Medium voltage switchgear for a sustainable industry

Powering Business Worldwide

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There are, of course, a great many types of transportation available today and the challenge facing the rail industry is to make traveling the railways as reliable, efficient, safe and comfortable as possible. Rail can be a conservative industry and driven by regulations and increased globalization, train builders and railway operators must find ways to reduce downtime, increase productivity and enhance safety and security to drive profitability and make the industry more sustainable for the future.

Indeed, the environment and sustainability within the sector are major concerns as research has shown that there is the potential to reduce up to 56% of the carbon footprint of the railway sector (within the EU) by 2050. This reduction is attributable to a number of integrated factors such as engine efficiency, energy efficiency and the use of renewables, making train design more sustainable and easy to upgrade.

For the purposes of this paper we are considering that the railway sector can be sub-divided into four separate areas: Infrastructure; Rolling stock; Control signaling and Service. MV Switchgear is primarily focused in two of these areas; Infrastructure and Control signaling (although Service is worthy of consideration too) and we'll be assessing the role that Medium Voltage Switchgear has in these areas and the major role the latest technology can have in relation to sustainability, safety, the total cost of ownership, energy efficiency and reliability. In fact all of the core aspects that we identified earlier as being major challenges for the industry today.

This paper, authored by Bert ter Hedde of Eaton, is written specifically with the needs of decision makers in the rail industry in mind, especially those involved in power supply for rail and signaling projects. Eaton has an unusual perspective on the industry, being able to offer expertise across electrical, hydraulic and filtration solutions. Eaton's focus on energy efficiency and safety means that its customers can rest assured that they'll be able to meet stringent regulations and drive the industry towards a sustainable future.

Eaton has been operating in the rail sector for more than 50 years. During that time it has established itself as a trusted partner to rail operators such as SNCF and the Swiss National Railway, Dutch national railway and worked with train builders such as Alstom; Siemens and Bombardier.

Infrastructure

The latest thinking in the rail industry in relation to its infrastructure is for infrastructure owners to invest in new, more reliable and resourceefficient technologies to reduce sector cost (CAPEX) and also to concentrate more than ever before on the monitoring of infrastructure condition and maintenance to increase system reliability and cost efficiency (OPEX).

The infrastructure owners are building intelligent infrastructure that is autonomously monitored in real-time and offers high levels of energy efficiency which results in a reduced carbon footprint. The best MV switchgear, used in 24kV systems, reflects this focus on CAPEX as it offers reduced financing costs and OPEX as its monitoring capability details how energy is being used. Remote operation obviates the need to send personnel to sites and simplified maintenance reduces this activity and also leads to reduced downtime.

But, as important as the arguments surrounding CAPEX and OPEX are in the rail sector foremost in the minds of both operators and train builders is the requirement to avoid the liability and reputational damage that can accrue through accidents and the contravention of safety and environmental standards. Which, and in particular relation to MV switchgear, is why it will be a surprise to some people that equipment that uses an outdated and highly toxic gas is still being incorporated into modern systems.

High voltage switchgear is one of the few applications where the use of SF_6 gas is still permitted. This is based on the premise that there is no viable alternative. However, in the range 1-52kV there is a perfectly viable option in the form of vacuum switchgear with solid dielectric insulation. Vacuum switchgear is similar in size and technically equivalent, if not superior, to SF_6 switchgear.
The notion that there is no viable alternative to SF_6 switchgear for high voltage applications, which is exploited by the producers of SF_6 and manufacturers of SF_6 switchgear, can be attributed in part to the different methods of classifying voltage levels. IEC terminology identifies two voltage bands – "low voltage" for applications up to 1,000V a.c. and "high voltage" for anything greater than 1,000V. However the term "medium voltage" is widely used for distribution voltages in the range 1kV-52kV. Thus it is perceived by some that SF_6 is the only option for systems greater than 1kV when, in reality, vacuum switchgear is a "green" option up to 52kV.

F-gas Regulations

The Fluorinated Greenhouse Gas Regulations 2009 impose strict legal requirements upon personnel and companies in five industry sectors that use fluorinated greenhouse gases (F gases). These gases include the fluorocarbons (CFCs and HFCs) as well as sulphur hexafluoride (SF6). High voltage switchgear is one of the five industry sectors along with refrigeration and air conditioning, fire protection systems and certain types of solvent. In the Netherlands, the government has supported a Green Switching initiative. This group is working to increase awareness of the issues surrounding non-carbon greenhouse gases and to promote the development of alternative technologies. It believes that there should be tighter controls over the use of SF6 with a ban on its use up to 52kV. In the USA, the Environmental Protection Agency (EPA) is promoting a voluntary SF6 emission reduction programme. Between 2000 and 2006, emissions by these utilities fell from 15.1% to 6.5%. Meanwhile, the Leadership in Energy and Environmental Design (LEED) system for rating green buildings, developed by the US Green Building Council, is being adopted in many parts of the world as a way to quantify and compare sustainability. Use of vacuum switchgear with solid dielectric will help achieve the objectives of the LEED standards.

SF6 switchgear

Approximately 8000 tonnes of SF6 are produced annually, of which 80% is used in electrical switchgear. It is used for two functions - circuit interruption and insulation. For circuit interruption SF6 offers excellent arc quenching and heat transfer properties. It has a high chemical stability and a fast dielectric recovery time with self-healing properties under electrical discharge conditions. Under normal operating conditions it is non-flammable and non-explosive, making it an excellent alternative to oil-filled switchgear, which has largely disappeared as a technology over the last thirty years.

As an insulating medium, SF6 has an electrical breakdown strength approximately three times that of air at atmospheric pressure. This means that by filling a circuit-breaker enclosure with SF6 gas the phase-to-phase and phase-to-earth distances can be reduced, making for compact equipment. This is the principal reason why SF6 gas has been used so extensively as an insulant in gas insulated switchgear (GIS) even where vacuum technology is used for circuit interruption.

However, an enormous drawback is that SF6 is one the of six most potent greenhouse gases identified by the Intergovernmental Panel on Climate Change (IPCC) and consequently included in the Kyoto list of substances whose use and emission should be minimised. Although far less common than carbon dioxide, it has a global warming potential (GWP) listed as 23,900. This means that one tonne of SF6 has the same greenhouse effect as 23,900 tonnes of CO2. At present its contribution to global warming is only small but, unlike other greenhouse gases, it is largely immune to chemical and photolytic degradation so its effects are cumulative. The annual rate of increase in the atmosphere is said to be 8% and lifetime in the atmosphere is estimated as 3,200 years (CO2 is 50-200 years).

Under the F-gas Regulations, the use of SF6 was prohibited for most applications including sports shoes, tennis balls, car tyres and double glazing. However, its continued use for HV switchgear is permitted on the basis that there is no viable alternative. Nevertheless, the Regulations imposed strict requirements for the manufacture, use, maintenance and disposal of SF6 switchgear, including special requirements for the training and certification of personnel. The extent of leakage of SF6 into the atmosphere is not known but emissions of 6-13% over the complete product lifetime have been estimated. Under the F-gas Regulations all larger systems containing SF6 should be inspected regularly and emissions should be prevented as far as possible during maintenance. Some authorities insist on continuous monitoring of all gas-filled enclosures to detect leaks.

SF6 also poses a number of health risks. For example, although it is non-toxic and chemically and thermally stable under normal conditions, it can break down into highly toxic substances such as HF, SOF2, SF4 and S2F10 when exposed to arcing, partial discharges or incineration. Under normal operating conditions these are generally re-combined after a discharge is cleared but some toxic residue may remain in the housing. If there is a catastrophic failure, these products could be released into the atmosphere, exposing the public to risk. Consequently, SF6 switchgear should not be used in residential areas, commercial buildings, shopping malls, railway stations or underground installations.

Asphyxiation is another risk. SF6 is a colourless, odourless gas which is about five times the density of air. Consequently locations should be well-ventilated and gas analysing equipment may be needed to alert staff to any risk from leakage. End-of-life disposal is another important consideration. Measures must be in place to recover the SF6 gas and personnel need to be protected against risks from harmful by-products. The presence of these by-products restricts the ability of the materials to be recycled.

It should also be borne in mind that while these products are manufactured under controlled conditions in industrialised countries, they are being sold worldwide, including countries where controls embodied in the F-Gas Regulations and similar legislation are not enforced. End-of-life disposal becomes even more uncertain in these countries. The risks are exacerbated when used equipment containing SF6 gas is exported as waste to third-world countries where it may be dismantled by unqualified personnel.

Vacuum switchgear

Vacuum interruption is a proven technology, introduced more than 40 years ago. Arc interruption takes place in a vacuum "bottle". Vacuum interrupters do not require leakage monitoring equipment. Electrical performance is comparable and, at times, better than SF6 switchgear. While capital cost is slightly higher, total life-cycle cost is lower due to the lower maintenance costs. Plus, all the materials can be recycled at end of life.

Continuous development has seen the size of a 15kV vacuum interrupter bottle come down from180mm diameter in 1967 to 50mm today. Meanwhile modern sealing techniques ensure that units retain their vacuum for more than 40 years. On the rare occasions when leaks do occur, they normally manifest themselves early in life; so rigorous production testing helps identify such leaks before units reach the field. Any leaks are, of course, completely harmless to the environment.

Vacuum circuit-breakers are suitable for a wide range of medium voltage switching applications including transformer secondary protection, capacitor switching and motor switching. They are used by utilities for ring main units and MV switchboards. They are suitable for current ratings from 100A to more than 4,000A and fault levels from 6kA to 50kA.

As well as their compact size, vacuum circuit-breakers offer excellent electrical performance. They will normally withstand a rated AC power frequency voltage (an overvoltage due to power system switching operations) of 2-4 times normal operating voltage. Rated lightning impulse is 4-12 times normal operating voltage. However, in normal service the breaker contacts are closed so lightning over-voltages are mostly seen by the phase-to-earth or phase-to-phase insulation; in the rare event of a lightning impulse appearing across the open contacts of the vacuum interrupter, the current will be quickly broken. Under similar conditions an SF6 puffer-type circuit-breaker, air circuit-breaker or minimum oil circuit-breaker would probably explode.

An interesting characteristic of the vacuum circuit-breaker is self-conditioning of the contacts. Rough spots that can occur on the contact surfaces are smoothed out by the diffused discharge when the contacts are opened on-load.

Vacuum interrupters are constructed from materials that can be recovered and recycled at the end of life. They do not contain greenhouse gases; nor do they present potential health hazards due to the products of decomposition. No special precautions are necessary to protect the environment from the results of leaks or during disposal.

The compact size of modern vacuum insulator bottles means that special measures are necessary to improve insulation levels. A 150mm ceramic length will only have a Basic Insulation Level (BIL) of 125kV in air. For this reason insulators may be immersed in a dielectric medium such as oil or SF6 gas to raise the BIL to 170kV. Oil is being phased out because of the fire risk, so SF6 insulation is favoured by many manufacturers.

However, an alternative approach is to enclose the vacuum interrupter in a potting compound such as polyurethane or epoxy. In some cases an epoxy insulator with a contoured profile, similar to the 'sheds' used on overhead line insulators, is used to increase creepage distances. This is especially valuable when the equipment is used in harsh environments involving heavy atmospheric pollution or condensation as common in rail applications. In some cases the entire interrupter and associated busbar are enclosed in solid insulation.

Modern vacuum switchgear with solid dielectric insulation is comparable in size to the SF6 gas insulated equivalent. The circuit-breaker assembly can operate in a normal enclosure with no special sealing or gas filling, and there is no need for costly monitoring equipment. Maintenance is negligible and life can be expected to be 40 years or more.

Total cost of ownership

While the unit cost for gas insulated switchgear is lower than for the solid insulated switchgear described above, total cost of ownership is much higher for the GIS equipment. The specialist nature of the pressure checks needed by GIS equipment means that trained personnel with specialist equipment will have to carry out the work. One estimate has put the annual cost of this maintenance as 9% of the equipment value per year. This does not include any other safety and insurance costs involved. Disposal costs for GIS equipment at end of life are difficult to quantify. Recycling of parts and by-products is not practicable and dismantling, transport and disposal costs will be high. In contrast the solid-insulated equipment is fully compliant with ISO 14001, covering environmental management systems and standards and all parts are capable of being recycled.

There is no justification – environmentally, technically or financially - for using SF6 gas-insulated switchgear for circuit-breakers and ring main units up to 52kV. In fact vacuum interrupters up to 145kV are now in service. However, solid insulation has yet to catch up with this.

While focusing on Total Cost of Ownership (TCO) one area where a move away from a traditional approach is paying dividends in the rail sector is in the integration of medium and low voltage equipment. The traditional way of approaching this is demonstrated in Fig 1.

However, there are large savings to be made in the TCO by using a package substation approach. A package substation is a combined electrical distribution system containing medium voltage switchgear, a transformer and a low voltage distribution board in a single housing. Access to the MV switchgear, transformer and LV switchgear is restricted to authorised personnel. The systems are prefabricated under controlled conditions and can be installed and connected on site in a very short space of time.

An Eaton M2L substation consists of the following tailormade components:

- Medium voltage switchgear system (type Xiria or Xiria E).
- Transformer (cast resin insulated).
- Low voltage distribution installation (type Power Xpert CX or CXH). Fig1: M2L Comparison illustration

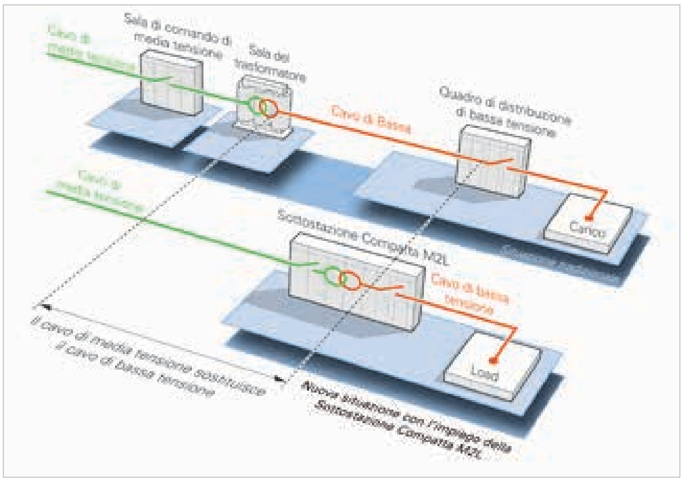

Fig. 1: M2L Comparison illustration

Fig. 2: The package substation approach

Table: Cost comparison

Costs	Conventional solution	With M2L distribution board	Differences	Information
Investment costs Low voltage installation	€ 50,000	_		Capitole 40
Medium voltage installation	€ 10,000	_		Xiria
Transformer	€ 30,000			1.600KVA/5.2
M2L Distribution board		€ 130,000		Capitole 40/ Xiria/ Transformer including installation and assembly on location
Building costs Technical room	€ 27,500	–		
Medium voltage cable	€ 1,750 (50 meters)	€ 3,500 (100 meters)		€ 35 per meter
Low voltage cable	€ 34,000 (50 meters)	_		€ 680 per meter
Installation & assembly costs Installation costs	€ 10,000	_		Already included in the price for the M2L distribution board
Assembly costs	€ 10,000	_		Already included in the price for the M2Ldistribution board
Operating costs	€ 10,000	_		Difference in power loss based on 10 years in operation
Total	**€ 190,750**	**€ 133.500**	**€ 57.250**	

Fig. 3

The package substation approach (as shown in Fig 2) offers numerous benefits, not least of which is a significant reduction in the TCO (see Fig 3 for cost comparison). TCO is influenced as it is possible to minimise the use of expensive low voltage cables through the placement of the transformer much closer to where the power is needed (the centre of gravity of load). This eliminates the need for long and relatively expensive low voltage cables or busbar systems. When using the package substation, a proportionately longer medium voltage cable is sufficient. The package substation approach (as shown in Fig 2) offers numerous benefits, not least of which is a significant reduction in the TCO (see Fig 3 for cost comparison). TCO is influenced as it is possible to minimise the use of expensive low voltage cables through the placement of the transformer much closer to where the power is needed (the centre of gravity of load). This eliminates the need for long and relatively expensive low voltage cables or busbar systems. When using the package substation, a proportionately longer medium voltage cable is sufficient.

The integrated solution results in considerable savings on assembly costs and limits the numbers of terminations. Instead of assembling a heavy package of low voltage cables or busbar systems, the package substation only requires a single medium voltage cable to be connected. The connection with the transformer has already been pre-terminated and tested. In addition, the package substation can be installed in a general MV switch room without problems. This eliminates the need for the construction of medium voltage and/or transformer rooms. Plus, the packages come pre-assembled and tested and only take an average of two working days to set up and test the system on the site.

Rail control and signaling

While the above information on environmental sustainability and total cost of ownership is applicable to medium voltage switchgear wherever it is being used, be that in relation to rail infrastructure or signaling and control, there are several aspects of its application in signal and control systems that are worthy of mention. Rail signaling and control applications predominantly operate at the 12kV level and they are by their definition 'always on' and therefore MV switchgear used here is always used in conjunction with a UPS (Uninterruptable Power Supplies).

Some market research from Eaton has shown that the demands which are currently prevalent are that better control and signaling management is required to increase capacity of the lines and traffic which leads to more profitability and increased safety. Also, shared information platforms and robust IT tools make it possible for real-time data exchange for reliability of schedules, flexibility in options, efficiencies, etc.

These demands are in turn driven by the customers' demands for more trains, which are running more regularly to more places. There is a continual, ever-escalating, trade off in terms of maintaining passenger happiness and the flexibility of the rail management system. Aligned to which there is a growing demand for increased resilience. In the event of an incident, systems must restart quickly and system performance in degraded mode must be close to normal operational mode. Plus operators require interoperability between countries.

Technical support and service

But, increasingly, just being able to supply medium voltage switchgear that technically does its job and hits all of its marks in relation to safety and environmental concerns is only half the battle. For some time there has been a movement in the industry towards both pre-and post-sale services as a condition to winning business. The train builders request engineering capability and infrastructure owners request project management capability and there has been a certain amount of transformation in the industry as equipment vendors have had to adapt to the changing needs of the industry in relation to its demands on its suppliers.

To that end the larger players have become more important to the industry. Not necessarily those whose sole business is confined to the rails sector but those whose ability to bring to bear large amounts of manpower and large resources onto a project, on a global scale, is proven. Additionally, this can often bring fresh thinking into the sector through experience in other industries –although as stated earlier in the paper rail is essentially a conservative environment. Much thought is now given to resource management – having the right people for the right jobs –although the counterpoint to this is that system reliability is a major consideration as reliable equipment requires less resources now and for the future.

Summary

As we have seen in this paper the applications of MV switchgear in the rail sector are numerous (and that doesn't take into account the use of MV switchgear in distributing electrical power to the retail environments that increasingly are built alongside rail hubs) but there is a real challenge to ensure that the correct environmental and safety decisions are made regarding its use.

Eaton's medium voltage power distribution

The series of Eaton Medium Voltage systems offers switchgear and components for applications in distribution networks (main stations, sub stations and transformer stations) and industrial power supplies. These technically high quality systems are air- or epoxy-resin insulated and are always equipped with circuit breakers based on proprietary vacuum interrupters.

The medium voltage switchgear systems carrying Eaton's brand are based on the use of vacuum circuit-breakers combined with solid insulation material. MV switchgear provides centralized control and protection of medium voltage power equipment and circuits and efficiently distributes the power for rail infrastructure or rail control projects. Eaton SF6 free solutions deliver high performance with environmentally friendly technology and save more than 50% of the space required for switchgear over traditional models. Power Xpert UX – IEC medium voltage primary distribution switchgear up to 24 kV features a single busbar and withdrawable vacuum circuit breakers or contactors.

Power Xpert FMX – IEC medium voltage primary and secondary distribution switchgear up to 24 kV features a single busbar and plug-in type circuit breakers

Xiria – IEC medium voltage ring main units (RMUs) are used for secondary distribution up to 24 kV and distribution switchgear for rail control and rail infrastructure projects up to 24 kV. The Xiria product family is a compact, environmentally friendly RMU, supplied in one, two, three, four or five-panel versions.

Xiria E – Extendible switchgear used for secondary distribution up to 24 kV. Xiria E is metal-enclosed, single busbar, solid and air-insulated IEC switchgear with fixed vacuum circuit breakers and load-break switches.

Xiria M – Provides effective integrated metering solutions within the Xiria product family range.

Automated Xiria with remote terminal unit (RTU) – Focused on Xiria RMU applications for the medium voltage Smart Grid, the RTU enables measurement and control on the medium voltage and transformer side of a RMU to reduce outage time and the possibility of outages.

Xiria is the name of Eaton's product family for a new generation of medium voltage switchgear. The Xiria family started more than a decade ago with the introduction of the Xiria ring main unit. This ring main unit consists of a block containing three panels. Due to the quick acceptance and worldwide interest in more configurations, Eaton consequently developed a four, five and two panel block. Due to the fact that the individual units cannot be coupled and are limited in the number of panels and protection and control equipment, the single panel version was developed. This single panel version is called Xiria E. E in this case stands for Extendable.

Power consumption metering

The Xiria family includes multiple possibilities and configurations for Power consumption metering. These configurations are indicated as Xiria M-versions. M stands for metering. The transformers for power consumption metering can be either integrated into the block-type Xiria switchgear or housed in a separate metering panel. This dedicated metering panel can be integrated with both the current block type switchgear and the new single extendable panels.

Eaton's Low voltage power distribution and Motor Control Center

Power Xpert CX and CXH make up a product family that both cover the entire range of applications, but with focus on Power Distribution and Motor Control respectively.

Both the CX and CXH platforms are fully scalable and complementary, enabling you to create a fit-for-purpose low voltage system comprising entirely Eaton components. Power Xpert CX, Power Distribution and Motor Control.

The Power Xpert CX is Eaton's IEC low voltage power assembly up to 6300 A. The system provides reliable power distribution and motor control functionality for all commercial and industrial applications.

Power Xpert CXH, Motor Control Center and Power Distribution.

Power Xpert CXH is Eaton's IEC high-performance Motor Control and distribution center up to 6300 A. The system provides reliable motor control and power distribution functionality for applications that have the highest requirement for reliability and safety. CXH is a reliable solution for applications where the motor control is vital.

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Publication No. WP022004EN / CSSC-430

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