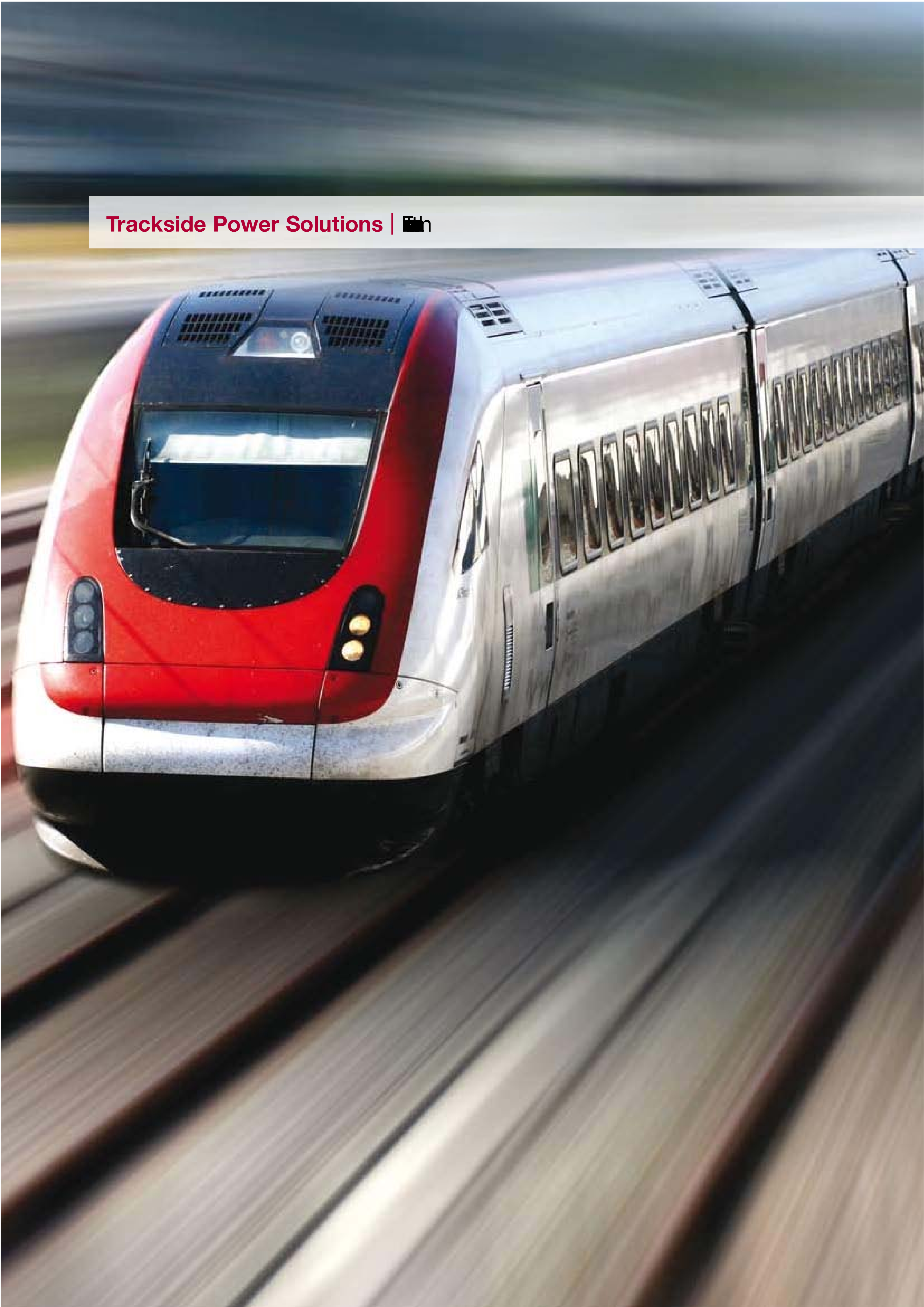
Trackside Power Solutions | [illegible]



Introduction

Public transportation by rail, though not new, is an area of growth, both commercially and technologically. New imperatives of efficiency and "de-carbonisation" coupled with population growth, particularly in urban areas, puts rail transportation at the centre of urban and social planning. Efficiency, long a subject of "lip service" in an industry whose infrastructure and labour costs far outweigh their energy costs, is now a matter of concern, causing new electronic solutions to be increasingly adopted - without dislodging reliability from its paramount position.

Thycon Trackside Diode Rectifiers (TSDR)

The most common category of trackside equipment is the basic diode rectifier and transformer.

Whereas long-distance rail utilises 25kV/50Hz, urban transit in Australia is all based on DC overhead line (catenaries) in the standard voltages of 600, 750 or 1500VDC for which diode rectifiers are most commonly used, usually in the 12-pulse configuration of Fig. 1. 6 and 24-pulse systems are also used.

Diode rectifiers are commonly used because of their simplicity and robustness and the fact that they operate at a good power-factor of about 0.95 (depending on transformer reactance). They suffer however from a number of short-comings, namely that the DC voltage output is unregulated, the current cannot be limited or interrupted in the event of a short-circuit and that braking trains cannot regenerate to the supply and must dissipate their kinetic energy in on-board braking resistors.

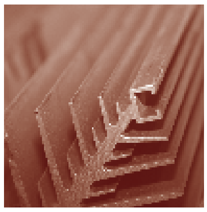
Rectifier Protection includes over-current and over-voltage protection. In Fig. 1, each diode has an individual RC protection network to damp out over-voltages caused by diode recovery and line borne transients. External transients are attenuated by the AC and DC snubbers and also by surge suppressors at the transformer and on the DC rail.

Internal shorts caused by diode failure are protected by diode fuses fitted with trip-indicator switches. Depending on the design requirements, the parallel diodes of Fig. 1 may include redundant devices so that full rated operation can be maintained even with failed diodes (and blown fuses).

External short-circuit protection is assured by co-ordinating the surge and overload capabilities of the diodes with those of the breakers.

Features

- high current ratings, high overload capability
- low cost
- low maintenance
- very rugged press-pack diode technology
- high power factor



Substation

Thycon Trackside Thyristor Rectifiers (TSTR)
Thyristor rectifiers, based on the topology of Fig. 1, have the ability to regulate the output DC voltage by phase control. This can advantageously compensate the natural voltage “regulation” (sag) of the transformer, which in traction applications is considerable. The impedance of a track-side transformer is deliberately set at a high value to limit the fault currents caused by catenary shorts and the reactance may be typically 10% but can be as high as 12%. Each rectiformer output is fitted with a mechanical circuit breaker, which, for 10% reactance, will limit the fault current to 10 times the nominal current and clear the fault within about 200ms. The rectifiers are designed to accept overload currents (typically 3 times nominal) lasting perhaps only a minute but due to the transformer reactance, the output voltage would then drop by over a third which is outside the usual (and already large) tolerance of ±20%.

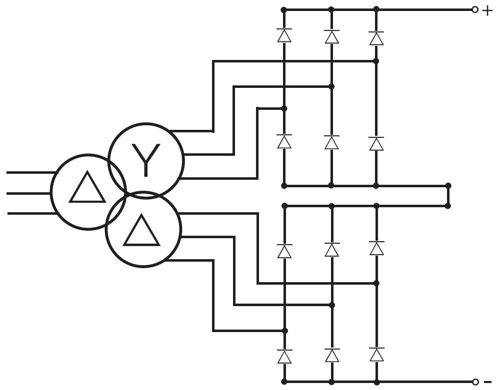


Fig 1 : 12 Pulse rectifier and transformer connection

The thyristor rectifier can compensate for this voltage drop by increasing the conduction angle of the thyristors. Also, in the case of a short-circuit, the fault current can be interrupted within 20ms (worst case of an asymmetric fault current) which reduces erosion of the breaker contacts by minimising the number of breaker operations. The peak fault current is, however, not reduced, so the electromechanical stress on the cabling remains.

Just as with the diode rectifier, the classical thyristor rectifier does not allow regenerative braking energy to be returned to the grid. Furthermore, the advantage of phase-controlled voltage-regulation, is slightly off-set by the need for power-factor compensation, which, nevertheless, can easily be added to the installation.

Features
- less voltage sag or greater allowable distances between stations
- correction/compensation of line-voltage distortions and asymmetry by phase control
- fault-current limitation by thyristor blocking
- rugged thyristor technology

Transmission

Thycon Trackside Reversing Thyristor Rectifiers (TSRTR)

Modern rolling stock in general and on urban DC lines in particular, is usually designed to brake regeneratively but the energy returned to the line is not always returned to the AC grid but absorbed by other trains in the motoring mode (the energy which cannot instantaneously be absorbed being dissipated in the on-board braking resistors).

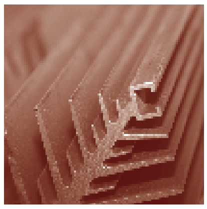
The statistical probability that the braking energy of some trains will be absorbed by the motoring trains, increases with the number of operating trains i.e. during rush-hour and diminishes at the start or end of the business day. This “hit-and-miss” approach was acceptable as long as energy and environmental concerns were low on the agenda but today’s priorities and policies are clearly changing. Furthermore, for cities with a high proportion of tunnels and growing traffic, rheostatic braking brings its own ventilation problems.

The ability therefore to recover braking energy has many advantages which are of growing importance. Trains spend most of their time motoring but their braking power may be instantaneously three times their motoring power requirements. It is in many cases sufficient to replace only a part of the track-side power supplies with reversible supplies to efficiently absorb the braking energy peaks, say, one out of three supplies may be sufficient to improve efficiency, reduce ventilation problems and stabilise the catenary voltage.

Figure 3 illustrates the importance of energy recovery which shows a typical load profile of an EMU (electro-multiple unit). Depending on the required inverter size the TSRTR utilises a separate bridge assembly for the inverter, or if footprint size is a constraint utilises the advanced bi-directionally controlled thyristor (BCT) developed by ABB.

Features

- less voltage sag or greater allowable distances between stations than for diode rectifiers
- correction/compensation of line-voltage distortions and asymmetry by phase control
- fault-current limitation by thyristor blocking
- braking energy recovery and improved voltage stability (2-quadrant operation)
- rugged thyristor technology and same component count as for diode and thyristor rectifiers with only 1-quadrant capability
- reduced braking resistor capacity in rolling stock

Train line

Thycon Trackside Thyristor Inverter (TSTI)

Many existing trackside supplies are based on diode or thyristor rectifiers (single quadrant operation) and were installed at a time when energy conservation was as secondary concern. Where such substations continue to provide satisfactory service, they may be retrofitted with thyristor inverters to return braking power to the MV grid. In general, these inverters are rated for full power but for relatively short periods of operation, typically for about one minute.

Features

- braking energy recovery and improved voltage stability (2-quadrant operation)
- no "negative voltage regulation"; DC voltage remains clamped to the low-impedance MV network
- reduced energy costs
- less heat dissipation in tunnels and enclosed stations
- designed for retrofitting; no need to discard existing supplies
- reduced braking resistor capacity in rolling stock
- rugged thyristor technology

Thycon Advanced Trackside Solutions

Improvements in semiconductor characteristics make new topologies practical for various energy management solutions, all of which are encountered in track-side applications though they have not yet been applied to this domain to any significant degree to date, mainly for reasons of cost.

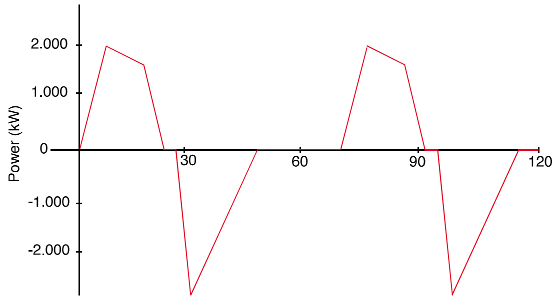
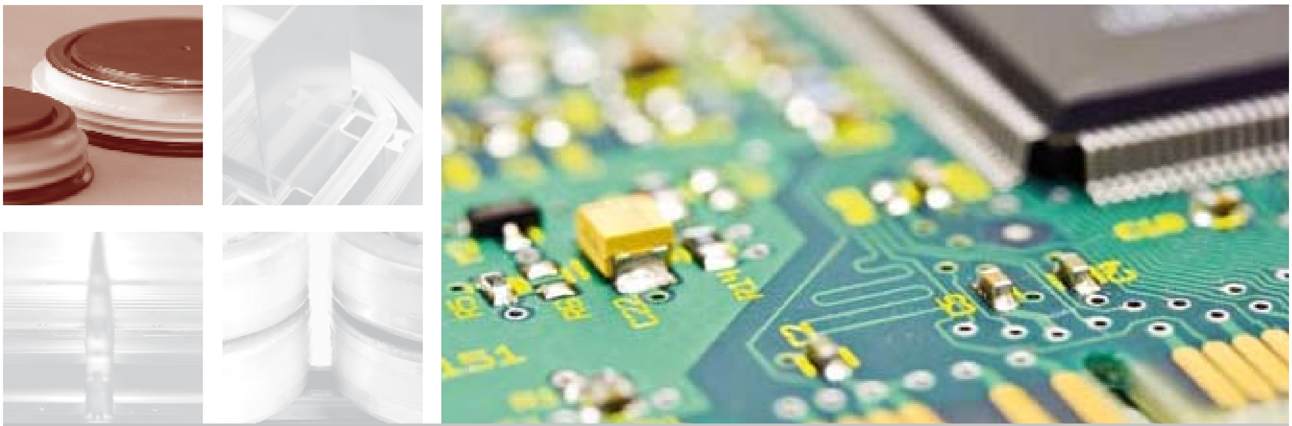


Fig 3 : case study of an EMU profile

Active Rectifiers are the most versatile of all rectifier solutions; these can be either voltage source inverters (VSIs) or current source inverters (CSIs). They can automatically compensate for the lagging power-factor caused by the transformer reactance and they have lower total harmonic distortion than line commutated rectifiers. They use Turn-off Devices (ToDs) such as IGBTs, GTOs or IGCTs which can interrupt the current (they are self-commutated as opposed to line-commutated) and this fact also makes them capable of interrupting a fault current and therefore no longer having to rely on slow mechanical breakers and high transformer reactances. The disadvantage to this technology is that ToDs are much more expensive than thyristors or diodes and that they generate higher losses, which makes the cooling more costly.

Active Rectifiers can also fulfil an Active Filter function, which make this approach the most flexible but also the most expensive solution.



Control circuitry

Power Factor Correction
As mentioned earlier, track-side transformers have a high p.u. reactance leading to a reduced power-factor which is further reduced when using thyristor rectifiers.

A common approach to compensating power-factor is by the use of compensating capacitors. These may be mechanically switched via contactors but this results in step-changes in power-factor and the corresponding line voltage as well as mechanical wear of the contacts. The sudden changes of capacitance can lead to over-voltages and unexpected resonance effects, depending on harmonic content and impedance of the line.

A continuous control of power-factor, as used in the Thycon Active Power Factor Regulator (APR) is a preferred approach as the power-factor is seamlessly held at unity as the train loading varies. The APR also allows filtering so that harmonic distortion, notching, flicker and short term sagging are all minimised as illustrated in Figs 4a and b.

The APR can correct lagging power factor and leading power factor, where required. The APR can easily be fitted to existing installations or integrated into a TSTR at the design stage.

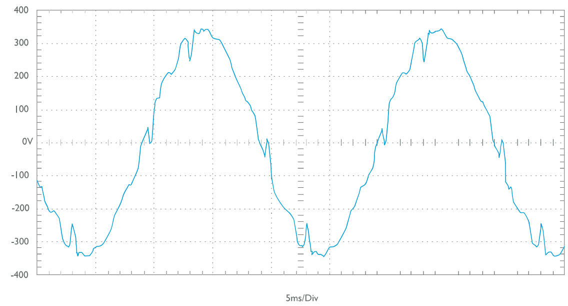


Fig 4a : Supply voltage without APR-THVD : 8%

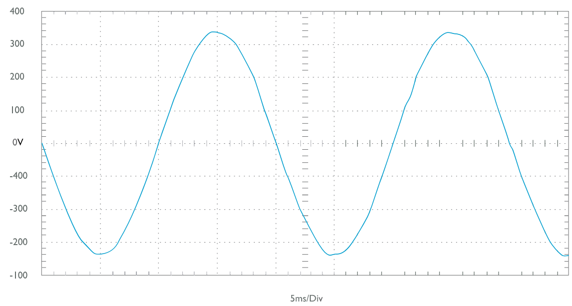
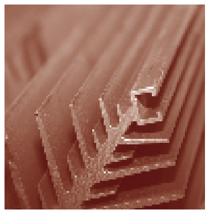


Fig 4b : Supply voltage with APR-THVD : 1%

Features
- continuous, accurate power factor regulation
- minimised distortion, notching, flicker and short term sagging
- energy saving
- robust thyristor technology
- seamless PF control; no contactor switching (all solid-state)
- low-loss



Train station

Solid State Breakers

All Trackside power supplies are protected by mechanical circuit breakers. A traction supply network (be it via third rail or catenary) is subject to frequent faults by the nature of its exposure and distribution. Mechanical breakers are slower than fuses but in view of the frequent faults, fuse-protection is not a popular solution as recurring replacement in remote locations is impractical. It is therefore common practice to make the transformer impedances high (up to 12%) in order to limit the fault amplitude during the long response time of the mechanical breaker.

This approach, though simple, has three significant short-comings:

- the power supply is subject to voltage sag which limits the traffic density
- the power-factor is lowered which requires greater compensation
- the fault currents remain nevertheless high and of long duration

Thycon SSB can be realised as AC or DC versions...

For instance, a 3MW/1500V substation with 10% reactance has a 20kARMS (57kAPK asymmetric) fault current of 200ms duration; these faults stress the cable connections and cause erosion of the breakers and consequently add to the infrastructure maintenance costs.

Simple but sophisticated solutions are available today for improving protection. Electronic circuit breakers are very much faster than mechanical breakers. Typically, a solid-state breaker (SSB) can :

- *detect* a fault within microseconds of its occurrence (di/dt detection)
- *limit* the fault within microseconds of detecting it
- *clear* the fault within 3ms of having limited it

Train lines

New environmental concerns... leading to higher efficiency demands despite greater traffic density...

Thus, a 2kA rectifier with a 5kA trip limit, would never experience a fault of more than 5200A, even with a 3% transformer reactance. With an SSB, there are no more asymmetric fault peaks and no long-duration faults of high RMS value; peak amplitudes are reduced 10-fold, RMS over-currents are reduced 20-fold and fault-duration, 70-fold.

Thycon SBB can be realised as DC or AC versions (i.e. for bi-directional rectiformers) and can easily be retrofitted to existing supplies.

Conclusion

Power management or “conditioning” is now ubiquitous in all electric power installations from transmission and distribution through (renewable) power generation and power security to transportation rolling stock. Trackside power management has been slow in relinquishing classical techniques as the focus in the Traction industry has long been on rolling stock performance and infrastructure reliability. New environmental concerns are, however, leading to higher efficiency demands despite greater traffic density which will require new technology also in the power supply infrastructure.

As illustrated above, Thycon offers a host of power management solutions for new designs as well as for upgrading existing installations. Thycon’s 40 year experience in power conversion allows optimal active and reactive power support in combination with advanced electronic fault-protection and harmonic filtering, all microprocessor-based diagnostics and controls.