# Traction Power Supplies Not another PSU

AUTHOR: Paul Hooper, Technical Director
and Professional Head of Discipline, Railway Electrification

Paul is a Chartered Electrical Engineer and strategic railway consultant with over 30 years railway systems experience specialising in railway electrification. He is the Atkins Professional Head of Discipline for Electrification. He has a broad range of experience as a senior business manager, project director / manager and engineer involved in multi-disciplinary projects. Paul has a background in the management and design of railway infrastructure projects from feasibility study through detailed design and contract preparation to implementation, commissioning and incident investigations. He has also provided specialist rail input to energy / carbon reduction and electrification business case projects in the UK and overseas.

## INTRODUCTION

In 2014, at the start of Network Rail's Control Period 5 (CP5), all looked bright for electrification. After many years with no major projects, suddenly electrification was back on the railway agenda.  Fast forward five years and, although many projects were successfully delivered, the cost challenges, particularly on Great Western Electrification Programme (GWEP), made headlines and the emergency brakes were applied to electrification projects, except for in Scotland where a rolling programme has continued. With the decarbonisation agenda now getting political attention and legal commitments to net zero emissions, the Rail Industry Decarbonisation Taskforce have identified that rail electrification will need to play a key role in decarbonising transportation.

Electrification systems consist of two main integrated sub-systems - the electrical system and the mechanical "contact" system. The contact system provides the interface to the trains and can be either above the train (overhead line) or at track level (third rail). The Subway in Glasgow, most of the Southern Region, Merseyrail, Docklands Light Railway and a few other routes use the third rail system to provide power to trains (London Underground uses a similar four rail version) whereas other routes use the overhead line system. The third rail systems use a DC power supply. This article is primarily about AC overhead line systems but many of the electrical issues also apply to DC third rail networks. It should also be noted that some overhead systems are also DC, including trams and the Tyne and Wear Metro.

A key part of the electrical system is the traction power and distribution equipment. This consists of the feeder stations and sectioning locations that take the power from the public electricity networks, transform it to the railway operational voltage, distribute it to the trains (through the contact system) and provide the control and protection to keep the system safe. Since 1956, the UK has adopted a 25kV single phase AC system (the voltage between the contact system and the rails) for all new mainline electrification projects. In recent years, autotransformer systems have been introduced that distribute at 50kV but only half of this is seen by the trains (ie the overhead contact system remains at 25kV relative to the rails). The total power available is predominantly limited by the capacity of the feeder stations. When additional power is needed, a power supply upgrade (PSU) project is required. This can involve the upgrading of existing equipment or, more often, a restructuring of the system, with additional new feeder stations and often conversion to autotransformers. Figures 1 (an autotransformer) and 2 (SF6 circuit breakers) give examples of the type of equipment used in Railway power distribution networks.

There have been many PSU projects over the years including in Scotland, Anglia, Southern (on the third rail DC network), West Coast and now East Coast. Each of these projects has been a result of the increase in electric traction beyond that allowed for in the design of the original electrification schemes. They all have included significant alterations to the power system architecture and have been both costly and disruptive.Traditionally power has been taken from the National Grid (400kV and 275kV) and Distribution Network Operators' networks (132kV). These are three phase transmission and distribution networks, whereas the railway operates on a single phase. Supply transformers reduce the voltage to the required railway voltage (50kV or 25kV for UK mainline overhead lines) but in order to minimise the effect on the supply networks, different phase pairs are used at adjacent sites. This requires the railway to keep supplies from adjacent sites separate – hence the need for neutral sections in the overhead line.

Network Rail have published a Traction Decarbonisation Network Strategy (TDNS) that identifies the electrification of a significant proportion of the currently non-electrified network over the next 30 years (126 lines, 13,000 single track km).  Publication of this document, along with emerging supporting regional programmes, gives an opportunity to approach traction power design in a new way. However, this must be done cost-effectively without significantly increasing the costs on individual projects, since this would undermine their business cases.Traction power supply equipment typically has a design life of over 40 years. We therefore need to be designing a system now for a decarbonised railway with a significantly expanded electrification network, not just for individual route electrification projects.

## NEUTRAL SECTIONS

A key element of the electrical power system for AC overhead line systems is the location of neutral sections. In the UK there are generally two types used. Short neutral sections consist of insulating rods cut into the overhead line equipment with an earthed (neutral) section between – hence the name. Network Rail standards allow these for use up to 100mph although they operate up to 125mph on older overhead line equipment. For higher speeds a succession of four "insulated overlaps" are installed – the so-called Carrier Wire type. These have the advantage of improved dynamic performance between the contact wire and the pantograph, but each overlap is typically 40-50m long, making their siting relative to signals and other features of the railway a challenge. Neutral sections are required at the location where the overhead line could be supplied from out of phase supplies in normal or degraded mode supply arrangements. This is normally at feeder stations and mid-way between them (mid-point sectioning locations).

DESIGN FOR WHOLE NETWORK

The proposed extent of electrification in the longer term has been mapped out as part of the TDNS. A national/regional power supply system approach is needed identifying potential grid connection points. In Scotland this is well advanced with a national Major Feeding Diagram developed to supply the rolling programme of electrification. Network Rail have started this exercise in England and Wales by mapping potential supply points (132kV and above) within 5km of the TDNS proposed electrified network. The regional programmes for electrification then need to be mapped such that short-term project decisions can be made taking into consideration the longer-term requirements.

As has been seen in the past, there will no doubt be increased demands on the system over time. In addition, TDNS shows an electrified network of lines, not just primarily single main lines as has generally been the case in the past (WCML, ECML, GWML, MML). The traction power system should therefore be designed for a network, allowing for future increases in demand and making best use of existing and emerging technology whilst working with National Grid to ensure the capacity will be available when required.
Where it is likely that demand in the future will require it, particularly on high speed and freight routes, autotransformer systems should be designed up-front. However, as the costs of the autotransformers, additional switchgear and along track autotransformer feeders (ATFs) are significant, it may be cost effective to design and install an interim stage using "Classic" feeding arrangements, installing the autotransformers and associated equipment at a future date when the demand increases. This is not the same as making passive provision, which does not include designing the final autotransformer system, but includes some allowances based on subjective assumptions.

This can result in a "Classic" system being designed with significant alterations required as part of a future conversion project, including new OLE structures or costly low-level cable routes and reconfiguration of substations.

NEW LINES

The TDNS clearly states that it does not cover new lines and "Beeching reopenings". However, any power supply strategy should consider known future projects. The Integrated Rail Plan (IRP) needs to be taken into account when published (due before end of 2020). The IRP is considering how best to integrate HS2, Northern Powerhouse Rail (NPR), Midlands Rail Hub and other proposed rail investments. HS2 and NPR will have a significant impact on the existing railways in South Yorkshire. In addition, Transpennine Route Upgrade, East Coast PSU and Midland Mainline will all place demands on the power supply system in the area.

NEW AND EMERGING TECHNOLOGY

One of the challenges with railway electrification is how to keep a three-phase supply network balanced when only using a single phase. Converting all three phases to a single phase is not a new concept. Connecting a three-phase motor to a single phase generator is one way and has been used in the past, particularly when changing the frequency. For historic reasons, German influenced railways have used this method for converting from 50Hz national supplies to 16.7Hz (at 15kV) for use on the railway. Although some engineers favour the 16.7Hz, 15kV systems, it is not practicable to convert the UK network with all the implications on rolling stock conversion and a complete replacement of the electrical equipment (we are where we are). It is now possible to achieve the same result with Static Frequency Converters (SFCs) using semiconductor technology.

A SFC feeder station (with three phase 50Hz input and single phase 50Hz output) has been installed at Potteric Carr (near Doncaster). A SFC feeder station is currently being installed at Hambleton as part of the EC PSU project and is proposed for Ravensthorpe for the Transpennine Route Upgrade, with SFCs being actively considered for other sites. In addition to the phase balancing, there are also advantages in that there is less need for neutral sections (the supply can be synchronised to the railway, independent of the National Grid). Neutral sections will, however, still be required for the foreseeable future with existing transformer feeder stations widespread.

However, there are also limitations with SFCs in that the voltage drops very rapidly when capacity is reached, potentially leading to service disruptions, unlike a transformer supply which can operate at up to 200% of the transformer rating for typically two hours. This has implications, particularly when a feeder station is "covering" for an outage at an adjacent feeder station. It is known as "N-2" when both independent supplies at a feeder station are unavailable.

SFCs will also limit any short-term increase in load demand on the network that a transformer supply would be able accommodate. However, SFCs do have a role to play, particularly in locations where phase balancing on the distribution networks is a particular concern and for power supply upgrade projects where they can potentially be used as "infill". Other emerging technologies to be considered include energy storage devices, both lineside and on-board trains, and

Figure 1: An autotransformer within a traction substation compound (photograph: Garry Keenor).

potentially locally generated supplies. Although unlikely to replace connections to the distribution networks, lineside energy storage and local generation could help reduce the peak load on the grid and reduce the need for costly power supply upgrades. Discontinuous electrification using on-board energy storage to "bridge the electrification gaps" is part of this equation but generally not suitable for freight routes.

PROTECTION AND CONTROL

Enabling new supply points and new technologies to be introduced without causing significant disruption and unnecessary costs must be an aim for the future of electrification. Using SmartGrid technology is therefore essential. There are various definitions for SmartGrid but most include the application of digital technology to monitor, control and provide network information using the latest generation of automated electrical power systems.

The railway has already developed the basic architecture for this with the IEC 61850 standard adopted on the GW main line. This gives the ability to quickly and automatically isolate faults and reconfigure autotransformer systems, thus minimising service disruption. The technology provides distance to fault analysis to accurately identify the location of faults on the overhead line reducing the time to identify and repair any damaged equipment. Using SmartGrid also enables the introduction of new technologies thus helping to futureproof the system. Although there are additional costs, the long-term advantages are significant and pressure to reduce project costs by adopting cheaper systems should be avoided.

The technology also provides the opportunity to up-skill staff, providing further benefits in a digital age. Standards need to be developed to enable procurement of "technology agnostic" systems, not dependant on individual suppliers for ongoing maintenance and future changes, and compatible with the national Supervisory Control and Data Acquisition (SCADA) system.

BUDGETING

Traditionally, the costs of traction power supplies are included in the overall costs of an electrification project. Where each project was developed and installed in isolation this made sense. However, with the emergence of a long-term network strategy, attributing the full power supply costs to the first project in an area will result in either disproportionate costs for that project, or a sub-optimal longer-term solution that will require costly and disruptive re-work on subsequent projects as the network is joined up. Consideration therefore needs to be given to a national or regional power supply project, as in Scotland, independently budgeted from specific route projects, to ensure the optimal overall solution.

CONCLUSION

With the UK hosting the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow in November 2021 and the legal requirement to bring all greenhouse gas emissions to net zero by 2050, the need to electrify the UK's railways has again risen up the Government's priority list. In order to meet the target, following the report from the Rail Industry Decarbonisation Taskforce, Network Rail have produced the Traction Decarbonisation Network Strategy showing 13,000 single track km of new electrification is required. To avoid repeating some of the mistakes of the past, the opportunity to approach traction power design from a whole system perspective must be grasped as part of the overall drive to make electrification cost effective and prevent unnecessarily costly PSU projects in the future.

Figure 2: SF6 circuit breakers (photograph: Garry Keenor).

TECHNICAL ARTICLE

AS PUBLISHED IN

# The PWI Journal

## January 2021

VOLUME 139 PART 1


**#thepwi**

W thepwi.org

PermanentWayInstitution

@PermWayInstit

Permanent Way Institution

@the_pwi

If you would like to reproduce this article, please contact:

Kerrie Illsley
CREATIVE MANAGER
Permanent Way Institution
kerrie.illsley@thepwi.org

PLEASE NOTE: Every care is taken in the preparation of this publication, but the PWI cannot be held responsible for the claims of contributors nor for the accuracy of the contents, or any consequence thereof.

PERMANENT WAY INSTITUTION
THE PROFESSIONAL COMMUNITY FOR RAIL INFRASTRUCTURE ENGINEERING