Thought leadership
White Paper

The science of fuse selection in the rail industry

EATON
Powering Business Worldwide

Gabor Takacs

Senior Field Applications Engineer, Eaton

The rail industry has always operated in a harsh environment, placing high demands for mechanical and electrical equipment. It has a wide range of operating temperatures, severe shock and vibration requirements and an uncompromising high-voltage electrical supply system. Recently higher demands have been placed on manufacturers and owners for lower operating costs, and yet provide more functionality, improved reliability and higher expectations for passenger comfort and safety.

In addition, rail is a conservative industry, often driven by differing local regulations and operating requirements. Train designers are also under pressure to meet the challenge of reduced downtime to drive operator profitability. Suppliers to the rail industry are more frequently being asked, and must have the ability, to customise their products for optimum performance for multiple individual rail projects. It is here that those suppliers have to provide greater support and technical knowledge.

This paper is written specifically for decision makers charged with providing protection to the electrical feeds in the rail traction market. This includes both light rail and heavy rail rolling stock, fed from a third rail system or via pantographs. Eaton, with in excess of 50 years' experience in the rail sector, is able to offer a high level of expertise in electrical, hydraulic and filtration products, including standard and custom high speed fuse solutions.

Eaton's focus on reliability and safety enables its customers to be confident that they will be able to provide both guidance in circuit protection selection and deliver the most suitable fuse solution.

Overview

There is a great deal of distinction and understandable confusion between the fuse requirements for an industrial application and those of today's modern electric rail systems. A fuse used in a standard industrial installation will have predictable input voltages and protection characteristics, and the choice will usually be a standard off-the-shelf product item.

With rail, it is not as straight forward, as the supply voltage used by rail operators varies quite considerably. In the UK for example, the electrified portion of the network uses a mixture of very high voltage AC and lower voltage DC. Overhead 25kV 50Hz is used predominantly for the main lines and 750V DC for the Southeast and Merseyrail.

For rolling stock, there are two groups to be considered, light and heavy rail. Light rail is used for mainly commuter traffic and primarily the power is supplied through a third rail. Heavy rail is the term reserved for higher-capacity, higher-speed systems or for moving freight. Connection is made using a pantograph and in Europe the supply voltage is traditionally 15kVac and 25kVac. The global definition of light and heavy rail becomes blurred, but in Europe light rail is increasingly defined as a mass transit system with low frequency or short trains.

Unlike an industrial application which gets power from a fixed source, rolling stock receives its power from long supply lines. The current profile drawn by the train varies quite dramatically, based on the distance between stations, the rise and fall of the track and train speeds.

This all complicates the choice of fuse protection for a traction project, which can sometimes require a completely new design of fuse to fully meet all the requirements of the manufacturer of the rolling stock. It is vitally important that the fuse provider can provide the support and knowledge to develop a reliable solution.

Applications

A fuse has only one purpose – over current protection. Overcurrents can take the form of two types; an overload or a short circuit. An overload is defined as a slow and low rise in the conducted current. If unprotected, eventually parts or cables in the load will heat up and even melt, potentially causing a fire. A short circuit on the other hand is defined as a rapid rise in current. In the case, without a fuse there would be no “gradual” heating of the cables, with the load being severely damaged or even causing an explosion. The fuse’s function in both cases should be to interrupt the current before damage occurs.

If the application is for a heavy rail system, then usually the main electrical feed will be supplied via an overhead catenary or pantograph high wire system. Fusing will also be required for auxiliary power and distribution, the AC/DC or DC/AC converters, instrumentation and control, plus electrical breakers. As previously mentioned, in pantograph systems a wide variety of voltages are used around the globe, complicating the choice of fuses. Even in Europe if a standard off-the-shelf fuse is selected for a project in Italy, it cannot be used on a network in France because the supply voltage is different.

For light rail, urban, metro and subway systems throughout the world, the main electrical feeds are usually supplied by a live third (or fourth) rail. They are characterised by the power being supplied by a live (outside) third rail and being returned through the rolling stock wheels to the grounded rails. In some installation, a center fourth rail, which is isolated from the running rails, may be used for the return path.

As high voltages require significantly more insulation, third rail systems are normally supplied by DC voltages under 1000V. In general, rail networks in Europe use a nominal 750Vdc, but according to the EN 50163 standard, that voltage can be between 500V and 1000Vdc.

The supply rail is mounted to the same sleepers as the running rails, and is raised above the sleepers by insulators. The train receives power via a sliding connection, referred to as a “skate” or “shoe”. The shoe design must allow easy replacement as they wear during use or may become damaged. Third rail systems, due to the mechanical nature of the connection, are usually limited to a maximum speed of 160 km/h (100mph). As the supply voltage is lower, the current drawn is significantly higher.

Availability of information for best fuse selection

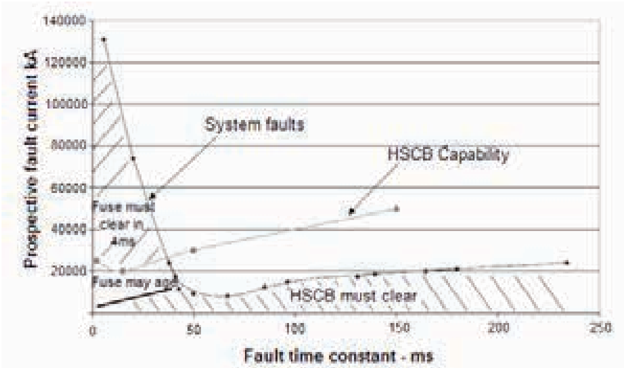
The train designer has to provide a wide range of information to ensure that the fuse will provide protection and be reliable over the lifetime of the train. The value of the supply voltage is usually readily available, but the train start, run and stop nature is very cyclical and complicates the selection of the fuse. Large currents are drawn as the train accelerates, particularly when traversing an incline, shortly followed by lower currents during a coasting period or when stopping. This cycle can sometimes be extremely short and can put stress on the fuse.

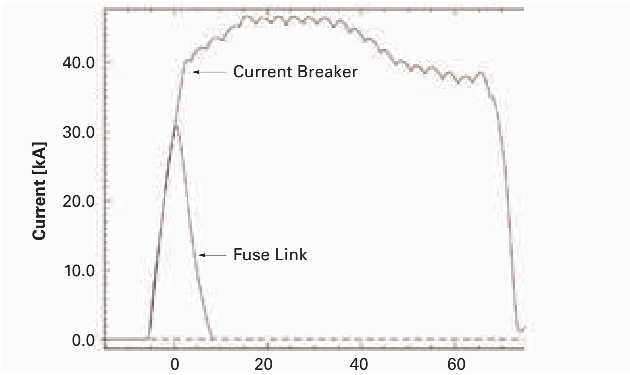
For existing installations, the current cycles can be easily measured and may already be available from prior testing. For rolling stock being designed for new installations, this is not known and the operator may have to provide an estimate from simulation and computer modelling of the anticipated loading. Information on the distances between substations where the power is being supplied to the rails is also important. The available supply current on third rail systems will be significantly higher closer to the substation than when the train is at a mid-point of the track. The high inductance of steel rails affects the current profile and at a long distance can cause the available current to be relatively low. Fuse links must be selected to cope with a range of fault conditions, like a lost shoe on a third rail system, and often special fuses are used to ensure reliability under these conditions. The complexity increases when fuses are used in conjunction with circuit breakers, making the selection even more difficult.

Using fuses with circuit breakers

In some rail projects only a fuse is used, in others the operators prefer just a circuit breaker. When the power circuit has a low inductance, it is capable of supplying large amounts of current during a fault condition and a combination of fuses and high speed circuit breakers (HSCB) is implemented. The fuse link is used to protect the HSCB when the fault current is faster or greater in value than the HSCB can operate. Relying just on a HSCB to operate can damage the breaker as it starts to open. Adding a fast operating fuse can interrupt the current before the breaker begins to trip and avoid damage.

All possible overload and fault conditions must be analysed when deploying a fuse link - HSCB combination and the performance of both forms of protection compared. The further the distance a train is from a station, the greater the inductance of the rail. This increases the time constant* making it harder for the fuse to interrupt. A breaker’s function is to protect against low over-currents with a high time constant. A fuse link protects the circuit breaker from high fault currents with a low time constant. This can be seen from the charts below showing fault current against fault time constant.





Record of proving tests, showing HSCB and fuse link on same graph.

*As the inductance in a DC circuit limits the rate of rise of the current, the time taken for the current to rise to 63% of its final value is called the time constant.

Fuses that are used with HSCBs should have fast-acting (high speed) characteristics – IEC utilisation Class aR. For power systems without a circuit breaker, a slower acting fuse can be considered – IEC utilisation Class gR or gG.

Selection of the fuse for normal (non-fault) conditions

A fuse link should be capable to interrupt all the possible combinations of fault current, time constant and voltage rating. It should not however, interrupt during normal continuous operation.

The starting point for the fuse selection is the maximum possible voltage of the supply voltage. It must be noted that there is a difference in labelling requirements between the IEC standards.

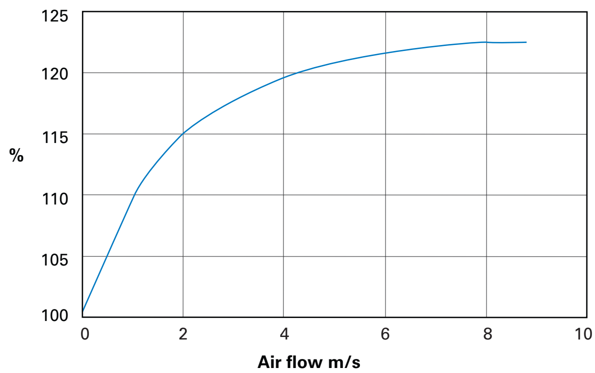
IEC 60269 covers the requirements for low-voltage fuses, whereas IEC 60077 specifies the requirements for electrical equipment on rolling stock. This can cause confusion, but testing can be carried out to obtain compliance if required.

There are a number of important performance considerations that affect the long term reliability of the fuse link. These include ambient air temperature, any available air cooling, the thermal connection factor, the RMS current, the amplitude and duration of peak currents and lost shoe situations. Available space for the fuse should not be key driver, as a modified standard or custom fuse can accommodate restrictions on size.

For safety reasons, the fuse will normally be housed within an enclosure. Temperatures above 25oC within the enclosure will typically require derating of the fuse current carrying capability by 0.5% for every oC. Excessively high ambient temperatures, above 60oC, should be discussed with the manufacturer to ensure capability in the application.

The ambient temperature of the enclosure will be increased by heat generated by the fuse itself, due to power loss. This will be made worse by a current increase due to a lost shoe condition as the train will operate for a period of time before be serviced. Remember that the power dissipated with be the square of the current: P = I2R where I is the current and R the resistance of the fuse link and connection. For a fast acting fuse (IEC utilisation classes aR and gR), the power loss will be 50% higher than that of a slow acting fuse (IEC utilisation classes gS and gG).

If the enclosure has ventilation slots or holes, air movement across the fuse from when the train is travelling will positively impact the fuse continuous current rating as shown by the chart below.



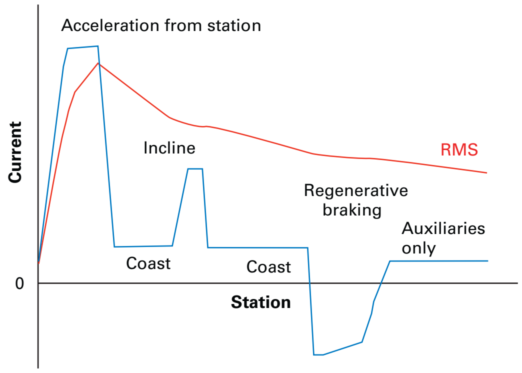
Improvement of current carrying capability with airflow.

Just 2m/s airflow can allow the fuse to be rated at 115%. It is recommended that if the airflow factor is unknown, then any rating multiplier should be ignored, and will provide an increased safety margin improving the fuse life over its operating time. Generally speaking, most traction applications do not have a reliable source of forced air cooling for the fuse.

Long term fuse reliability is heavily dependent on the amount of RMS current the fuse is subjected to over its operating life. The current carrying capacity will include temperature derating, and rerating due to cooling airflow. It must also account for the number of shoes and any lost shoe(s) scenarios.

Access to real-life data from an existing rail installation will be important in calculating the RMS current. For new installations, it is very helpful if the operator or rolling stock designer can provide any form of data profile from simulation or modelling. Ideally if the data is tabulated on a spreadsheet, it is a relatively easy task to calculate the RMS current level. This RMS current will be key basis for selecting the appropriate fuse.

It must be noted that the time scale of the RMS current profile should be similar to that of the thermal time constant of the fuse that is being considered for the application. For most third rail systems, this will be approximately two hours for the temperature of the fuse link to stabilise.

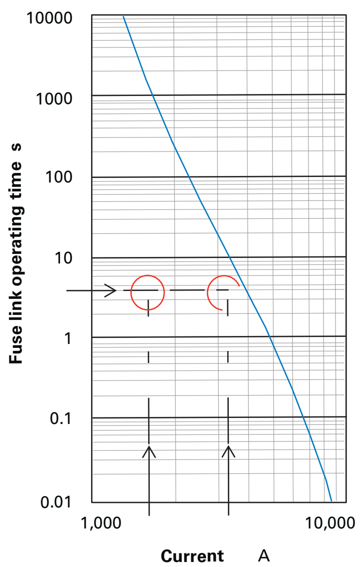


Typical train current profile between stops.

Fuse links are designed to quickly react to an over current condition; however fuses that handle wide variations in current can suffer fatigue, which can reduce fuse life due to heavy thermal cycling leading to mechanical stress. Fuse fatigue is exasperated if the peak currents are often close to the nominal fuse rating. A safety factor multiplier should be used, referred to as the G factor.

Using the customer supplied train operating current, either measured or simulated, the amplitude and duration of the peak current can derived. In addition to the RMS value, the peak operating condition is an important factor in determining the choice of fuse link. For reliable operation over the lifetime of the rolling stock, a suitable margin must be employed between the operating peak currents to the normal fuse characteristics. An industry guideline, rather than performing complex calculations, is to refer to the melting time-current curve found in the manufacturer's fuse datasheet and use a safety factor of 2.

The information supplied for the train operating current, must provide data for all the current pulses for the entire journey. Overcurrents occur during train acceleration and regenerative braking, and the magnitude will vary during the journey due to track inclines and the distance between the stations (the inductive effect of the rails). Each peak current value and duration time must be compared to the melting time-current curves.



Typical train current profile between stops

Using the above curve, we can now walk through an example. Assume that the pulse has peak current of 1600A current and is 4 seconds in duration. This indicated by the solid red circle. A G factor (or Duty Class) safety margin of 2 (3200A) is then applied and is shown by the dashed red circle. This point must lie to the left of the fuse link melting curve, to provide reliable operation for many years.

The rolling stock manufacturer will also advise how many shoes will be deployed, and care must be taken to ensure the shoe/fuse combinations and appropriate currents are considered. During normal operation, a lost shoe condition can occur due to damage from foreign objects on the rails. Most systems are able to detect that situation and remedy it quickly, relieving the fuse link from carrying excessive currents.

If a lost shoe is not detected, and it is possible that the train continues to operate for an extended period, then the worst case scenario should be applied and the fuse sized accordingly. This can result in much larger fuses being deployed and co-ordination with other protection devices. In the event that a fuse link ruptures due to an overload, the train's effectiveness will decrease and will probably have to be removed from service.

From the above we can now calculate the minimum current rating of the fuse using the formula below. The G-factor is the safety margin multiplier. The K-factors are multipliers for ambient temperature, air cooling and thermal connector factors.

Many physical styles of fuse are available, and fuse designers will strongly advise that fuses should not be chosen because of their dimensions! The mounting configurations for fuse links vary between applications, and are dependent on how the cables interface with the shoes and the load.

Sufficient space in the enclosure around the fuse has to be provided. Normal operation will see fuse temperatures of around 50oC, but during a fault or lost shoe condition, it is possible that the fuse will reach temperatures of 150oC or higher. Care must be taken to ensure that the enclosure will not be damaged. Space must also be provided for electrical isolation to allow adequate creepage and clearance.

Vibration is a common environment in the rail industry. Experience suggests that fuse problems that arise with vibration are more likely to be caused by the mounting arrangements. Large fuses have more mass and the enclosure should be rated and tested accordingly.

Conclusions

In this paper we have provided an overview explaining the differences between industrial and rail traction fuse requirements, and how the selection of a rail fuse is more complex.

The purpose and application of fuses was discussed for both light and heavy rail.

The fuse selection process for normal operating conditions was reviewed in detail, to give an idea to the electrical protection decision makers of the information they will be asked to provide. This includes a projection of the current profile of all aspects of the system, including pulse current throughout the train's journey, and any lost shoe events.

Long term fuse reliability is essential to operator profitability, customer satisfaction and safety. A small investment of time in choosing a provider of electrical protection, who can provide a high level of support and knowledge, will quickly be repaid. Eaton Cooper Bussman has experienced Field Application Engineers who work with rolling stock designers on rail projects, from the initial concept stage to final installation.

About Eaton

Eaton has over 100 years of experience in the design and manufacture of fuse links. Using a global network of engineering, manufacture and distribution Eaton is able to draw upon a wealth of knowledge. As railway systems and standards have changed, so have the protection needs. Eaton is continually developing new, and improving existing, designs to meet these ever changing requirements. The experience of Eaton in protecting semiconductor devices has proved invaluable as train systems have moved to power based converters for the variable speed motor drives and also for auxiliary power conversion.

Throughout its history, Eaton has been continually chosen to supply the industry's key train manufacturers and Eaton Bussmann series products can be found all across the globe and are extensively used across America, Europe and Asia and numerous other countries.

Powering Business Worldwide

Eaton Industries GmbH
Hein Moeller Str. 7-11
53115 Bonn
Eaton.eu

Publication No. WP132004EN / CSSC - 430