WHITE PAPER

A Step Forward on the Technology Path to an All-electrically Operated Train

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Introduction

Efficiency will drive the future of public transportation. The constant growth of urban centers increases commute and travel times. This results in an increased need for more efficiently engineered railway solutions. The electrification of passenger trains will help the transportation industry reach a new level of efficiency by offering transportation that weighs less and uses less energy. Electrically operated trains are gaining importance for a nation's transport infrastructure mix. Emerging countries will be investing in new, optimized railroad infrastructure. Developed countries are expected to look for solutions which will allow them to upgrade and refurbish their existing train networks. From an engineering perspective, line power disruptive technology will play an integral role in railway electrification.

TE Connectivity (TE) is contributing to the portfolio of modern rail technology with its innovative VESA vacuum circuit breaker (VCB) for 25kV and 15kV vehicles. The VESA VCB is a main circuit breaker located on the train roof near the pantograph(s). In contrast to existing line power circuit breaker technology, which is normally based on pneumatic actuation, TE's solution is electro-magnetically operated. Without the need for compressed air to actuate the line power circuit breaker, the infrastructure complexity of the train is reduced with corresponding train equipment weight and space savings. Electro-magnetic actuation offers performance advantages that include immediate availability, fast response time, reduced contactor bounce and energy-efficient operation. The VESA product features a slim on-roof profile for reduced aerodynamic drag that helps to reduce the energy consumption, and therefore the carbon footprint, of a train over its lifetime.

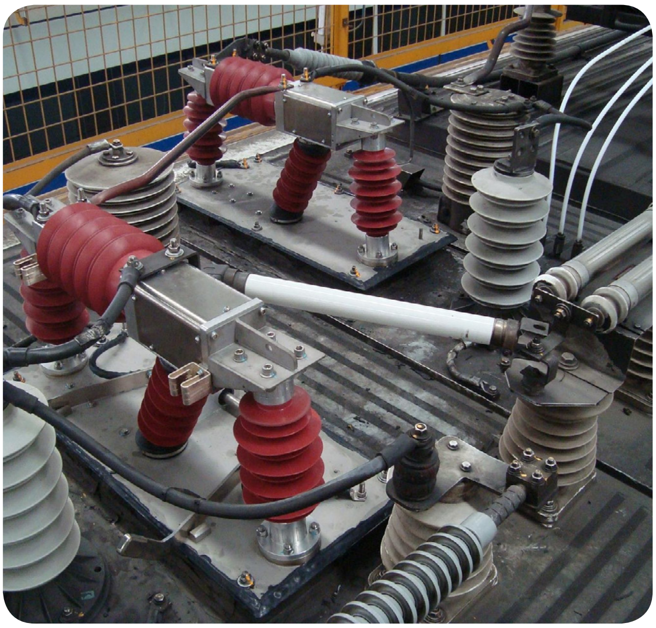
TE is leading this vacuum circuit breaker technology shift and is currently the only supplier with a substantial quantity of electro-magnetically operated VCB´s in the field. The first unit was installed over five years ago and there are now more than 800 units in service on four continents.

By changing from pneumatic to electro-magnetic actuation, the train manufacturer is provided with a lower overall cost solution by reducing or removing the need for pneumatic systems. For the train operator the electro-magnetically actuated VESA VCB provides low running costs due to reduced maintenance needs and minimized train energy consumption. Reduction or removal of the train's pneumatic systems may result in additional space for fare-paying passengers, further enhancing the economic benefit for the operator.

1. Principle Function of Line Power Circuit Breakers

Line power circuit breakers are instrumental to run a train safely, smoothly and on schedule. A pantograph is used to collect current from the overhead lines. The line power circuit breaker is typically located on the train roof, in the power line, between the pantograph(s) and the main traction transformer. Its function is to break the current entering the train when required. The line power circuit breaker's primary function is performing as a safety critical line power main circuit switch, being required to fulfill the following functions:

- Routinely operate at neutral sections
- Disconnect in an emergency (in the event of a power supply fault)
- Ensure that the train's main power supply is isolated and earthed through the integrated earthing switch during maintenance. This is essential to protect lives.



This application shows part of a modern high- speed train. Two line power circuit breakers sit on the train roof in the middle between two pantographs with the power cables from both pantographs running towards the circuit breakers. As long as the circuit breaker contacts are in the closed position, the electric energy flows into the train.

Why Line Power Circuit Breaker Technology Is Important

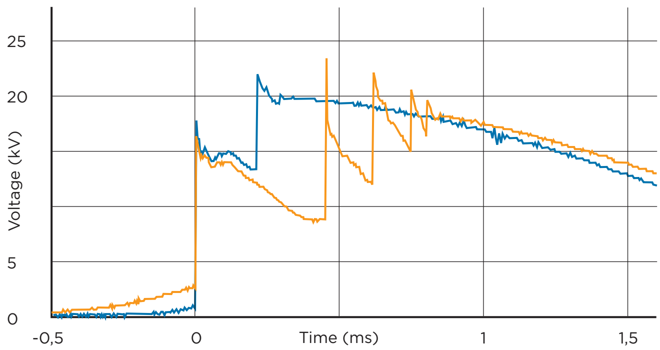
Traditionally, circuit breakers are actuated by compressed air, which is provided by compressor and reservoir system. The pneumatic infrastructure of the line power circuit breaker is independent from the main pneumatic system, which feeds the train brakes. While the additional pneumatic circuit breaker system has been considered a proven technology for decades, pneumatic systems tend to be seen in a more critical light today due to their space and weight requirements, relative complexity, reliability issues and associated maintenance needs.

A pneumatic system comprises of an electrically driven compressor, pipes transporting the compressed air to the actuator(s), valves controlling the air flow and pressure, and the actuator itself. The air needs to be dry and free of particles at all times to avoid contamination and condensation, which can lead to valve blocking, e.g. by icing up. Despite the particulate filters and dryers, it is a challenge to run a clean pneumatic airline system. The system complexity and number of possible faults requires significant maintenance effort, and increased potential for unscheduled work.

Pneumatic actuation does not result in a fast start-and-go system. When a train is started, it takes idle time to build up the air pressure required to operate the system. Also, if there is a fault while on a track, a pneumatic system will take time to recharge, whereas an electric system is instantly available. This is especially important in low temperature environments where compressed air systems can take longer to come back up to pressure.

Additionally, pneumatic systems are less energy efficient due to the rules of thermodynamics. Air needs to be compressed and energy is dissipated in the form of heat loss. Actuating the circuit breaker with electric energy in one step eliminates the air compression stage (and the energy losses that are associated with it).

Back to Back Performance Test of TE's Electro-magnetically Operated VESA VCB and a Typical Line Circuit Breaker with Pneumatic Actuation



2. Principle of TE's Electro-magnetically Operated VESA Vacuum Circuit Breaker

TE's new electro-magnetically operated VESA VCB uses the train's low voltage power supply and built-in energy storage to change the state of a magnetic actuator. To open or close the circuit breaker, a command signal is applied to the VCB low voltage control circuit, which then supplies power to the electro-magnetic actuator. As the actuator changes state it moves the contacts in the vacuum interrupter (also called vacuum 'bottle') via an external drive rod.

Once the actuator has changed state, permanent magnets provide the force necessary to hold the contacts inside the vacuum interrupter together against the constant pre-load of a spring on the actuator. The opening movement to achieve the 'open' position is aided by the force of this opening spring. The unit interfaces with the electronic control system on the train and the control logic can be customised to individual applications.

Characteristic	Value
Nominal line supply voltage (U_n)	25 kV
Rated operational voltage (U_e)	30 kV
Rated operational frequency (f)	50 Hz
Rated dielectric withstand (U_{50})	75 kVrms
Rated impulse withstand voltage (U_{imp})	170 kV
Rated operational current	1000 Arms
Rated making / breaking capacity	50 / 20 kA
Rated short time withstand current	25kA / 1s
Closing time	42 ms (typical)
Contact separation time	18ms (typical)
Low voltage circuit supply	24, 48, 72, 110 -30/+25% Vdc
Operating temperature range	-50 to + 70°C
Height	• Above roof line: 490 mm • Below roof line: 140 mm
Base plate dimensions	940 x 430 mm
Weight - with earthing switch - without earthing switch	105 kg 95 kg

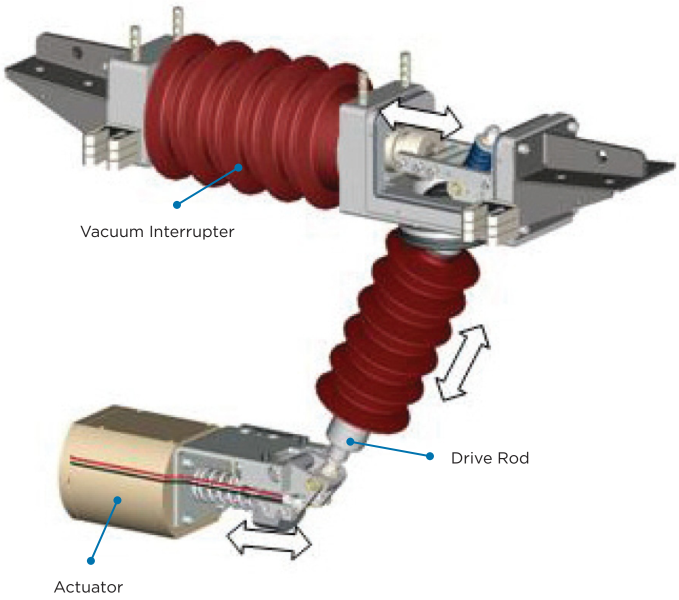
Table 1: Core facts and figures on the electro-magnetically operated VESA VCB: this table gives typical ratings for a 25kV vacuum circuit breaker. Ratings for 15kV vacuum circuit breakers are available on request.

The electro-magnetically operated VESA VCB is compliant with all major specifications used in the rail industry, including:

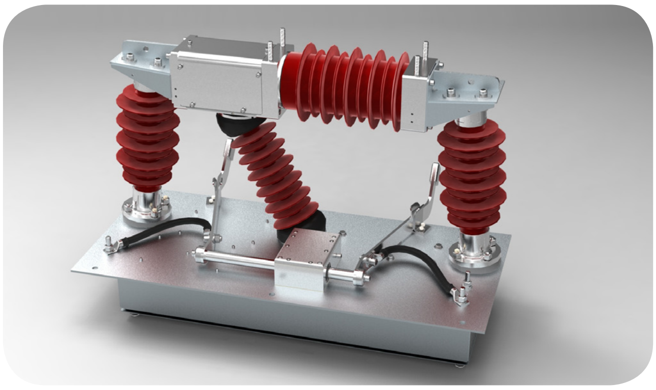
- IEC 60077-4
- EN 50121-3-2
- EN 61373
- EN 60529
- EN 62217 Ed 2/CDV
- EN 50124-1

Customized designs for specific applications are also available upon request.

The VESA VCB's Principle of Operation



Design of the VESA VCB



3. System Benefits

RELIABILITY:

The original motivation to develop an alternative solution to pneumatic actuation of circuit breakers was to achieve a more reliable system that needs less servicing.

SPACE SAVINGS:

Pipes, valves, dryers, and filters of the compressed air supply and the secondary services need to back up the primary air supply in case of failure. This can be eliminated by moving to an all electric solution. A smaller sized VCB air supply and a compressor for the pantograph actuation can be used. There is no longer a need for pneumatic plumbing. Also, changing the pantograph actuation from pneumatic to electrical results in a redundant auxiliary air system.

WEIGHT SAVINGS:

TE's electro-magnetically operated VESA VCB is amongst the lightest in its class and is less than half the weight of some pneumatic products in the market.

BACKWARDS COMPATIBILITY:

The VESA VCB can be retrofitted as part of refurbishments, refits, or major maintenance cycles. The product is a compact design that fits the industry standard and is backwards compatible with most train roofline systems currently in use. As a result the VESA VCB can be fitted to trains originally designed for pneumatics with minimal effort. It can be directly connected to the electronic control system, reducing complexity and helps to increase the scope and precision of sub-system control.

CUSTOMIZATION:

To facilitate tailored customer solutions, the electro-magnetically operated VESA VCB can be customized in several ways. The choices include earthing arms, various operating voltage options (15/25 kV), the integration of additional control relays and feedback switches to suit the customer's electrical interface. The control logic can also be customized to ensure compatibility with the specific train's control system.

ENERGY SAVINGS:

The low electric power consumption of the VESA VCB contributes to reduced power demand on the train's low voltage system, while traction energy savings come from the significant overall weight savings combined with reduced aerodynamic drag:

- Overall train weight reductions, compared with pneumatic circuit breakers, of up to 100 kilos per circuit breaker unit plus the weight saving associated with reducing on-train pneumatic equipment.
- Potential cross-sectional area reduction by a factor of 4, providing dramatic reduction of aerodynamic drag up to 5000 EUR a year per VCB unit.
- Power consumption of the TE's VESA VCB is under 10 Watts, even when switched frequently.

COST SAVING POTENTIAL:

Operation shows reduced maintenance hours. Due to self-cleaning insulators and the reduced reliance on the pneumatic systems on the train there are significant reductions in maintenance hours needed to keep the product in optimal service condition. The table below shows, that within an operating time of four years, TE estimates a savings potential of 120 hours by installed unit.

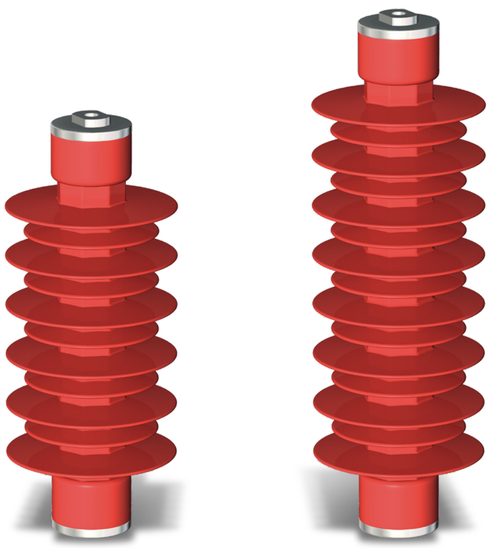
Service	Pneumatic line circuit breaker*	Electro-magnetic vacuum circuit breaker	What?
Weekly	0.5 hours	0 hours	Cleaning ceramics
Annual	10 hours	2 hours	Cleaning of pneumatic filters, moister traps etc.
4 years	24 hours	10 hours	All peripheral work and unit maintenance

Table 2: Sample maintenance calculation
*includes pneumatic system maintenance

INSULATION MATERIAL:

Line power needs to be insulated from the machine body and train structure. Various insulator housing materials are available, typically porcelain and silicone rubber. Each has known disadvantages. Silicone is easily deformed in high speed airflows and susceptible to electro-chemical breakdown in certain environments. Porcelain, although strong, is heavy, susceptible to impact damage and requires regular cleaning / maintenance.

For the insulation of its electro-magnetically operated VESA VCB, TE uses innovative polymer technology for enhanced product reliability. TE insulators are made from a very robust polymer which withstands high speed airflow, resists breakdown in even the most aggressive environments, and is lightweight whilst being very resistant to impact. At the same time, it features a unique self-cleaning effect. For 30 years, this high performance EVA material has been in use worldwide in medium and high voltage systems in all types of environments. This is another factor with which TE reduces overall weight of the VESA VCB and maintenance costs, whilst proving a very robust solution.



Complex weather shed geometries as exemplified in this image can be fabricated in a cost-effective way by direct molding of polymer. This combination of materials and manufacturing technology provides the ability to form the longest creepage paths in the industry and excellent performance in even the most adverse conditions.

ENGINEERING NOTES:

EXPLOSION-PROOF DESIGN: The VESA VCB design removes the risk of internal drive rod flashover in hollow insulators by utilizing an external drive rod approach.

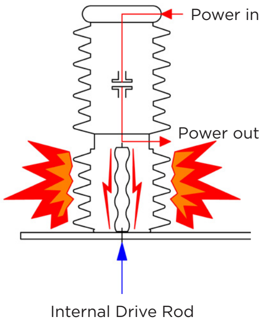
Internal flashover in hollow porcelain insulators occurs when

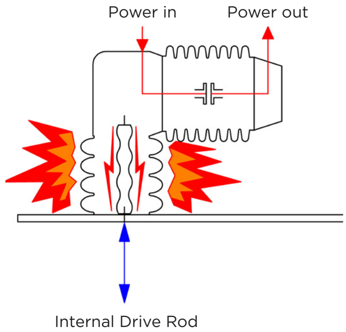
- the surface of the internal drive rod becomes contaminated over time by dirt.
- deposits or moisture cause a pollution type flashover leading to an internal power arc.
- pressure builds up in the confined space and ultimately explosive failure of the porcelain housing, resulting in ceramic fragments spread over a wide area.

Lab test: Explosion after an internal flashover in a hollow insulator demonstration flying debris.

In the TE design, the conductive components are isolated from the rest of the machine on TE polymer-based insulators. Drive is taken from the actuator in the base to the vacuum bottle assembly via an external drive rod. This solid external drive rod has a self-cleaning polymer shed that is resistant to pollution flashover. Even if used in extreme environments the external drive rod is visible and can therefore be inspected for pollution build up. The design has seen extensive service use with no flashover events having ever been recorded; even if a flashover were to occur there is no explosion risk with the external drive rod configuration.

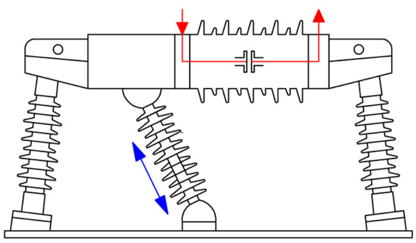
Internal Drive Rod Designs





- Drive rod is not visible
- Drive rod does not self-clean
- Drive rod cannot be easily inspected
- Explosion risk if flashover (hollow insulator)
- Fragments / projectile risk

External Drive Rod Design



- Drive rod is visible (easily inspected)
- Drive rod self-cleans due to special polymer
- Extremely low flashover risk
- No explosion risk should flashover occur

4. Future Technology Path

Ideally, a circuit breaker would switch at precise times on the alternating current cycle (e.g. at a current zero) to minimize electrical disturbances associated with switching that are known to shorten electrical equipment life. So called 'point on wave' switching is not an option with existing circuit breakers. With pneumatic actuation the required system response for point on wave switching is unachievable because the reaction time is simply too long and contactors are subject to significant bounce. Once the change to electro-magnetically operated VCB´s is made, time precise switching will become more of a realistic option and in principle, electric actuation is an enabling technology for point on wave switching. From this point of view, TE's electro-magnetically operated VESA VCB is a step towards a smarter future.

The VESA VCB also brings a host of data logging and communications options, including additional failsafe features, communication with the TCMS and various wireless options that will tailor the TE's VCB to the customer's needs.

Summary

After five years of development and design evolution based on field data, the VESA VCB is a proven TE solution. Over 800 deployed and operated units confirm that the continuous improvement process has taken this new and beneficial railway technology to maturity.

The VESA VCB is successfully operating in different climates, ranging from the cool temperatures in Europe to hot and dry South Africa, and the high rainfall and humidity of China. In all of these climates the performance has been qualified for high speed and medium speed trains (metros, commuter suburban and freight trains) around the world.

TE's electro-magnetically operated VESA VCB´s have lighter weight, are easy to install, provide higher levels of safety and need less energy to be operated. Providing the market with a lower total installed cost solution, allowing removal of bulky pneumatic systems, this innovative TE solution offers an exciting and reliable product for both new designs and refurbishment programs.

Further Information on TE's VESA Vacuum Circuit Breaker
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TE'S PRODUCT INFORMATION CENTERS

Need help? Have questions? We are here for you. You choose: call, email or chat with us online. Dedicated technical experts available around the world, are ready to serve you in English and twelve other languages. Our goal is to provide you with the help you need: nine out of ten questions are answered immediately or within 24 hours.

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TE connectivity