Special Reduced	2	9	0.9			11.9

Table 38. 25kV AC Phase 2 Electrical Clearance Costs

CATEGORY	MAYNOOTH		MALAHIDE TO DROGHEDA	DART NORTH	DART SOUTH	OVERALL
	APPROXIMATE COST (€M)					
Minimum Normal (Free Running)	8.2	10.8	8.9	10.2	23.1	61.2
Minimum Normal (Fitted)	7.2	10.8	3.8	5.1	14.2	41.1
Reduced	3.1	10.8	1.8	2.3	6.4	24.4
Special Reduced	2	9	0.9	2.3	6	20.2

6.3 CC2 Capital Cost (Rolling Stock)

CC2.1 Rolling Stock

Indicative costs for rolling stock units are taken from NTA's Fleet Management Strategy which is an ongoing study. It is assumed that a total of 450 rolling stocks units are procured for the purpose of this assessment. Rail electrification is to take place in tandem with the procurement of additional fleet.

It is assumed that the existing EMUs are retained until the end of their life expectancy in both scenarios, as the cost and lead times associated with replacing these units are prohibitive.

Dual voltage trains are required for the introduction of 25 kV AC System to ensure interoperability of fleet across the network. Dual Voltage trains are taken to be 6% more expensive than DC EMUs.

Capital Costs for new rolling stock are provided in Table 39 below.

Table 39. Rolling Stock Costs

TYPE OF FLEET	ASSUMED COST PER UNIT (€M)	UNITS	1500 V DC COST (€M)	25 kV AC PH 1 AND PH 2 COST (€M)
DC EMU	1.7	450	765	0
AC EMU (+3%)	1.75	Nil	0	0
Dual Voltage EMU (+6%)	1.8	450	0	810
BEMU (+35%)	2.4	Nil	0	0
*Total Cost		450	765	810

*These costs are indicative only and subject to final validation by the fleet strategy.

6.4 Summary of Capital Cost

A summary of capital costs for 1500 V DC and 25 kV AC options is provided in this section.

The 25 kV AC option is assessed under two scenarios:

- Phase 1: 25kV AC is installed on newly electrified lines with existing DART retained at 1500 V DC. 25kV AC and 1500 V DC co-exist on the network; and
- Phase 2: 25kV AC is installed on all lines including conversion of the existing DART to 25 kV AC.

These scenarios reflect the options for introduction of 25kV AC considered under TC6 Phasing and Installation.

Clearance to structures costs for the 'minimum normal fitted' scenario are used.

A summary of capital costs for 1500 V DC and 25kV AC Scenarios is provided in Table 40 below.

Table 40. Summary of Capital Costs

CAPITAL CRITERIA	1500 V DC COST (€M)	25 KV AC PH 1 COST (€M)	25 KV AC PH 2 COST (€M)
CC1.1 Power Supply Costs	48.1	45	77.9
CC1.2 OHLE	90	91.8	119.3
CC1.3 Depot Costs	165	174.8	174.8
CC1.4 Clearance to Structures	21.8	21.8	41.1
CC2.1 Rolling Stock	765	810	810
TOTAL COST	1090	1143	1223

For newly electrified lines, there is an estimated cost difference of €53M with 1500 V DC being the cheaper of the two options.

The estimated difference in Capital Cost for full implementation of the two systems is €133M with 1500 V DC being the cheaper of the two options.

6.5 CC3 Operational and Maintenance Costs

Operational and Maintenance Costs consist of:

- CC3.1 Substations maintenance costs;
- CC3.2 OHLE maintenance costs;
- CC3.3 Rolling stock maintenance costs; and
- CC3.4 Usage Charges for electricity.

For the purpose of this assessment, Operational and Maintenance Costs are based on 1500 V DC and 25 kV AC Systems being fully implemented. This approach allows for a direct comparison between running costs for the two systems into the future.

A maintenance period of 30 years is used to demonstrate the cumulative difference in running costs. It is noted that infrastructures within a rail electrification system have varying lifecycle costs, but that most assets have lifespans greater than 30 years.

A per annum cost and a '30 year period' cost are provided for each criterion.

An annual inflation rate of 1% has been applied as a separate calculation to demonstrate the 'time value of money' impact on running costs. The 1% is based on standard Operational and Maintenance cost factors used for NTA Economic Appraisal. It is noted that the inflation rate for electricity charges is likely to be highly variable due to energy sources used in Ireland to generate electricity.

CC3.1 Traction Substation Maintenance Costs

It is common industry practise for Traction Substation maintenance costs to be expressed as a percentage of new asset capital costs. This approach was also used in the 2011 Rail Electrification Study. The appropriate range as an annual cost is between 1% to 3% of the investment costs. 3% is used for the purpose of this assessment.

Existing traction substations are taken to have the same asset value as new substations, however, they are expected to require more maintenance work due to the age of the assets. A penalty of 10% is applied to take this into account giving a 3.3% per annum maintenance cost for existing substations.

Traction substation maintenance costs are provided in Table 41, 42 and 43 below.

Table 41. 1500 V DC Traction Substation Maintenance Costs

COST CONSIDERATIONS	1500 V DC NEW	1500 V DC EXISTING
Asset capital cost of substation	1.75	1.75
Number of Substations including two sub-fed	18	13
Total Asset Value of substations	31.5	22.75
Annual Maintenance (@3% CAPEX for new and 3.3% for existing substations)	3%	3.3%
Total Cost Per Annum (€m)	0.95	0.75
	1.7	
Cost for 30 Year Period (€m)	51	
Cost for 30 Year Period (€m) with annual inflation @ 1%	61.4	

Table 42. 25 kV AC Phase 2 Traction Substation Maintenance Costs

COST CONSIDERATIONS	1500 V DC EXISTING	25 KV AC NEW
asset capital cost of substation	1.75	4.3
Number of Substations including two sub-fed	13	3
Total Asset Value of substations	22.75	12.9
Annual Maintenance (@3% CAPEX for new and 3.3% for existing substations)	3.3%	3%
Total Cost Per Annum (€m)	0.75	0.39
Cost for 30 Year Period (€m)	22.5	11.7
Cost for 30 Year Period (€m) with annual inflation @ 1%	27.1	14.1
TOTAL COST	41.2	

Table 43. 25 kV AC Phase 2 Traction Substation Maintenance Costs

COST CONSIDERATIONS	25 KV AC PHASE 2 NEW
Asset capital cost of substation	4.3
Number of Substations including two sub-fed	5
Total Asset Value of substations	21.5
Annual Maintenance (@3% CAPEX for new and 3.3% for existing substations)	3%
Total Cost Per Annum (€m)	0.65
Cost for 30 Year Period (€m)	19.5
Cost for 30 Year Period (€m) with annual inflation @ 1%	23.5

Traction substations for a full 25kV AC network are estimated to be €1.05m cheaper to operate per annum than a full 1500 V DC network. This equates to a saving of €37.9m over a 30 year period with annual inflation included.

Traction substations for a full 25kV AC network are estimated to be €0.49m cheaper to operate per annum than a mix of 1500 V DC / 25 kV AC as per Phase 1. This equates to a saving of €17.7m over a 30 year period with annual inflation included.

CC3.2 OHLE Maintenance Costs

OHLE maintenance costs can be expressed as a percentage of the asset capital cost. The range as an annual cost is between 1% to 3% of the overall investment costs. A cost of 3% was used for the purpose of this assessment.

There is no difference between 1500V DC and 25kV AC maintenance costs for OHLE.

Fundamentally the assets and its maintenance are similar, predominantly centred around asset condition/ replacement and conductor wire tensioning. In addition to maintenance costs, OHLE may need to consider life time expired asset replacement. In general, the economic asset life of catenary systems is between 30 to 50 years of which the contact wire may need replacement between 5 and 30 years, depending upon the type and frequency of traffic.

OHLE Maintenance costs are provided in Table 44 below.

Table 44. OHLE Maintenance Costs

OHLE TYPE	ANNUAL MAINTENANCE (@3% CAPEX)	UNITS	1500 V DC COST (€M)	25 KV AC COST (€M)
25kV AC Catenary System	€27,000/ km	150km	0	4.05
1500V DC Catenary System	€27,000 / km	150km	4.05	0
Total Cost Per Annum (€m)			4.05	4.05
Cost for 30 Year Period (€m)			121.5	121.5
Cost for 30 Year Period (€m) with annual inflation @ 1%			**146.3**	**146.3**

The cost of maintaining 1500 V DC and 25kV AC OHLE is estimated to be the same for 25 kV AC Phase 1 and Phase 2.

DC EMUs operating on the 1500 V DC System are estimated to be €1.46M cheaper to maintain per annum than dual voltage units which are required for both 25 kV AC options.

This equates to a saving of €52.4m over a 30 year period with annual inflation included when compared to using dual voltage rolling stock.

CC3.3 Rolling Stock Maintenance

Rolling Stock maintenance costs reflect costs provided under Bundle 6 of the DART Expansion Programme Options Assessment Study based on a fleet of 450 EMUs.

The maintenance cost is taken to be €0.46 km/annum per EMU based on the proposed train services pattern. An additional maintenance cost of +6% is assumed for dual voltage rolling stock.

Rolling stock maintenance costs are provided in Table 45 below.

Table 45. Rolling Stock Maintenance Costs

TYPE OF FLEET (450 UNITS)	1500 V DC COST (€M)	25 KV AC PH 1 AND PH 2 COST (€M)
DC EMU	24.4	0
Dual Voltage EMU (+6%)	0	25.86
Total Cost Per Annum (€m)	24.4	25.86
Cost for 30 Year Period (€m)	732	775.8
Cost for 30 Year Period (€m) with annual inflation @ 1%	881.6	934.4

CC3.4 Charges for use of Electricity

There are several different charging costs associated with the use of electricity. These costs can be split into three main groups;

- Direct supply consumption charges;
- Non-direct supply consumption charges; and
- Demand and Capacity Based Charges.

Direct supply consumption charges consist of per unit energy costs charged by the supplier to the customer.

Non-direct supply consumption charges are 'Pass Through Costs for Business Electricity Customers' as described by the Commission for Regulation of Utilities (CRU) in their 2018 of document of the same name. The Pass Through Costs considered within the CRU publication are shown on the diagram below.

Figure 22. CRU Pass Through Costs for Business Electricity Customers

Cost	Charge	Description
Generation	Capacity Payments	Payment made to generators for availability separate from energy production.
	Market Operator Charges	Charges levied on generators and suppliers for the operation of the wholesale markets.
	Imperfection Charges	Constraint costs on the network are recovered by imperfection charges.
Networks	Network Transmission use of system charges (TUoS)	Charges levied for the building, maintenance and operation of the transmission network.
	Network Distribution use of system charges (DUoS)	Charges levied for the building, maintenance and operation of the distribution network.
PSO	Public Service Obligation Levy	Levied for support for renewables, security of supply and indigenous fuels (peat).

Demand and Capacity charges are based on the type of connection a customer has to the power supply network. 1500 V DC Systems connections are assumed to be DTS-D1 Large Energy Users based on their connection to the 38 kV network. 25kV AC Systems are assumed to be DTS-T Large Energy Users based on their connection to the 110 kV network.

For the purpose of this assessment, 1500 V DC and 25 kV AC Systems are assumed to use the same quantity of power to operate the same train services pattern. This power consumption is measured in kilowatt hours (kwh) or megawatt hours (MWh).

Estimates for the following key criteria are required when comparing the charging regimes for 1500 V DC and 25 kV systems:

- Power consumption (kwh, MWh);
- Max Demand (kVA);
- Maximum Import Capacity (kVA); and
- Installed Capacity (kVA).

The power consumption was estimated by factoring up 2017 DART power consumption on a straight-line basis using the increase in 'Trains per direction per hour (TPDPH) as a growth factor.

For 1500 V DC, the straight-line accumulation was also used to estimate the Max Demand and Maximum Import Capacity (MIC). Max Demand is taken as 90% of MIC. The installed capacity is estimated by combing the supply feeds for each traction substations into a total figure.

For the 25 kV AC System, estimates are based on a comparison with a 25 KV AC system in Glasgow. This approach is considered to be less accurate as baseline figures are extrapolated from an alternative rail electrification system. The baseline figures are factored up on a straight line basis using the increase in 'Trains per direction per hour (TPDPH) as a growth factor. MIC, Max Demand and installed capacity are calculated using a similar approach to the 1500 V DC method.

Charging rates were taken from a 2017 Traction Power Supply bill and from ESB[22] and EirGrid[23] Statement of Charges documents.

The key criteria for estimating charging costs are listed in Table 46 below.

Table 46. Key Criteria for Charging Cost Assessment

KEY CRITERIA FOR CHARGING	1500 V DC	25 kV AC
Max Demand (kVA) [24]	57,000	41,000
Maximum Import Capacity (kVA)	62,000	47,000
Installed Capacity (kVA)	85,000	63,000
Power Consumption (kWh)	157,344,000	

Total estimates charges for the 1500 V DC and 25 kV AC Phase 1 and Phase 2 Systems are provided in Table 47 below. Further details on charging costs are provided in an Appendix.

Table 47. Summary of 1500 V DC and 25 kV AC Charges

22 ESB Networks DAC Statement of Charges 9/2018

23 EirGrid Statement of Charges 2018/2019 09/2018

24 It is noted that 1500 V DC estimate is based on an understanding of the existing 1500 V DC system while 25 kV AC is based on a comparison of an alternative systems and involves a higher degree of professional judgement

ANNUAL CHARGES	1500 V DC COST (€M)	25 KV AC PHASE 1 COST (€M)	25 KV AC PHASE 2 COST (€M)
Non direct supply consumption	4.2	4.2	4.1
Direct supply consumption	9.8	9.8	9.8
Demand and Capacity Based Charges	4.6	3.7	3.4
Total Charges for Year	18.6	17.7	17.3
Total Charges for 30 Year Period	558	531	519
Cost for 30 Year Period (€m) with annual inflation @ 1%	672.1	639.1	625.1

Full 25 kV AC System electricity charging costs are estimated to be €1. 3M cheaper than those required to operate a 1500 V DC System. This equates to a saving of €47m over a 30 year period with annual inflation included when compared to using a 1500 V DC System.

Electrifying new lines in 25 kV AC and retaining existing in 1500 V DC is cheaper than a full 1500 V DC Network but more expensive than a full 25 kV AC network.

Summary of Operational and Maintenance Cost

A summary of combined operational and maintenance costs for 1500 V DC and 25 kV AC Systems is provided in Table 48 below.

Table 48. Summary of Operational Costs

O & M COST	1500 V DC COST (€M)	25 KV AC PH 1 COST (€M)	25 KV AC PH 2 COST (€M)	1500 V DC COST (€M)	25 KV AC PH 1 COST (€M)	25 KV AC PH 2 COST (€M)
	Per Annum			Over 30 year Period		
CC3.1 Substation Maintenance Costs	1.7	1.1	0.65	51	34.2	19.5
CC3.2 OHLE Maintenance Costs	4.05	4.05	4.05	121.5	121.5	121.5
CC3.3 Rolling Stock Maintenance	24.4	25.9	25.9	732	775.8	775.8
CC3.4 Charges for use of Electricity	18.6	17.7	17.3	558	531	519
	Per Annum			Over 30 year Period		
TOTAL COST	48.75	48.75	47.86	1462.5	1462.5	1435.8
COST FOR 30 YEAR PERIOD WITH ANNUAL INFLATION @ 1%				1761.5	1761.5	1729.3

A 25 kV AC System is estimated to be €0.89M cheaper per annum to operate and maintain than a 1500 V DC System and 25 kV AC Phase 1 mixed system.

This equates to a saving of €32.2m over a 30 year period with annual inflation included.

The full conversion of the system to 25 kV AC could enable further savings in the future as dual voltage fleet are gradually replaced with 25kV AC EMUs.

Overall Summary of Cost Evaluation

A summary of the overall costs for each of the scenarios is provided in Table 49 below.

Clearance to Structures costs for the 'minimum normal fitted' scenario are used.

Operational and Maintenance costs are taken for a 30 Year Period.

Table 49. Summary of Overall Costs

COST	1500 V DC	25 KV AC PHASE 1	25 KV AC PHASE 2
CC1.1 Power Supply Costs	48.1	45	77.9
CC1.2 OHLE	90	91.8	119.3
CC1.3 Depot Costs	165	174.8	174.8
CC1.4 Clearance to Structures	21.8	21.8	41.1
CC2.1 Rolling Stock	765	810	810
TOTAL CAPITAL COST	1090	1143	1223
CC3.1 Substation Maintenance Costs	51	34.2	19.5
CC3.2 OHLE Maintenance Costs	121.5	121.5	121.5
CC3.3 Rolling Stock Maintenance	732	775.8	775.8
CC3.4 Charges for use of Electricity	558	531	519
O&M Cost for a 30 Year period with annual inflation @ 1%	1761.5	1761.5	1729.3
TOTAL COST	2851.5	2904.5	2952.3

Key Conclusions from Cost Evaluation

A 1500 V DC System is estimated to be cheaper to install and operate over a 30 year period by €53M when compared to 25kV AC Phase 1, and €100.8 when compared to 25 KV AC Phase 2.

The need for dual voltage rolling stock, and associated infrastructure such as depots, is one of the main disadvantages of introducing a 25 kV AC system.

A key consideration when comparing 1500 V DC with 25kV AC from a cost perspective is whether the longer term cost savings attributed to 25kV AC outweigh the short to medium term capital expenditure savings that would be attributed with 1500 V DC.

7| CONCLUSION, KEY CONSIDERATIONS AND NEXT STEPS

7.1 Introduction

This report has assessed the proposed electrification of the GDA Rail network, with particular focus on two electrification systems: 1500V DC and 25kV AC. These two options are seen as the most appropriate electrification system options for the GDA. They have been assessed under technical and cost criterion with a view to allowing the National Transport Authority and Iarnród Éireann to make an informed decision on which system is the best to proceed with in the context of supporting the delivery of the DART Expansion programme.

7.2 Need for Electrifying the GDA Rail Network

Generally in most countries there is a drive to electrify rail networks, particularly suburban rail networks with closely spaced stations with high levels of passenger demand and on interurban rail lines carrying heavy and frequent services. One of the key benefits of electrifying the full GDA Rail network is the higher rate of acceleration and better performance when compared to diesel and the greater security of power supply, lower maintenance costs and environmental benefits.

One of the key components of the DART Expansion Programme involves the electrification of existing rail lines as identified in the Government's Project Ireland 204025 – National Planning Framework (NPF) and National Development Plan (NDP) 2018-2027 and the NTA's Greater Dublin Area (GDA) Transport Strategy26.

At present, the only part of the Irish rail network that is electrified is the existing DART (Dublin Area Rapid Transit) line. DART consists of a north-south line from Malahide, north County Dublin, to Greystones, County Wicklow with a branch to the peninsula of Howth.

The main and immediate driver for full electrification of the GDA rail network is linked to the requirement to meet increased passenger demand, operational issues and phasing associated with the DART Expansion Progamme. While this is the immediate issue, any decision should also give some consideration of the potential for longer term electrification of InterCity routes.

25 Project Ireland 2040 is the Government's overarching planning policy initiative for development up to 2040. It was published along with its associated documents the National Planning Framework to 2040 and the National Development Plan 2018-2027 in February 2018.

26 The Transport Strategy for the Greater Dublin Area, 2016-2035 was prepared and published by the National Transport Authority in 2016.

7.3 Choice of Electrification System

There are two principal types of Rail Electrification Systems – the DC (Direct Current) electrification system and the AC (Alternating Current) electrification system. The difference is based on the type of source supply system that is used while powering the electric locomotive systems.

This report has identified the issues and solutions associated with the electrification of the GDA rail network with specific consideration given to two electrification options:

- 1500V DC; and
- 25kv AC.

A 1500V DC overhead contact system is used to provide electrical energy to the existing DART network. The expansion of the existing 1500V DC system, therefore, is considered a viable option for the electrification of the full GDA rail network.

25 kV AC is the most widely used system in new electrification schemes. There is also several instances in Europe and elsewhere where existing DC systems are replaced with 25 kV AC; to accommodate higher levels of heavier rail traffic and/or on interurban networks. Recent examples include announcements in Slovakia and Czech Republic to convert 3kV DC Lines to 25kV AC and the Mumbai project referenced in Chapter 2. The use of 25 kV AC for GDA rail electrification is therefore considered a viable option for the full GDA rail network.

Consequence of the Existence of 1500V DC

A key consideration in the choice of an electrification system for the GDA rail network is the fact that the 1500V DC system between Malahide / Howth and Greystones already exists. This means that there is significant in-house experience with this system within Irish Rail and it is supported by a fleet of existing EMUs along with dedicated maintenance facilities at Fairview. Expansion of the existing system involves lower risk due to familiarity with the infrastructure and its operational requirements.

Moving to 25kV AC will require operating two systems in tandem and the need to purchase dual voltage rolling stock (to allow for interoperability between the two systems). Furthermore, existing DART EMUs cannot be converted to operate on 25kV AC and have very little residual value.

Consequence of Electrifying New Lines

International experience indicates that under a green field site scenario only the 25 kV AC option is likely to be considered. This is due to less capital and running costs when starting from new. Therefore, for example, electrifying the Malahide to Drogheda section in 25kV AC may be more appropriate (in the context of that section alone).

Consequence of Reconfigured GDA Rail Network

Another key consideration is the fact that the existing and future rail network assumptions have changed since the previous 2011 study was undertaken which affect the previous recommendations on GDA rail network electrification.

The Phoenix Park Tunnel (PPT) is now integrated into the DART Network, with Connolly as the major hub connecting the Maynooth, Kildare and Northern rail lines. The PPT was not part of the DART Expansion rail network that was considered in the 2011 Study. The implication of this is that DART Underground is not a short to medium component of the DART Expansion programme and is, therefore, not required to be in place to allow GDA electrification to proceed. DART Expansion is now intended to be delivered as a programme of projects which requires potential segmentation of the electrification schemes so that individual lines can be progressed independently, with each line intended to have uniform design and equipment specified throughout.

Previously, with DART Underground being assumed as an integral part of DART Expansion whilst the use of the PPT was not assumed, the network was to operate as two corridors:

- Maynooth – Greystones; and
- Hazelhatch to Malahide/Drogheda (operating through DART Underground).

This assumed operation, influenced the thinking with regard to how electrification could be delivered and to the choice of electrification system (i.e. whether 1500V

DC or 25kV AC). For example, with DART Underground assumed, the Maynooth – Greystones corridor could operate in 1500V DC whilst the Hazelhatch to Malahide/Drogheda could operate in 25kV AC independently, without the need for 1500V DC / 25kV AC system separation sections. This provided an opportunity to consider future proofing against intercity electrification on the Cork-Dublin-Belfast corridor to which 25 kV AC would be a better system. However, under the current DART Expansion programme all lines meet at Connolly Station and interact with the existing DART Line which is electrified at 1500 V DC.

Overall, the consequence of this network change is that electrification of each of the newly electrified lines may be progressed independently and the interaction between 1500V DC and 25 kV AC systems need careful consideration if the 25 kV AC is being introduced.

Consequence of Delivery and Phasing

Delivery of electrification in 1500 V DC is expected to be more straightforward than in 25kV AC for the following reasons:

- Iarnród Éireann has in-house experience of 1500 V DC systems so expansion of the same system should not create unknown technical issues;
- There will be no significant impact on the existing electrified section of the DART network (currently in 1500 V DC) with little or no service disruption during extension works; and
- Existing fleet and new rolling stock units will be able to operate with flexibility across the DART network.

A downside of the 1500 V DC option is that approximately 18 new traction substations will be required. The commissioning of these substations may create scheduling issues for connection, commissioning and energisation works to be carried out by ESB. Suitable sites for each traction substation need to be identified with each site compound including roads likely to require an area of 1000m2.

The 25 kV AC option will require fewer substations than that of the 1500 V DC option. There will be approximately 4-5 required for the 1 x 25 kV AC option and 2 required for the 2 x 25 kV AC option[27]. These substations are typically larger than those required for 1500V DC option and involve more complicated grid connections. Suitable sites for each traction substation need to be identified with each site compound including roads likely to require an area of 3000m2.

The delivery of an overall 1 x 25 kV AC system will require a two-stage phasing-in strategy. The first phase involves electrifying new lines at 25 kV AC which will co-exist with the existing 1500 V DC DART network. The second phase involves the conversion of the existing DART network to 25 kV AC.

For 25 kV AC and 1500 V DC to co-exist a number of implementation measures are required, as follows:

- Three 1500 V DC/ 25kV AC interface neutral zones;
- New dual voltage or bi-mode rolling stock units to ensure interoperability for units across the network; and
- Depots at Maynooth and Drogheda will need to accommodate dual voltage rolling stock or bi-mode rolling stock.

In addition, for the 25 kV AC option the existing 1500 V DC EMU will continue to be maintained at Fairview Depot and is likely to be retained until the existing fleet become ready for scrappage from 2035 onwards.

The conversion of existing 1500 V DC to 25 kV AC may result in significant disruption to existing DART services works. Existing masts could potentially be retained but other components (arms, insulators, head spans, etc) need replacement. The resolution of sub-optimal clearance issues will involve works to approximately 20 structures. The gradual phasing of these works could help mitigate against this disruption.

Consequence of Cost

The cost difference between 1500 V DC and 25 KV AC systems is largely driven by the existence of the 1500 V DC system and the requirement for additional upfront cost for a full fleet of dual voltage or bi-mode stock associated with introducing a 25 kV AC system. This makes 1500 V DC a more cost effective solution to implement in the short to medium term.

A 1500 V DC System is estimated to be cheaper to install and operate over a 30 year period by €53M when compared to 25kV AC Phase 1, and €100.8 when compared to 25 KV AC Phase 2.

The need for dual voltage rolling stock, and associated infrastructure such as depots, is one of the main disadvantages of introducing a 25 kV AC system from a cost perspective.

A key consideration when comparing 1500 V DC with 25kV AC from a cost perspective is whether the longer term cost savings attributed to 25kV AC outweigh the short to medium term capital expenditure savings that would be attributed with 1500 V DC.

27 The 2 x 25 kV AC system will require two traction substations at Inchicore and Balbriggan. The use of two substations means that all newly electrified lines must be commissioned at the same time to provide redundancy associated with N-1 degraded conditions. This is not considered a feasible option due to the need for all lines to be electrified simultaneously.

Uncertainty around availability of power supply

It should be noted that consultation is ongoing to with ESB regarding the availability of power supply to facilitate future connections.

Power supply demand estimates including within this study for both 1500 V DC and 25 kV AC are for indicative purposes only. A traction power simulation study needs to be carried out to accurately determine power supply requirements for rail electrification systems.

Consequence of the NTA Fleet Management Strategy

At the time of writing this report, the Fleet Management Strategy indicated a preference for the introduction of bi-mode units in the form of battery electrified modified units (BEMUs). The strategy identified that dual voltage BEMUs are not being considered in the GDA context.

The strategy proposes the introduction of BEMUs prior to the newly electrified lines becoming operational. This means that BEMUs will need to operate using 1500 V DC to enable charging from the existing DART system.

The consequence of this strategy is that the existing DART needs to be retained at 1500 V DC to facilitate the introduction of the BEMUs and continued operation of these units for their expected asset life cycle.

7.4 Pros and Cons Assessment

A pros and cons assessment has been undertaken for 1500 V DC and 25 kV AC to highlight the positive and negative elements of both options when compared to one another, particularly in the context of GDA rail electrification.

OPTION	PROS	CONS
1500 V DC	• Overall, the 1500 V DC system is estimated to cost €100.8M less to install, operate, and maintain over the first 30 year period than a full 25 kV AC System. • The 1500 V DC system is estimated to cost €53M less to install, operate, and maintain over the first 30 year period than electrifying new lines in 25 kV AC and retaining the existing 1500 V DC network. • The capital cost is estimated to be €133m less for full implementation of 1500 V DC, when compared to full 25 kV AC. • The capital cost is estimated to be €53m less for newly electrified lines only, when conversion of the existing 1500 V DC to 25 kV AC is not included in the cost for the 25 kV AC scenario. • There will be no significant impact on the existing electrified section of the DART network, with little or no service disruption during extension works anticipated. • Existing fleet and new rolling stock units will be able to operate with flexibility across the DART network • Iarnród Éireann has significant in-house experience of 1500 V DC systems so expansion of the same system should not create technical issues unknown to them. • Traction substation compounds are smaller with overall site compound including roads likely to be 1000m2 • Generally, there is greater flexibility to deal with N-1 degraded conditions in case of incident at a substation.	• The system is estimated to cost €0.89M more to operate and maintain per annum based on O&M cost estimates. This will increase further when dual voltage or bi-mode rolling stock are no longer required for the 25kV AC Option. • A higher number of traction substations are required, estimated at 31 substations in total. • The commissioning of a high number of traction substations, estimated at 18, may create scheduling issues for connection, commissioning and energisation works carried out by ESB. • Intercity electrification at 25 kV AC can still be delivered, however, this will result in a global electrified rail system, GDA and InterCity, in two types type of electrification. • Stray currents need to be assessed for newly electrified line, however, Iarnród Éireann is familiar with these requirements due to experience of the existing 1500 V DART Network.

OPTION	PROS	CONS
25 kV AC	• The system is estimated to cost €0.89M less to operate and maintain per annum. The running cost savings can be expected to increase further when dual voltage fleet are replaced with 25kV AC EMUs following full conversion to 25kV AC. • Requires substantially fewer traction substations, likely to be 4-5 for a 1 x 25 kV AC scenario. • Less maintenance work is required overall due to the smaller number of traction substations. • 25kV AC technology is most suited for longer distance trips and is compatible with longer term electrification of InterCity services without the need for dual voltage technology. • Provides an opportunity for further expansion of the DART network, to Sallins as an example, without the need to deliver additional traction substations. • Provides an opportunity for a global electrified rail system, GDA and InterCity, in one type of electrification. This is beneficial from a resourcing and asset management perspective.	• Overall, a full 25 kV AC system is estimated to cost €100.8M more to install, operate, and maintain over the first 30 year period. • Electrifying new lines in 25 kV AC and retaining existing 1500 V DC network is estimated to cost €53M more to install, operate, and maintain over the first 30 year period than a 1500 V DC network. • The capital cost is estimated to be €133m more for full implementation of 25 kV AC, when compared to 1500 V DC option. • The capital cost is estimated to be €53m more for newly electrified lines only, when conversion of the existing 1500 V DC to 25 kV AC is not included in the cost for the 25 kV AC scenario. • Iarnród Éireann are not familiar with 25 kV AC systems. The introduction of a new system may result in technical issues that are currently unknown to them. • Requires a strategy where 25kV AC and 1500 V DC co-exist on the network. This requires the inclusion of three 1500 V DC/ 25kV AC neutral zone interfaces. • New dual voltage or bi-mode rolling stock units are required to ensure interoperability for units across the network. • Depots at Maynooth and Drogheda need to accommodate dual voltage rolling stock or bi-mode rolling stock • A mitigation measure is required where existing fleet continue to be maintained at Fairview Depot. This measure is retained until the existing fleet become ready for scrappage from 2035 onwards. • There may be significant disruption to existing DART services as a result of the conversion works. Existing masts could potentially be retained but other components (arms, insulators, head spans, etc) need replacement. The resolution of sub-optimal clearance issues will involve works to approximately 20 structures. The gradual phasing of these works could help mitigate against this disruption. • Traction substation compounds are larger with overall site compound including roads likely to be 3000m2. • EMC Interference for 25 kV AC systems is higher and mitigation measures are required. Existing DART infrastructure will need to be immunised. • 25 kV AC systems result in unbalanced loads on the system that need to be managed. • Generally, there is less flexibility to deal with N-1 degraded conditions in case of incident at a substation. • The 2 x 25 kV AC system requires two substations. This means that all newly electrified lines must be commissioned at the same time to provide traction substation redundancy associated with N-1 degraded conditions. This is not considered a feasible option due to the need for all lines to be electrified simultaneously

7.5 Next Steps

The key next step is to conclude discussions with ESB on feasibility of providing power supply for 1500 V DC and 25 kV AC Systems.

APPENDIX A

Future Traction Power Consumption And Data Analysis

DRAFT OPTIONS REPORT

Power Demand DC

Sub Station	Capacity	M.I.C.	Max Demand	Max Demand Date	Train Running Data (TPHPD)				% (TPHPD) Increase			Max Demand Increase(Based on TPHPD Increase). Allows for 12.5% load increase for all EMU's being 8 car.			Where possible new substations will be based on similar substaitons within the existing DART network for comparison purposes until power simulaiton can be carried out	M.I.C Level (Max Demand + 10%)			
					Existing	2025	2029	2035	2025	2029	2035	2025	2029	2035	Notes	Existing	2025	2029	2035
		kVA	kVA	Date								kVA	kVA	kVA			kVA	kVA	kVA
Greystones TPH																			
Greystones	2 * 3,000 kva	750	690	Dec 17	2	1	2	2	-50%	0%	0%	431	776	776	No increase in traffic by 2035. Bray TPH located south of Bray Station	758	474	853	853
Brayhead TPH															Possible Conversion to Sub Station for 2035 Service Pattern. Will reduce demand on adjacent substations				
Bray															Sub fed from Shankhill. Possible Installation of HV Connection to suit service pattern subject to power modelling				
Shankill	2 * 3,000 kva	2,250	1,576	Dec 17	6	5	7	9	-17%	17%	50%	1,510	2,035	2,561		1733	1661	2239	2817
Killiney TPH															Possible Conversion to Sub Station for 2035 Service Pattern. Will reduce demand on adjacent substations				
Dalkey	2 * 3,000 kva	1,070	822	Jun 17	6	5	7	9	-17%	17%	50%	788	1,062	1,336		904	867	1168	1469
Dun Laoghaire	2 * 3,000 kva	1,000	1,068	Aug 17	6	8	8	12	33%	33%	100%	1,558	1,558	2,270		1175	1713	1713	2496
Blackrock															Sub fed from Sandymount Possible Installation of HV Connection to suit service pattern				
Sandymount	2 * 3,000 kva	2,400	1,825	Feb 18	6	8	8	12	33%	33%	100%	2,661	2,661	3,878		2007	2927	2927	4266
Pearse	2 * 3,000 kva	1,000	732	Feb 18	6	10	11	16	67%	83%	167%	1,312	1,434	2,045		806	1444	1578	2249
Connolly TPH															Possible Conversion to Sub Station for 2035 Service Pattern. Will reduce demand on adjacent substations (Particularly Glasnevin Substation)				
Fairview	2 * 3,000 kva	1,350	1,207		6	10	9	12	67%	50%	100%	2,163	1,962	2,566		1328	2380	2158	2822
Killester TPH																			
Raheny	2 * 3,000 kva	932	1,140		6	10	9	12	67%	50%	100%	2,042	1,852	2,422		1254	2247	2038	2665
Howth Jct TPH																			
Portmarnock	1 * 3,000 kva	700	760		3	10	7	9	233%	133%	200%	2,627	1,868	2,374		836	2890	2054	2612
Malahide	2 * 3,000 kva	505	370		3	7	7	7	133%	133%	133%	910	910	910		407	1001	1001	1001
Malahide TPH																			
Bayside	2 * 3,000 kva	1,550	1,655		3	3	3	3	0%	0%	0%	1,862	1,862	1,862		1821	2048	2048	2048
Howth TPH																			
															No Existing Data for Northern Lines but similar to TPHPD currently running through Dun Laoghaire. % Increase taken from first electric service 2029				
Donabate	2 * 3,000 kva	1,000	1,068		0	0	4	6	0%	0%	50%	0	1,202	1,736		0	0	1322	1909
Rusk & Lusk	2 * 3,000 kva	1,000	1,068		0	0	4	6	0%	0%	50%	0	1,202	1,736		0	0	1322	1909
Skerries	2 * 3,000 kva	1,000	1,068		0	0	4	6	0%	0%	50%	0	1,202	1,736		0	0	1322	1909
Ardgillan Castle	2 * 3,000 kva	1,000	1,068		0	0	4	6	0%	0%	50%	0	1,202	1,736		0	0	1322	1909
Balbriggan	2 * 3,000 kva	1,000	1,068		0	0	4	6	0%	0%	50%	0	1,202	1,736		0	0	1322	1909
Gormanstown	2 * 3,000 kva	1,000	1,068		0	0	4	6	0%	0%	50%	0	1,202	1,736		0	0	1322	1909
Draycott	2 * 3,000 kva	1,000	1,068		0	0	4	6	0%	0%	50%	0	1,202	1,736		0	0	1322	1909
Drogheda	2 * 3,000 kva	1,000	1,068		0	0	4	6	0%	0%	50%	0	1,202	1,736		0	0	1322	1909
															No Existing Data for Maynooth Lines but similar to TPHPD currently running through Dun Laoghaire. % Increase taken from first electric service 2025				
Glasnevin	2 * 3,000 kva	1,000	1,068		0	8	8	23	0%	0%	188%	1,202	1,202	3,204	Feeds Up and Down Lines through Glasnevin ,North Stand and Newcomen Junctions	0	1322	1322	3524
Ashtown	2 * 3,000 kva	1,000	1,068		0	8	8	13	0%	0%	63%	1,202	1,202	1,869		0	1322	1322	2056
Coolmine	2 * 3,000 kva	1,000	1,068		0	8	8	13	0%	0%	63%	1,202	1,202	1,869		0	1322	1322	2056
Dunboyne	2 * 3,000 kva	1,000	1,068		0	8	8	13	0%	0%	63%	1,202	1,202	1,869	Increased No. of trains as feeds Up and Down Lines beyond junction at Clonsilla	0	1322	1322	2056
Leixlip (Louisa)	2 * 3,000 kva	1,000	1,068		0	5	5	8	0%	0%	60%	1,202	1,202	1,842		0	1322	1322	2027
Maynooth	2 * 3,000 kva	1,000	1,068		0	5	5	8	0%	0%	60%	1,202	1,202	1,842		0	1322	1322	2027
															No Existing Data for Kildare Lines but similar to TPHPD currently running through Dun Laoghaire. % Increase taken from first electric service 2029				
Inchicore	2 * 3,000 kva	1,000	1,068		0	0	8	14	0%	0%	75%	0	1,202	2,003		0	0	1322	2203
Cherry Orchard	2 * 3,000 kva	1,000	1,068		0	0	8	14	0%	0%	75%	0	1,202	2,003		0	0	1322	2203
Balgaddy	2 * 3,000 kva	1,000	1,068		0	0	8	14	0%	0%	75%	0	1,202	2,003		0	0	1322	2203
Hazelhatch	2 * 3,000 kva	1,000	1,068		0	0	8	14	0%	0%	75%	0	1,202	2,003		0	0	1322	2203

0

Train Running Data matched against 2017 Figures				% Increase against 2017 Figures		
2017	2025	2029	2035	2025	2029	2035
53	119	184	285	225%	347%	538%

Power Demand AC

Sub Station	Transformer Capacity	M.I.C.	Max Demand	Max Demand Date	Train Running Data (TPHPD)				% (TPHPD) Increase			Max Demand Increase(Based on TPHPD Increase). 2035 allows for 12.5% load increase for all EMU's being 8 car.			Demand Capacity taken from similart site in the UK (Parkhead Feeder station) which is installed with 2 x10MVA transformers with 8TPDPH over 127 Single Track Kilomtres (STK).	M.I.C Level (Max Demand + 10%)			
					Existing	2025	2029	2035	2025	2029	2035	2025	2029	2035	Notes	Existing	2025	2029	2035
		kVA	*kVA*	*Date*								kVA	kVA	kVA	Maximum demand for each transformer taken ay 60% Capacity		kVA	kVA	kVA
Balbriggan	2 * 10Mva	N/A	6,000		0	0	4	6	***0%***	***0%***	***50%***	0	3,375	6,750		0	0	3713	7425
Grange	2 * 10Mva	N/A	6,000		0	10	9	12	***0%***	***-10%***	***20%***	5,400	5,400	6,750		0	5940	5940	7425
Blackrock	2 * 10Mva	N/A	6,000		0	10	11	16	***0%***	***10%***	***60%***	4,050	4,455	6,750		0	4455	4901	7425
Leixlip	3 * 10Mva	N/A	6,000		0	8	8	13	***0%***	***0%***	***63%***	4,253	4,253	6,750		0	4678	4678	7425
Incicore	2 * 23Mva	N/A	14,000		0	0	8	14	***0%***	***0%***	***75%***	0	11,813	15,750	Larger supply capacity to feed other lines if required	0	0	12994	17325

Train Running Data matched against 2017 Figures				**% Increase against 2025 Figures**		
2017	2025	2029	2035	2025	2029	2035
0	28	40	61	*0%*	*143%*	*218%*

Power Consumption AC

	MAX Train Pattern	Supply Capacity Per site	Feeding area in STK	Annual Consumption for 8TPHPD (Based on UK similar site)	Number of trains above or below 8TPHPD	Annual Consumption based on train pattern	Annual Consumption with 12.5% load increase for all
	TPHPD	MVA	STK	MWh	No.	MWh	MWh
Balbriggan	6	6,000	45	15439	0.75	11579	13027
Grange	12	6,000	40	15439	1.50	23159	26053
Blackrock	16	6,000	60	15439	2.00	30878	34738
Leixlip	13	8,000	36	15439	1.63	25088	28224
Incicore	14	14,000	50	15439	1.75	27018	30396

STK = Single Track Kilometre (Standard unit of measurement for new electrification)

Blackrock taken as double track between Bray and Greystones to allow for future expansion

Balbriggan taken without future extension to Belfast

Annual Consupmtion shown above is taken from a similar sized Feeder station in the UK which is in the Glasgow area and feeds an area with 127STK with 8TPHPD

Annual Consumption for all AC system is calculated as 132,438MWh. This willl need confirmation by power modelling to ensure all assumtions are correct

Annual Cost for energy consumption cannot be calculated until ESB are consulted with regard to distribution and associated standing charges for each connection site

APPENDIX B

Traction Power Supply Schematics For 1500 V Dc And 25 Kv Ac Options

DRAFT OPTIONS REPORT

Notes:

1. Do not scale from drawing
2. All new Substations provisionally located (power supply dependant)
3. All Substation converted from TPH are subject to power supply availability
4. All substations subject to increased power supply are subject to availability of power supply
5. Sectioning points are not shown for clarity
6. Future AC extensions not shown for clarity
7. New substations shown with only 1 incoming supply point
8. Substations shown without rectifier for clarity
9. Heuston station shown electrified but with simple layout
10. Switching and substation numbers are provisional
11. Additional TP Huts may be required on completion of power modelling
12. M.I.C. Figures are indicative and are quoted at 2035 timetable

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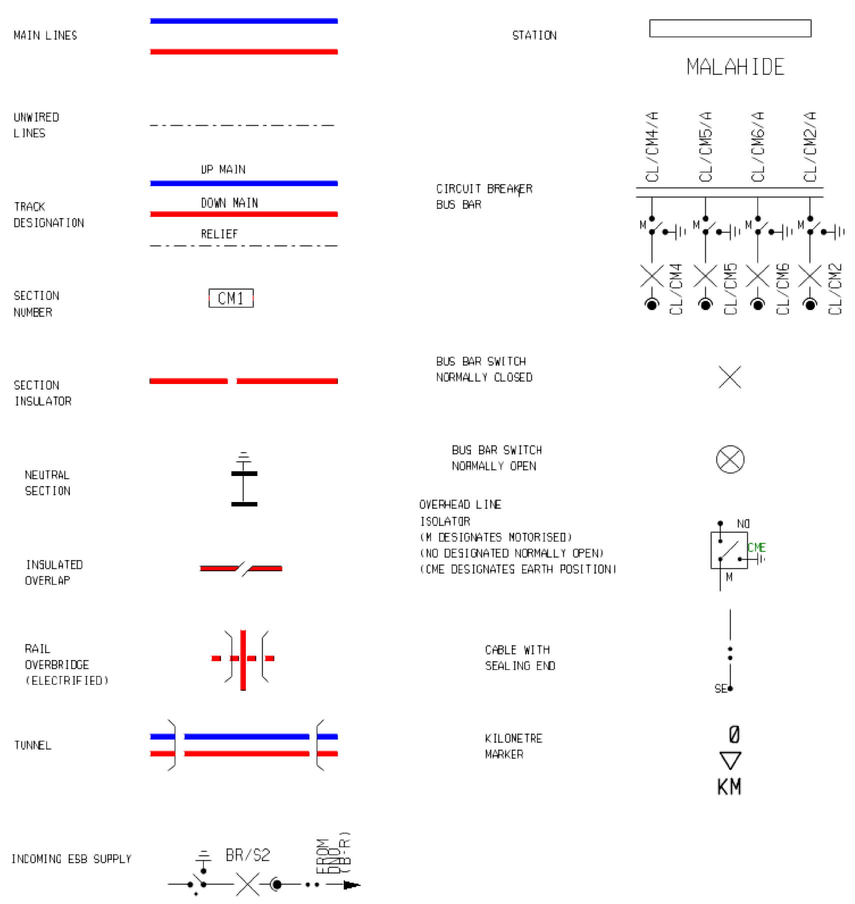

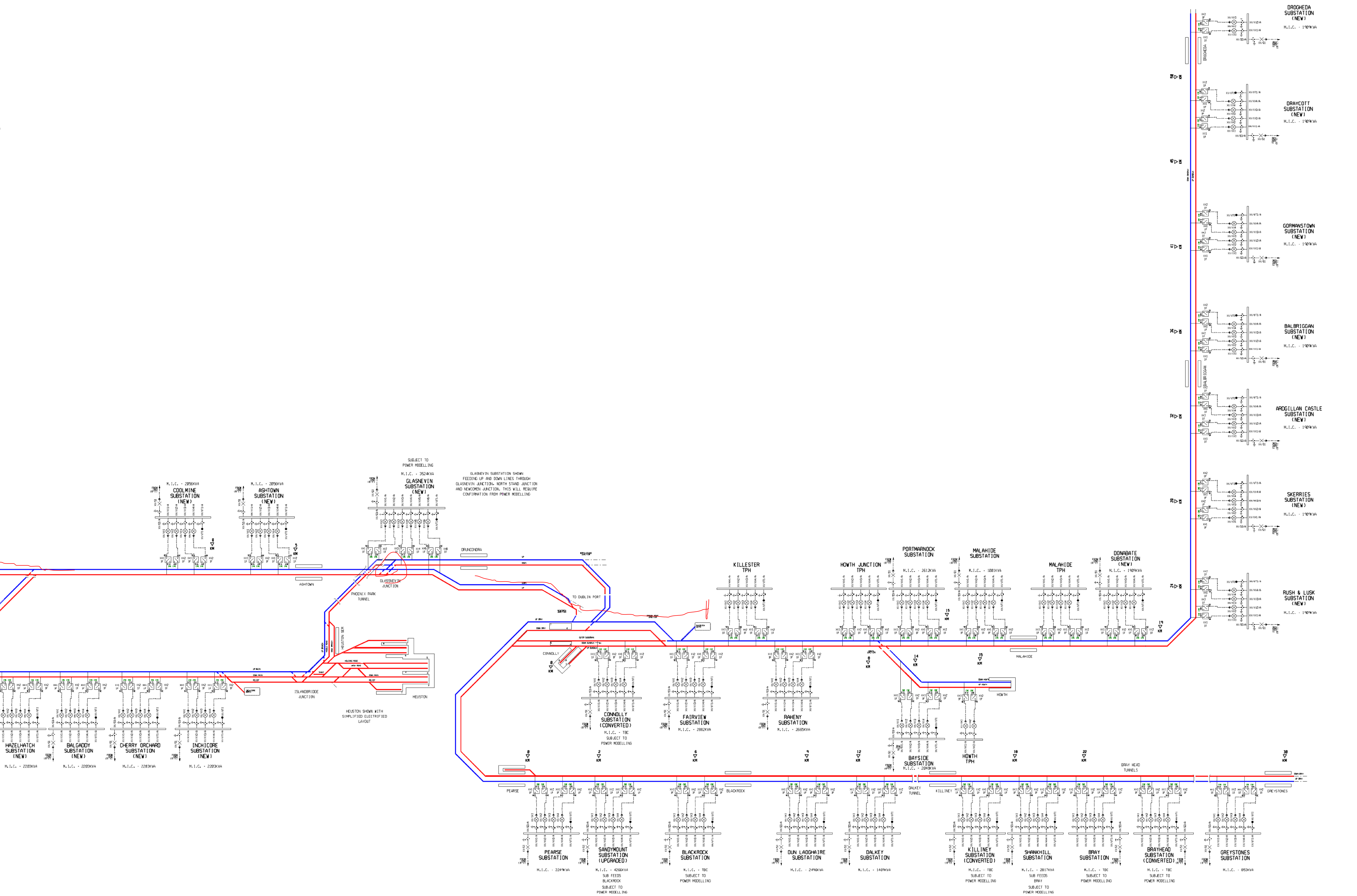

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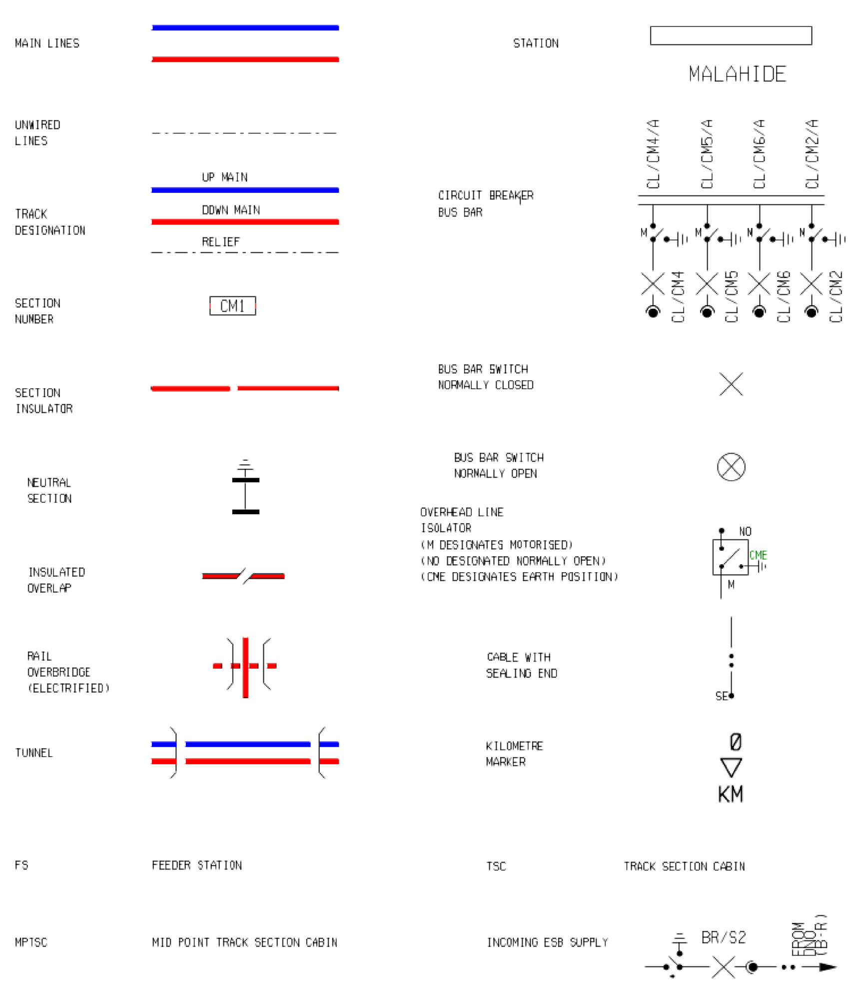
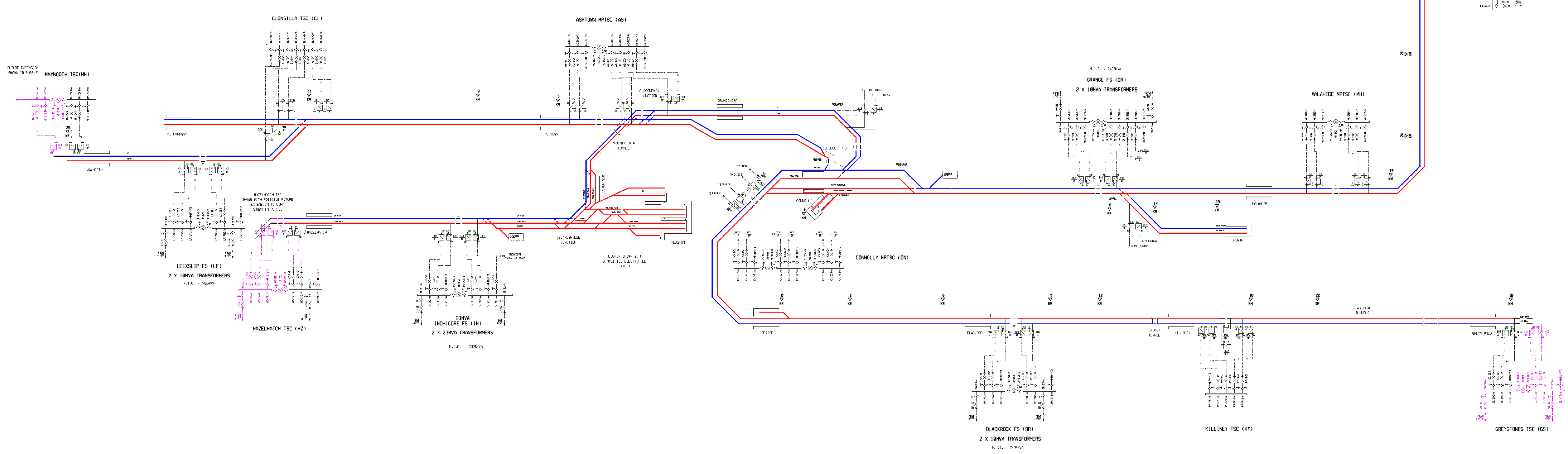
Checked: A. Connolly	Scale: NTS	Date: 04/01/19	Title: Electrical Schematic 1500v DC Network
Approved: A. Donnelly	Format	Client: Irish Rail	
Project Manager: A. Connolly	© This drawing is the property of SYSTRA Limited and the information can only be reproduced with their prior permission.		Drawing Number: 30046612/SCHEM/DC/001 — Rev. 01

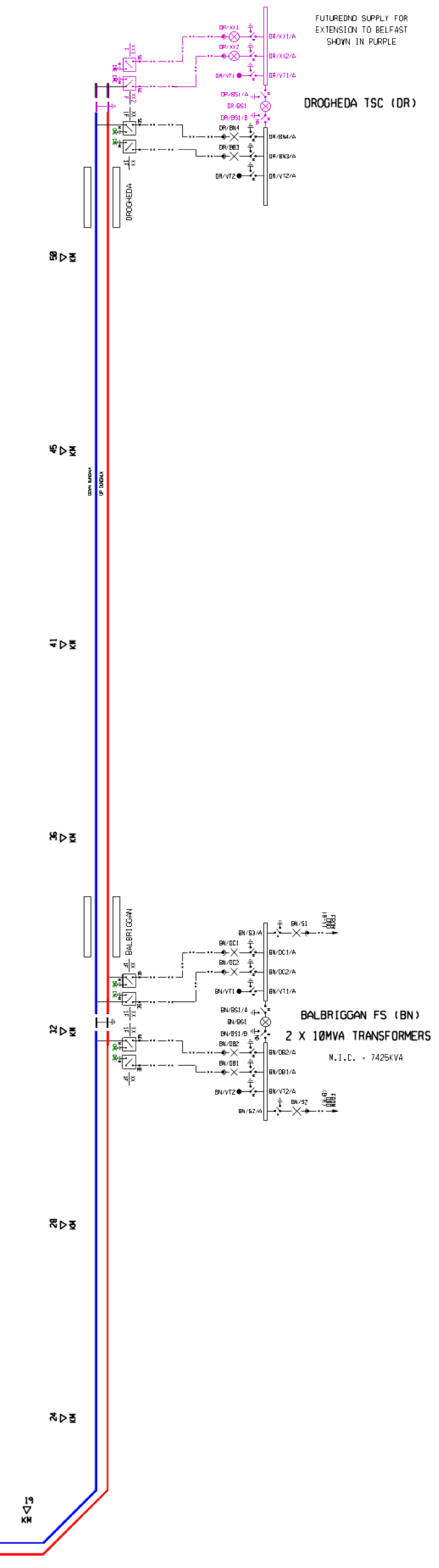
Notes:

1. Do not scale from drawing
2. AC Network Shown for 2035 timetable only
3. All new Substations provisionally located (power supply dependant)
4. All Section points are shown provisional
   All substations subject to increased power supply are subject
5. to availability of power supply
6. Intermediate sectioning points are omitted for clarity
7. Future extensions at TSC and FS shown in purple
8. New substations shown with 2 incoming supply points
9. Heuston station shown electrified but with simple layout
10. Switching and substation numbers are provisional
11. Third bus bar section added to connolly MPTSC to allow for operational flexibility (Allowing Inchicore to feed Up and Down Bray Lines)
12. M.I.C. Figures are indicative and are quoted at 2035 timetable

Key:







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Project Manager: A. Connolly	© This drawing is the property of SYSTRA Limited and the information can only be reproduced with their prior permission.		Drawing Number: 30046612/SCHEM/AC/001 — Rev. 01

APPENDIX C

Electrical Clearance And Power Supply Costing

DRAFT OPTIONS REPORT

	1500 V DC ESB Connection Costs						1500 V DC Substation Costs		
Existing	Existing MIC	Proposed MIC	Connection Cost based on Standard MV Three Phase Charges ESB	(< 5MVA) Overhead Line €per metre + VAT	3 phase (400s) Cable per metre + VAT	Trenching Road	1500 V DC Substation	Land Cost	Civils
				€9.00	€26.50	€148.60	€2m per new substation, €0.5m for upgrade		€0.15m per substation
Greystones	758	850	€ 3,020						
Bray	subfed from Shankill								
Shankill	1733	2820	€ 18,410				€ 500,000		
Dalkey	904	1470	€ 11,090						
Dun Laoghaire	1175	2500	€ 19,830						
Blackrock	subfed from Sanymount	subfed from Sanymount							
Sandymount	2007	4270	€ 41,720				€ 500,000		
Pearse	806	2250	€ 24,930						
Fairview	1328	2820	€ 21,450						
Raheny	1254	2670	€ 21,450						
Portmarnock	836	2610	€ 27,980						
Malahide	407	1000	€ 8,030						
Bayside	1821	2050	€ 3,050						
Proposed									
Donabate		1910	€ 32,370	€ 45,000			€ 1,750,000	€ 494,438	€ 150,000
Rusk & Lusk		1910	€ 32,370	€ 45,000			€ 1,750,000	€ 494,438	€ 150,000
Skerries		1910	€ 32,370	€ 45,000			€ 1,750,000	€ 494,438	€ 150,000
Ardgillan Castle		1910	€ 32,370	€ 45,000			€ 1,750,000	€ 494,438	€ 150,000
Balbriggan		1910	€ 32,370	€ 45,000			€ 1,750,000	€ 494,438	€ 150,000
Gormanstown		1910	€ 32,370	€ 45,000			€ 1,750,000	€ 370,828	€ 150,000
Draycott		1910	€ 32,370	€ 45,000			€ 1,750,000	€ 370,828	€ 150,000
Drogheda		1910	€ 32,370	€ 45,000			€ 1,750,000	€ 370,828	€ 150,000
Ashtown		2060	€ 32,370	€ 45,000			€ 1,750,000	€ 1,483,313	€ 150,000
Coolmine		2060	€ 32,370		€ 53,000	€ 14,860	€ 1,750,000	€ 494,438	€ 150,000
Dunboyne		2060	€ 32,370		€ 53,000	€ 14,860	€ 1,750,000	€ 370,828	€ 150,000
Leixlip (Louisa)		2030	€ 32,370		€ 53,000	€ 14,860	€ 1,750,000	€ 370,828	€ 150,000
Maynooth		2030	€ 32,370		€ 53,000	€ 14,860	€ 1,750,000	€ 370,828	€ 150,000
Glasnevin		3520	€ 56,890		€ 53,000	€ 14,860	€ 1,750,000	€ 1,483,313	€ 150,000
Inchicore		2200	€ 35,440		€ 53,000	€ 14,860	€ 1,750,000	€ 1,483,313	€ 150,000
Balgaddy		2200	€ 35,440		€ 53,000	€ 14,860	€ 1,750,000	€ 494,438	€ 150,000
Cherry Orchard		2200	€ 35,440		€ 53,000	€ 14,860	€ 1,750,000	€ 494,438	€ 150,000
Hazelhatch		2200	€ 35,440		€ 53,000	€ 14,860	€ 1,750,000	€ 494,438	€ 150,000
Connolly (TPH Conversion)		TBC subject to modelling							
Killiney (TPH Conversion)		TBC subject to modelling							
Bray Head (TPH Conversion)		TBC subject to modelling							
			€ 820,420	€ 405,000	€ 477,000	€ 133,740	€ 32,500,000	€ 11,124,845	€ 2,700,000
Total						€ 1,836,160			€ 46,324,845

MV Business Demand Customer Connection Charges (MIC 100kVA to 5MVA) MV Three Phase Connection (10kV or 20kV)	
MIC	Standard Charge
<500	€ 9,040
600	€ 10,500
700	€ 12,120
800	€ 13,570
900	€ 15,140
1,000	€ 17,070
1,200	€ 20,140
1,400	€ 23,190
1,600	€ 26,230
1,800	€ 29,320
2,000	€ 32,370
2,200	€ 35,440
2,400	€ 38,500
2,500	€ 39,970
2,600	€ 41,550
2,800	€ 44,640
3,000	€ 47,700
3,200	€ 50,780
3,400	€ 53,800
3,600	€ 56,890
3,800	€ 59,940
4,000	€ 63,000
4,200	€ 74,090
4,400	€ 85,890
4,600	€ 108,060

Note: The standard charge for 38kV connections is the same as the standard charge for the MIC level at MV and can

1500 V DC Substation	Cost Estimate
2011 Rail Electrification Study	1160000
Proposed Cost for this study	1740000

Land Value Costs		
1 acre	4045	
	per acre	per 1000m2
City centre	€ 25,000,000	€ 6,180,470
outer city centre	€ 6,000,000	€ 1,483,313
Dublin County	€ 2,000,000	€ 494,438
Kildare/Louth	€ 1,500,000	€ 370,828

25 kV AC Power Supply Costs

Line	Power Supply Requirements for 1x25kv Feed	Amount	Unit Price	Unit	Total Costs
Maynooth Line	For 110 kV connection, ESB estimation was 5.7m for connection, but 20% increase applied giving €6.9m all inclusive located in Leixlip	1	€ 6,900,000	per substation	€ 6,900,000
	One 25 kV AC substation: ESB estimation for 1500 V DC susbtation for DU was 3.6m including design, supply, installation, testing and commissioning of all equipment but excluding civil works, ESB connection and land acquisition. Assume susbtations 25kV AC cost the same and apply 20% increase to give 4.3m	1	€ 4,300,000	per substation	€ 4,300,000
	Land Value	3000		per m2	€ 1,112,485
	Civl works	1	€ 1,000,000	per substation	€ 1,000,000
Kildare Line	For 110 kV connection, ESB estimation was €5.7m for connection, but 20% increase applied giving €6.9m all inclusive located in Inchicore	1	€ 6,900,000	per substation	€ 6,900,000
	One 25 kV AC substation: ESB estimation for 1500 V DC susbtation for DU was 3.6m including design, supply, installation, testing and commissioning of all equipment but excluding civil works, ESB connection and land acquisition. Assume susbtations 25kV AC cost the same and apply 20% increase to give 4.3m	1	€ 4,300,000	per substation	€ 4,300,000
	Land Value	3000		per m2	€ 4,449,938
	Civl works	1	€ 1,000,000	per substation	€ 1,000,000
Northern Line (Connolly to Malahide)	For 110 kV connection, ESB estimation was 5.7m for connection, but 20% increase applied giving €6.9m all inclusive located in Grange	1	€ 6,900,000	per substation	€ 6,900,000
	One 25 kV AC substation: ESB estimation for 1500 V DC susbtation for DU was 3.6m including design, supply, installation, testing and commissioning of all equipment but excluding civil works, ESB connection and land acquisition. Assume susbtations 25kV AC cost the same and apply 20% increase to give 4.3m	1	€ 4,300,000	per substation	€ 4,300,000
	Land Value	3000		per m2	€ 1,483,313
	Civl works	1	€ 1,000,000	per substation	€ 1,000,000
Northern Line (Malahide to Drogheda)	For 110 kV connection, ESB estimation was €5.7m for connection, but 20% increase applied giving €6.9m all inclusive located in Balbriggan	1	€ 6,900,000	per substation	€ 6,900,000
	One 25 kV AC substation: ESB estimation for 1500 V DC susbtation for DU was 3.6m including design, supply, installation, testing and commissioning of all equipment but excluding civil works, ESB connection and land acquisition. Assume susbtations 25kV AC cost the same and apply 20% increase to give 4.3m	1	€ 4,300,000	per substation	€ 4,300,000
	Land Value	3000		per m2	€ 4,449,938
	Civl works	1	€ 1,000,000	per substation	€ 1,000,000
DART Southeast	For 110 kV connection, ESB estimation was 5.7m for connection, but €6.9m all inclusive located in Blackrock	1	€ 6,900,000	per substation	€ 6,900,000
	One 25 kV AC substation: ESB estimation for 1500 V DC susbtation for DU was 3.6m including design, supply, installation, testing and commissioning of all equipment but excluding civil works, ESB connection and land acquisition. Assume susbtations 25kV AC cost the same and apply 20% increase to give 4.3m	1	€ 4,300,000	per substation	€ 4,300,000
	Land Value	3000		per m2	€ 4,449,938
	Civl works	1	€ 1,000,000	per substation	€ 1,000,000
			TOTAL		**€ 76,945,612**

Land Value Costs

1 acre	4045	
	per acre	per 3000m2
City centre	€ 25,000,000	€ 18,541,409
outer city centre	€ 6,000,000	€ 4,449,938
Dublin County	€ 2,000,000	€ 1,483,313
Kildare/Louth	€ 1,500,000	€ 1,112,485

Individual Substation Costs

Maynooth Line	€ 13,312,485
Kildare Line	€ 16,649,938
NL (connolly to Malahide)	€ 13,683,313
NL (Malahide to Drogheda)	€ 16,649,938
DART Southeast	€ 16,649,938
Phase 1 Only	€ 46,612,361

APPENDIX D

Energy Usage Costing And Inflation Workings

DRAFT OPTIONS REPORT

				1500V DC												25kV AC				1500V DC				25kV AC				1500 V DC				25kV AC				
Structure No.	Name	Chainage (miles)	Existing Minimum Clearance	Required Clearance (m)	Clearance Difference (m)	Alteration of Structure	Cost Estimate (€)	Required Clearance (m)	Clearance Difference (m)	Alteration of Structure	Cost Estimate (€)	Required Clearance (m)	Clearance Difference (m)	Alteration of Structure	Cost Estimate (€)	Required Clearance (m)	Clearance Difference (m)	Alteration of Structure	Cost Estimate (€)	Required Clearance (m)	Clearance Difference (m)	Alteration of Structure	Cost Estimate (€)	Required Clearance (m)	Clearance Difference (m)	Alteration of Structure	Cost Estimate (€)	Required Clearance (m)	Clearance Difference (m)	Alteration of Structure	Cost Estimate (€)	Required Clearance (m)	Clearance Difference (m)	Alteration of Structure	Cost Estimate (€)	Notes
				4.83m Clearance								4.69m Clearance								Reduced Clearance for 1500V DC and 25 kV AC								Special Reduced Clearance				Special Reduced Clearance				
Maynooth																																				
D87A	N3 Navan Road	4.457	4.506	4.83	-0.32	Yes	€ 1,020,000	4.83	-0.32	Yes	1020000	4.69	-0.18	Yes	€ 1,020,000	4.69	-0.18	Yes	1020000	4.564	-0.06	Yes	1020000	4.564	-0.06	Yes	1020000	4.343	0.16	No		4.489	0.02	No		Reinforced Concrete
D87C	N3 Navan Road	4.534	4.671	4.83	-0.16	Yes	€ 1,020,000	4.83	-0.16	Yes	1020000	4.69	-0.02	Yes	€ 1,020,000	4.69	-0.02	Yes	1020000	4.564	0.11	No		4.564	0.11	No		4.343	0.33	No		4.489	0.18	No		Reinforced Concrete
D89	Talbot Ct	4.617	4.359	4.83	-0.47	Yes	€ 1,020,000	4.83	-0.47	Yes	1020000	4.69	-0.33	Yes	€ 1,020,000	4.69	-0.33	Yes	1020000	4.564	-0.21	Yes	1020000	4.564	-0.21	Yes	1020000	4.343	0.02	No		4.489	-0.13	Yes	1020000	Masonry/ Concrete
D811	Castleknock Rd/ Woodpark	4.811	4.432	4.83	-0.40	Yes	€ 1,020,000	4.83	-0.40	Yes	1020000	4.69	-0.26	Yes	€ 1,020,000	4.69	-0.26	Yes	1020000	4.564	-0.13	Yes	1020000	4.564	-0.13	Yes	1020000	4.343	0.09	No		4.489	-0.06	Yes	1020000	Masonry Arch
D813	Barnhill Crossroads	8.951	4.598	4.83	-0.23	Yes	€ 1,020,000	4.83	-0.23	Yes	1020000	4.69	-0.09	Yes	€ 1,020,000	4.69	-0.09	Yes	1020000	4.564	0.03	No		4.564	0.03	No		4.343	0.26	No		4.489	0.11	No		Masonry Arch
D814	Leixlip Confey (Captain's Hill)	10.351	4.616	4.83	-0.21	Yes	€ 1,020,000	4.83	-0.21	Yes	1020000	4.69	-0.07	Yes	€ 1,020,000	4.69	-0.07	Yes	1020000	4.564	0.05	No		4.564	0.05	No		4.343	0.27	No		4.489	0.13	No		Masonry Arch
D816	R148 Louisa Bridge	11.285	4.818	4.83	-0.01	Yes	€ 1,020,000	4.83	-0.01	Yes	1020000																									
D818	Pike Bridge	13.451	4.579	4.83	-0.25	Yes	€ 1,020,000	4.83	-0.25	Yes	1020000	4.69	-0.11	Yes	€ 1,020,000	4.69	-0.11	Yes	1020000	4.564	0.01	No		4.564	0.01	No		4.343	0.24	No		4.489	0.09	No		Masonry Arch
Hazelhatch																																				
DBO10	Glasnevin Cemetry Accodation Road	2.0641	4.501	4.69	-0.19	Yes	€ 1,800,000	4.83	-0.33	Yes	1800000	4.68	-0.19	Yes	€ 1,800,000	4.69	-0.19	Yes	1800000	4.564	-0.06	Yes	1800000	4.564	-0.06	Yes	1800000	4.343	0.16	No		4.489	0.01	No		
DBO9	Overbridge carrying MGWR (also UBD220 on MGWR)	2.0341	4.386	4.69	-0.30	Yes	€ 1,800,000	4.83	-0.44	Yes	1800000	4.68	-0.30	Yes	€ 1,800,000	4.69	-0.30	Yes	1800000	4.564	-0.18	Yes	1800000	4.564	-0.18	Yes	1800000	4.343	0.04	No		4.489	-0.10	Yes	1800000	
DBO8	Royal Canal-Twin Arches (also UBG4)	2.0206	4.365	4.69	-0.33	Yes	€ 1,800,000	4.83	-0.47	Yes	1800000	4.68	-0.33	Yes	€ 1,800,000	4.69	-0.33	Yes	1800000	4.564	-0.20	Yes	1800000	4.564	-0.20	Yes	1800000	4.343	0.02	No		4.489	-0.12	Yes	1800000	
DBO7	Faussagh Avenue	1.14895	4.4091	4.69	-0.28	Yes	€ 1,800,000	4.83	-0.42	Yes	1800000	4.68	-0.28	Yes	€ 1,800,000	4.69	-0.28	Yes	1800000	4.564	-0.15	Yes	1800000	4.564	-0.15	Yes	1800000	4.343	0.07	No		4.489	-0.08	Yes	1800000	
DBO6	Cabra Road	1.0883	4.3822	4.69	-0.31	Yes	€ 1,800,000	4.83	-0.45	Yes	1800000	4.68	-0.31	Yes	€ 1,800,000	4.69	-0.31	Yes	1800000	4.564	-0.18	Yes	1800000	4.564	-0.18	Yes	1800000	4.343	0.04	No		4.489	-0.11	Yes	1800000	Square Span-Concrete
DBO4	Blackquire Avenue	1.0117	4.4544	4.69	-0.24	Yes	€ 1,800,000	4.83	-0.38	Yes	1800000	4.68	-0.24	Yes	€ 1,800,000	4.69	-0.24	Yes	1800000	4.564	-0.11	Yes	1800000	4.564	-0.11	Yes	1800000	4.343	0.11	No		4.489	-0.03	Yes	1800000	
Hazelhatch to Phoenix Park Tunnel form part of Kildare 4 Tracking Study works																																				
Malahide to Drogheda																																				
DBB35	Beaversbrook (Beaverstown)	12.445	4.733	4.83	-0.10	Yes	€ 1,020,000	4.83	-0.10	Yes	€ 1,020,000																									
DBB41	Track (Kingstown/ Public Road)	14.436	4.749	4.83	-0.08	Yes	€ 1,020,000	4.83	-0.08	Yes	€ 1,020,000																									
DBB44	Track (Tyrrelstown/ Public Road)	16.1437	4.697	4.83	-0.13	Yes	€ 1,020,000	4.83	-0.13	Yes	€ 1,020,000																									
DBB76	Parkway (Colp Public Road)	30.233	4.736	4.83	-0.09	Yes	€ 1,020,000	4.83	-0.09	Yes	€ 1,020,000																									
DBB80B	McGraths Lane	31.871	4.768	4.83	-0.06	Yes	€ 1,020,000	4.83	-0.06	Yes	€ 1,020,000																									
DBB33A	Footbridge	11.784	<4.343	4.83	>0.5	Yes	€ 450,000	4.83	>0.5	Yes	450000	4.68	>0.3	Yes	€ 450,000	4.69	>0.3	Yes	450000	4.564	>0.1	Yes	450000	4.564	>0.2	Yes	450000	4.343	>0.1	Yes	450000	4.489	>0.1	Yes	450000	Steel
DBB38A	Footbridge	13.1581	<4.343	4.83	>0.5	Yes	€ 450,000	4.83	>0.5	Yes	450000	4.68	>0.3	Yes	€ 450,000	4.69	>0.3	Yes	450000	4.564	>0.1	Yes	450000	4.564	>0.2	Yes	450000	4.343	>0.1	Yes	450000	4.489	>0.1	Yes	450000	Iron
DBB55	R127 Skerries Rd	21.304	4.651	4.83	-0.18	Yes	€ 1,020,000	4.83	-0.18	Yes	1020000	4.68	-0.04	Yes	€ 1,020,000	4.69	-0.04	Yes	1020000	4.564	0.09	No		4.564	0.09	No		4.343	0.31	No		4.489	0.16	No		Masonry Arch
DBB57	Balbriggan Station Footbridge	21.1291	4.484	4.83	-0.35	Yes	€ 450,000	4.83	-0.35	Yes	450000	4.68	-0.21	Yes	€ 450,000	4.69	-0.21	Yes	450000	4.564	-0.08	Yes	450000	4.564	-0.08	Yes	450000	4.343	0.14	No		4.489	0.00	No		Reinforced Concrete
DBB80	McGraths Lane	31.869	4.644	4.83	-0.19	Yes	€ 1,020,000	4.83	-0.19	Yes	1020000	4.68	-0.05	Yes	€ 1,020,000	4.69	-0.05	Yes	1020000	4.564	0.08	No		4.564	0.08	No		4.343	0.30	No		4.489	0.16	No		Masonry Arch
DBB81	Footbridge		4.521	4.83	-0.31	Yes	€ 450,000	4.83	-0.31	Yes	450000	4.68	-0.17	Yes	€ 450,000	4.69	-0.17	Yes	450000	4.564	-0.04	Yes	450000	4.564	-0.04	Yes	450000	4.343	0.18	No		4.489	0.03	No		
Existing DART Lines																																				
DART SOUTH																																				
DBR72	Footbridge - Blackrock Station	15.1300*	4.69	4.83	DART-Already electrified 1500V			4.83	-0.14	Yes	450000																									
DBR76	Station Footbridge Seapoint	17.117	4.8	4.83	DART-Already electrified 1500V			4.83	-0.03	Yes	450000																									
DBR78A	Footbridge	17.330*	4.708	4.83	DART-Already electrified 1500V			4.83	-0.12	Yes	450000																									
DBR98	R119 Summerhill Road	19.1634	4.745	4.83	DART-Already electrified 1500V			4.83	-0.09	Yes	1020000																									
DBR101	Adelaide Road	21.304	4.69	4.83	DART-Already electrified 1500V			4.83	-0.14	Yes	1020000																									
DBR105	Barnhill Road	21.1328	4.818	4.83	DART-Already electrified 1500V			4.83	-0.01	Yes	1020000																									
DBR106	Dalkey Avenue	21.1364	4.726	4.83	DART-Already electrified 1500V			4.83	-0.10	Yes	1020000																									
DBR107	Footbridge	21.1309?	4.69	4.83	DART-Already electrified 1500V			4.83	-0.14	Yes	450000																									
DBR110	Cunningham Road	22.676	4.8	4.83	DART-Already electrified 1500V			4.83	-0.03	Yes	1020000																									
DBR111	Dalkey Station Footbridge	22.902	4.745	4.83	DART-Already electrified 1500V			4.83	-0.09	Yes	1020000																									
DBR147A	Arch	71.453	4.708	4.83	DART-Already electrified 1500V			4.83	-0.12	Yes	450000																									
DBR151	Footbridge	0.460*	4.708	4.83	DART-Already electrified 1500V			4.83	-0.12	Yes	450000																									
DBR68	Footbridge - Williamstown	14.1437	4.469	4.83	DART-Already electrified 1500V			4.83	-0.36	Yes	450000		DART-Already electrified 1500V			4.69	-0.22	Yes	450000		DART-Already electrified 1500V			4.564	-0.09	Yes	450000		DART-Already electrified 1500V			4.489	-0.02	Yes	450000	Concrete/ Steel
DBR74	Footbridge - Merrion Towers	15.1750*	4.598	4.83	DART-Already electrified 1500V			4.83	-0.23	Yes	450000		DART-Already electrified 1500V			4.69	-0.09	Yes	450000		DART-Already electrified 1500V			4.564	0.03	No			DART-Already electrified 1500V			4.489	0.11	No		Masonry/ Steel
DBR86A	Booking Hall & Footbridge	18.815	4.506	4.83	DART-Already electrified 1500V			4.83	-0.32	Yes	450000		DART-Already electrified 1500V			4.69	-0.18	Yes	450000		DART-Already electrified 1500V			4.564	-0.06	Yes	450000		DART-Already electrified 1500V			4.489	0.02	No		Reinforced Concrete
DBR93	Queens Road Footbridge	19.702	4.616	4.83	DART-Already electrified 1500V			4.83	-0.21	Yes	450000		DART-Already electrified 1500V			4.69	-0.07	Yes	450000		DART-Already electrified 1500V			4.564	0.05	No			DART-Already electrified 1500V			4.489	0.13	No		Girder & Hobsons
DBR94	Queens Road Footbridge	19.570*	4.579	4.83	DART-Already electrified 1500V			4.83	-0.25	Yes	450000		DART-Already electrified 1500V			4.69	-0.11	Yes	450000		DART-Already electrified 1500V			4.564	0.01	No			DART-Already electrified 1500V			4.489	0.09	No		Girder & Hobsons
DBR95	Footbridge	19.1120*	4.616	4.83	DART-Already electrified 1500V			4.83	-0.21	Yes	450000		DART-Already electrified 1500V			4.69	-0.07	Yes	450000		DART-Already electrified 1500V			4.564	0.05	No			DART-Already electrified 1500V			4.489	0.13	No		Reinforced Concrete
DBR97	Footbridge	19.1540*	4.616	4.83	DART-Already electrified 1500V			4.83	-0.21	Yes	450000		DART-Already electrified 1500V			4.69	-0.07	Yes	450000		DART-Already electrified 1500V			4.564	0.05	No			DART-Already electrified 1500V			4.489	0.13	No		Unknown
DBR99	Lower Eden Road	20.687	4.653	4.83	DART-Already electrified 1500V			4.83	-0.18	Yes	1020000		DART-Already electrified 1500V			4.69	-0.04	Yes	1020000		DART-Already electrified 1500V			4.564	0.09	No			DART-Already electrified 1500V			4.489	0.16	No		Reinforced Concrete
DBR103	Albert Road Lower	21.1112	4.451	4.83	DART-Already electrified 1500V			4.83	-0.38	Yes	1020000		DART-Already electrified 1500V			4.69	-0.24	Yes	1020000		DART-Already electrified 1500V			4.564	-0.11	Yes	1020000		DART-Already electrified 1500V			4.489	-0.04	Yes	1020000	Reinforced Concrete
DBR104	Castle Park Road	21.1281	4.635	4.83	DART-Already electrified 1500V			4.83	-0.20	Yes	1020000		DART-Already electrified 1500V			4.69	-0.06	Yes	1020000		DART-Already electrified 1500V			4.564	0.07	No			DART-Already electrified 1500V			4.489	0.15	No		Reinforced Concrete
DBR129A	Sheppanagh Cliffs - Rathsallagh	26.1074	4.653	4.83	DART-Already electrified 1500V			4.83	-0.18	Yes	1020000		DART-Already electrified 1500V			4.69	-0.04	Yes	1020000		DART-Already electrified 1500V			4.564	0.09	No			DART-Already electrified 1500V			4.489	0.16	No		Reinforced Concrete
DBR129B	Station Footbridge	26.1668	4.653	4.83	DART-Already electrified 1500V			4.83	-0.18	Yes	450000		DART-Already electrified 1500V			4.69	-0.04	Yes	450000		DART-Already electrified 1500V			4.564	0.09	No			DART-Already electrified 1500V			4.489	0.16	No		Masonry & Steel
DBR147C	On cliff walk	70.1530*	4.653	4.83	DART-Already electrified 1500V			4.83	-0.18	Yes	1020000		DART-Already electrified 1500V			4.69	-0.04	Yes	1020000		DART-Already electrified 1500V			4.564	0.09	No			DART-Already electrified 1500V			4.489	0.16	No		Concrete & Steel
Tunnel	Bray Head Tunnel 1	13.59	4.469	4.83	DART-Already electrified 1500V			4.83	-0.36	Yes	960000		DART-Already electrified 1500V			4.69	-0.22	Yes	960000		DART-Already electrified 1500V			4.564	-0.09	Yes	960000		DART-Already electrified 1500V			4.489	-0.02	Yes	960000	Rock
Tunnel	Bray Head Tunnel 4	14.69	4.451	4.83	DART-Already electrified 1500V			4.83	-0.38	Yes	3600000		DART-Already electrified 1500V			4.69	-0.24	Yes	3600000		DART-Already electrified 1500V			4.564	-0.11	Yes	3600000		DART-Already electrified 1500V			4.489	-0.04	Yes	3600000	Rock
DBR152	La Touche Pl	0.470*	4.598	4.83	DART-Already electrified 1500V			4.83	-0.23	Yes	1020000		DART-Already electrified 1500V			4.69	-0.08	Yes	1020000		DART-Already electrified 1500V			4.564	0.03	No			DART-Already electrified 1500V			4.489	0.11	No		Masonry Arch
DART NORTH																																				
DBB10	Track - Killester	2.422	4.726	4.83	DART-Already electrified 1500V			4.83	-0.10	Yes	1020000																									
DBB14	Track - Lein Gardens	3.351	4.69	4.83	DART-Already electrified 1500V			4.83	-0.14	Yes	1020000																									
DBB22	Station Road	6.1321	4.8	4.83	DART-Already electrified 1500V			4.83	-0.03	Yes	1020000																									
DBB27	R106 Main Street -Townbridge	8.1720*	4.8	4.83	DART-Already electrified 1500V			4.83	-0.03	Yes	1020000																									
DBQ3	Claremont Road	O/B	4.8	4.83	DART-Already electrified 1500V			4.83	-0.03	Yes	1020000																									
DBB9A	R103 Collins Avenue East	2.397	4.598	4.83	DART-Already electrified 1500V			4.83	-0.23	Yes	1800000		DART-Already electrified 1500V			4.69	-0.09	Yes	1800000		DART-Already electrified 1500V			4.564	0.03	No			DART-Already electrified 1500V			4.489	0.11	No		Reinforced Concrete
DBB12#	Brookwood Avenue	2.1467	4.653	4.83	DART-Already electrified 1500V			4.83	-0.18	Yes	1020000		DART-Already electrified 1500V			4.69	-0.04	Yes	1020000		DART-Already electrified 1500V			4.564	0.09	No			DART-Already electrified 1500V			4.489	0.16	No		Reinforced Concrete
DBB15#	Raheny Station Footbridge	3.1267	4.432	4.83	DART-Already electrified 1500V			4.83	-0.40	Yes	450000		DART-Already electrified 1500V			4.69	-0.26	Yes	450000		DART-Already electrified 1500V			4.564	-0.13	Yes	450000		DART-Already electrified 1500V			4.489	-0.06	Yes	450000	Concrete/ Steel
DBB16	Station Road	3.1279	4.414	4.83	DART-Already electrified 1500V			4.83	-0.42	Yes	1800000		DART-Already electrified 1500V			4.69	-0.28	Yes	1800000		DART-Already electrified 1500V			4.564	-0.15	Yes	1800000		DART-Already electrified 1500V			4.489	-0.08	Yes	1800000	Reinforced Concrete
SUMMARY OF STRUCTURES						25				*62	€61,270,000			19				*38	€41,130,000			13				20				2				15		
										*37 of which are on existing DART Lines								*38 of which are on existing DART Lines								*7 of which are on existing DART Lines								*6 of which are on existing DART Lines		
INDICATIVE COST ESTIMATE FOR STRUCTURES ON NEWLY ELECTRIFIED LINES							€27,900,000				€27,900,000				€21,780,000				€21,780,000				€15,660,000				€15,660,000				€900,000				€11,940,000	
INDICATIVE COST ESTIMATE FOR STRUCTURES ON EXISTING DART LINES							€0				€33,270,000				€0				€19,350,000				€0				€8,730,000				€0				€8,280,000	
INDICATIVE COST ESTIMATE OVERALL							€27,900,000				€61,170,000				€21,780,000				€41,130,000				€15,660,000				€24,390,000				€900,000				€20,220,000	

Chaging Assessment for Use of Electricity									
	1500 V DC					25 kV AC			
		MIC kVA	Max Demand kVA	Installed Capacity MVA			MIC kVA	Max Demand kVA	Installed Capacity MVA
		63,127	56,814	86			47,025	42,323	63
		Charging Rate	MIC kva x 12 months	Charge			Charging Rate	MIC kva x 12 months	Charge
	PSO Levy	3.4075	757524	2581263		PSO Levy	3.4075	564300	1922852
	Duos Capacity Charge	0.473834617	757524	358941		Duos Capacity Charge	0.473834617	564300	267385
	Standing Charge	€7,487.325 per MVA Capacity		640166		Standing Charge	€7,487.325 per MVA Capacity		471701
	TuoS - Demand Network	1467.1907/MW		83357		TuoS - Demand Network	€1734.6648/MW		73415
	Capacity, Service and	€2.2925/MWh		360712		Capacity, Service and	€2.2925/MWh		360712
	Transfer Charges	€3.5905/MWh		564945		Transfer Charges	€3.5905/MWh		564945
			KWH Used	157,344,274				KWH Used	157,344,274
Bill Items Category	Unit Of Measure	Average Rate	Consumption	Expenditure			Average Rate	Consumption	Expenditure
Demand Network Capacity Charge	-			€1,009,014					€999,072
Duos Capacity Charge	kVA	0.47383	757,524	€358,941			0.47383	564,300	
Duos Day Energy	kWh	0.00101	125,875,419	€126,820			0.00101	125,875,419	
Duos Night Energy	kWh	0.00007	31,468,855	€2,203			0.00007	31,468,855	
First Rate	kWh	0.06367	125,875,419	€8,013,988			0.06367	125,875,419	€8,013,988
Gas Charge	kWh	0.00217	157,344,274	€341,282			0.00217	157,344,274	€341,282
Imperfections Charge	kWh	0.00279	157,344,274	€439,282			0.00279	157,344,274	€439,282
Market Operator Charge	kWh	0.00028	157,344,274	€44,647			0.00028	157,344,274	€44,647
MIC Charge	kVA	2.36075	630	€1,487			2.36075	630	€1,487
Night Rate	kWh	0.04680	31,468,855	€1,472,686			0.04680	31,468,855	€1,472,686
PSO Levy	kVA	3.40750	757,524	€2,581,263			3.40750	564,300	€1,922,852
Standing Charge	-	-		€640,166			-		€471,701
Supplier Capacity Charge	kWh	0.01780	157,344,274	€2,800,189			0.01780	157,344,274	€2,800,189
TUoS Day Energy	MWH	5.16978	125,875	€650,748			5.16978	125,875	€650,748
TUoS Night Energy	MWH	5.18004	31,469	€163,010			5.18004	31,469	€163,010
	Non direct supply consumption		One Year	€4,226,900				One Year	€4,097,876
	Direct supply consupmtion		One Year	€9,827,956				One Year	€9,827,956
	Demand and Capacity Based Charges		One Year	€4,590,871				One Year	€3,395,113
	Total			**€18,645,727**		**Total**			**€17,320,945**
			Difference between 1500V DC and 25kV AC, with 25 kV AC cheaper by				**€1,324,782**		

Year	Inflation Rate	Traction Substation Cost		OHLE Cost		Rolling Stock		Charges for Electricity Usage	
		1500 V DC	25 kV AC	1500 V DC	25 kV AC	1500 V DC	25 kV AC	1500 V DC	25 kV AC
0	1.00	1.70	0.65	4.05	4.05	24.40	25.86	18.60	17.30
1	1.01	1.72	0.66	4.09	4.09	24.64	26.12	18.79	17.47
2	1.02	1.73	0.66	4.13	4.13	24.89	26.38	18.97	17.65
3	1.03	1.75	0.67	4.17	4.17	25.14	26.64	19.16	17.82
4	1.04	1.77	0.68	4.21	4.21	25.39	26.91	19.36	18.00
5	1.05	1.79	0.68	4.26	4.26	25.64	27.18	19.55	18.18
6	1.06	1.80	0.69	4.30	4.30	25.90	27.45	19.74	18.36
7	1.07	1.82	0.70	4.34	4.34	26.16	27.73	19.94	18.55
8	1.08	1.84	0.70	4.39	4.39	26.42	28.00	20.14	18.73
9	1.09	1.86	0.71	4.43	4.43	26.69	28.28	20.34	18.92
10	1.10	1.88	0.72	4.47	4.47	26.95	28.57	20.55	19.11
11	1.12	1.90	0.73	4.52	4.52	27.22	28.85	20.75	19.30
12	1.13	1.92	0.73	4.56	4.56	27.49	29.14	20.96	19.49
13	1.14	1.93	0.74	4.61	4.61	27.77	29.43	21.17	19.69
14	1.15	1.95	0.75	4.66	4.66	28.05	29.73	21.38	19.89
15	1.16	1.97	0.75	4.70	4.70	28.33	30.02	21.59	20.08
16	1.17	1.99	0.76	4.75	4.75	28.61	30.32	21.81	20.29
17	1.18	2.01	0.77	4.80	4.80	28.90	30.63	22.03	20.49
18	1.20	2.03	0.78	4.84	4.84	29.19	30.93	22.25	20.69
19	1.21	2.05	0.79	4.89	4.89	29.48	31.24	22.47	20.90
20	1.22	2.07	0.79	4.94	4.94	29.77	31.55	22.70	21.11
21	1.23	2.10	0.80	4.99	4.99	30.07	31.87	22.92	21.32
22	1.24	2.12	0.81	5.04	5.04	30.37	32.19	23.15	21.53
23	1.26	2.14	0.82	5.09	5.09	30.67	32.51	23.38	21.75
24	1.27	2.16	0.83	5.14	5.14	30.98	32.84	23.62	21.97
25	1.28	2.18	0.83	5.19	5.19	31.29	33.16	23.85	22.19
26	1.30	2.20	0.84	5.25	5.25	31.60	33.50	24.09	22.41
27	1.31	2.22	0.85	5.30	5.30	31.92	33.83	24.33	22.63
28	1.32	2.25	0.86	5.35	5.35	32.24	34.17	24.58	22.86
29	1.33	2.27	0.87	5.40	5.40	32.56	34.51	24.82	23.09
30	1.35	2.29	0.88	5.46	5.46	32.89	34.86	25.07	23.32
		61.4	**23.5**	**146.3**	**146.3**	**881.6**	**934.4**	**672.1**	**625.1**

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