Author: **Holger Blaak**

Knick

White Paper

Improving the Safety and Availability of Traction Power Supply Systems

Special components for the DC feeding systems ensure faultless emergency shutdown to avoid severe damages to the system and possible injury of people. Preventing unnecessary disruptions to operation with accurate fault detection has a considerable impact on rail traffic and availability of the system.

Worldwide, there are more than 7 billion dollars a year invested in permanently installed electrical equipment of railway networks. A considerable investment of this money will be spent on public transportation systems, where above average growth is expected over the coming years[1]. One reason for this is the increasing traffic congestion in metropolitan areas.
Another reason is the wish to achieve political aims concerning climate protection and conservation of natural resources.
Both are good reasons to promote the investments in public transportation systems.
Railway lines are installed or extended and existing networks are re-equipped with state-of-the-art technology. Uninterrupted and safe operation is of high priority for the operator of a public transportation system.
Therefore, high demands are placed on the technical equipment.

Figure 1: Switchgear for traction power supply with current and voltage measurement

The power supply of a public transportation system must be protected by a monitoring system which activates an emergency shutdown in the event of fault. These safety systems play an important role in the operation of the networks. They ensure the safety of people and protect the systems against damage. An essential prerequisite for their reliable operation is the precise measurement of the electrical parameters because only their analysis makes fault detection possible. Here, the conditions in railway applications pose specific demands on measurement technology.

Products which are specially tailored to the application provide a high degree of safety without unnecessarily reducing the availability of the networks.

Safety and availability are important requirements, which are often difficult to reconcile. In the following, we want to take a closer look at the structure of these systems and the way they work. We will derive optimal solutions.

The P40000 series of Knick transformers has been specifically designed for monitoring traction power supply systems. The P40000 provides high isolation according to global railway standard EN 50124.

Accurate signal transmission with negligible delay combined with a particularly high common mode rejection makes the P40000 an excellent fit for traction applications.
Required in monitoring systems for traction power are three things: safety (high isolation), reliability (accurate signal transmission), and efficiency of the network (reducing common mode interferences). The flexibility of the P40000 series of products with broad range power supply and switchable calibrated inputs allows for one device to achieve all current and voltage measurement tasks for safe, reliable, and efficient operation of railway networks. We will discuss how this is achieved in the following pages.

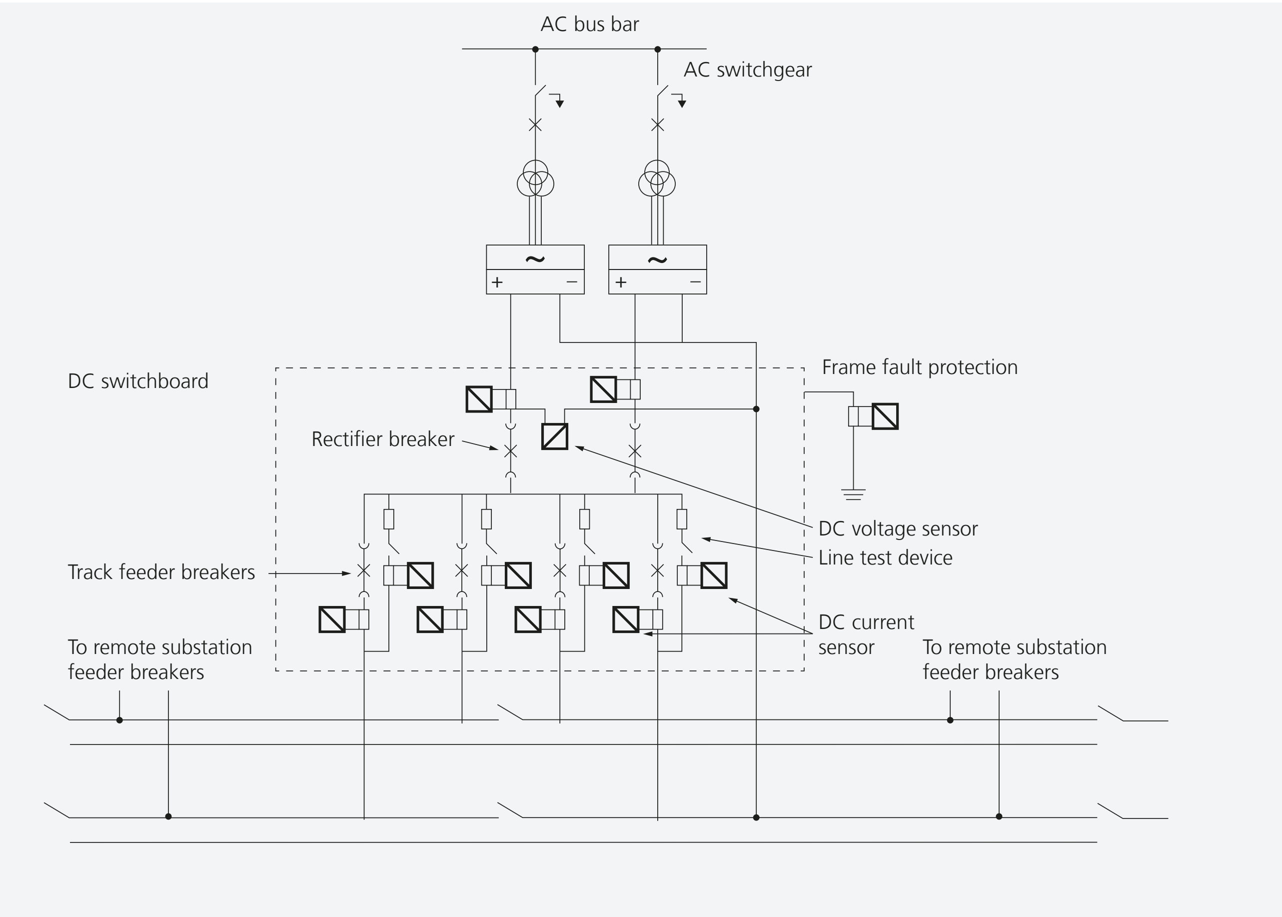


Figure 2: Typical DC trackside substation schematic diagram acc. to Newnes Electrical Power Engineer's Handbook, D. F. Warne

System structure and system design

Public transportation vehicles such as subways, suburban trains and trams/streetcars are usually powered by direct current. The supply voltages lie between 600 and 3000 V DC. The electric power provided per track section lies in the MW range. Monitoring systems which activate an emergency shutdown in the event of fault must be installed to protect persons and equipment. The demands placed on these monitoring systems for fault detection are very high: With such a high electric power, a false-negative assessment, i.e. an undetected short circuit, can pose a serious risk to persons and cause damage to system components. Therefore, the fault detection must be sensitive enough to ensure that no error goes undetected and to guarantee a safe shutdown at any time. Nevertheless, a high sensitivity may lead to an increased number of false-positive assessments. This means that the system would be shut down although no fault has occurred. Rail traffic would be unnecessarily disrupted. It is obvious that this scenario as well has a serious impact on railway operation and should be avoided. The specifity of fault detection is almost as important as the sensitivity, i.e. monitoring systems with high sensitivity and high specifity are required because they exclude risks while at the same time achieving a high availability of the railway system.

Different algorithms are used for fault and status recognition. They are mainly based on the analysis of the electrical parameters at the feeder points. In extensive networks, the electric power is supplied via substations located throughout the network.

These substations often operate several feeder points through which the power is supplied to the overhead line. At these feeder points the monitoring and protection equipment is installed. Depending on the monitoring task, the magnitude of the current as well as its rate of change is measured by a DC sensor (IEC 61992-1 /EN 50123-1). The voltage is also measured if required. This data is continuously analyzed in the safety relay. When a fault is detected, the safety relay activates the tripping mechanism of the corresponding circuit breaker under load. The current flow and therefore the power supply to this feeder point will be interrupted.

Depending on the type and location of the fault as well as the time elapsed since its occurrence, starting current and fault current are of comparable magnitude. Therefore, it is often not sufficient to monitor the magnitude of the current. According to IEC 61992-7-1 / EN 50123-7-1, the shape of the fault current is analyzed. The rate of rise dI/dt of the current is measured and evaluated to discriminate between starting currents and short-circuit currents.

This dI/dt analysis requires that the current is measured sufficiently fast and accurately to make it available for analysis because the rates of rise are different but not drastically so. To reproduce the current rise sufficiently well, the measuring device should have a cutoff frequency of > 5 kHz. The delay time (t90) should not significantly exceed 100µs. Faster detection speeds are not required.

For measuring the current, IEC 61992/EN 50123 specifies a widely used and established method. Here, the voltage drop across a shunt resistor placed in the current path is measured. This voltage – in practice approx. ±60 to ±150 mV – is proportional to the current flow.
The shunt voltages should preferably be low to reduce the power and therefore the generation of heat in the shunt. The lower power dissipation allows a shunt with smaller dimensions. To enable building compact installations, 60mV shunts are often used. Notably lower shunt voltages would impede the measurement.

Notably higher voltages would generate too much heat or the shunts would be too large. Shunt voltages of the magnitude mentioned above are a suitable compromise.

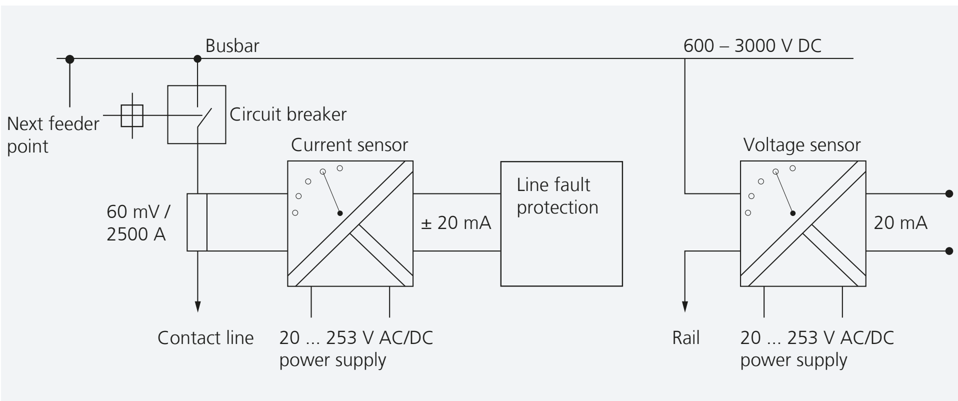


Figure 3: Substation feeder point

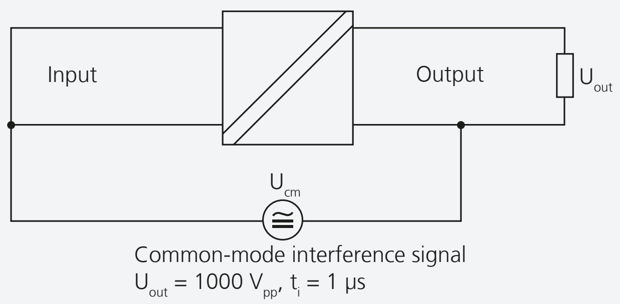
For practical reasons, simple Hall transducers are not viable alternatives when bad long-term behavior (inaccuracy / drift / temperature dependence) cannot be tolerated.

Usually, the voltage is directly measured by a measuring device with voltage divider. This method is mentioned in IEC 61992 / EN 50123.

The detected signals are galvanically isolated and transmitted as electrical standard signals (IEC 61992 / EN 50123) to the safety relay which processes the algorithms for signal evaluation and – in the event of fault – activates an emergency shutdown by tripping the circuit breaker. Occasionally, manufacturer-specific signals are transmitted (e.g. through a fiber-optic connection) possibly with subsequent conversion into standard signals.

Nominal voltage	**Maximum permanent voltage**	**Maximum non-permanent voltage (300 s)**
U_n	U_{max1}	U_{max2}
600 V	720 V	800 V
750 V	900 V	1000 V
1500 V	1800 V	1950 V
3000 V	3600 V	3900 V

Table 1: Nominal line voltages and maximum voltages in rail application (IEC 60850 / EN 50163)



$$\text{Common-Mode Rejection Ratio (CMRR)} = \frac{\text{Differential voltage gain}}{\text{Common-mode voltage gain}}$$

$$\text{Transient Common-Mode Rejection Ratio (T-CMRR)} = \frac{\text{Differential DC gain}}{\text{Common-mode transient peak value gain}}$$

Figure 4: Measuring the common-mode rejection

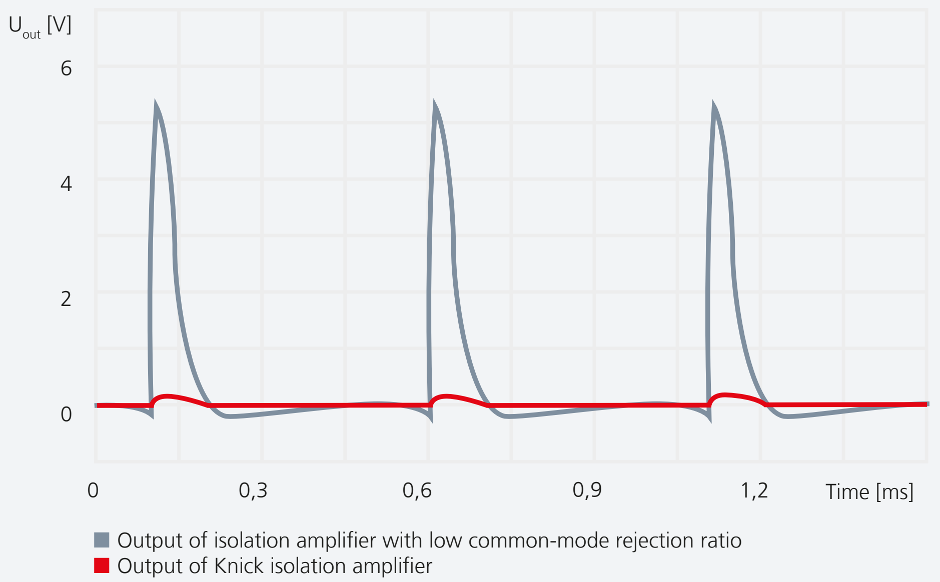


Figure 5: Steep slopes in the common-mode loads can cause accidental activation of the circuit breakers. High common-mode rejection is required.

Requirements for current and voltage measurement / selection criteria

Insulation and galvanic separation at high DC voltages

A basic requirement for current and voltage measurement is the sufficient insulation and galvanic separation (insulation coordination) to prevent possible destruction of the meter and downstream safety relay. The decisive parameter for railway applications is the rated insulation voltage U_{Nm} according to IEC 62497-1 / EN 50124-1, which stipulates minimum values for clearance and creepage distances. During the application, the rated insulation voltage of the meter must be higher than the maximum voltage occurring during operation. According to IEC 62497-1 / EN 50124-1, the rated insulation voltage U_{Nm} exceeds or equals the maximum permanent voltage U_{max1}. High non-permanent voltages (U_{max2}), however, must also be considered when they are likey to occur. When current is fed back as the train is braking, for example, the voltage may notably exceed the nominal voltage U_n. The measuring equipment must also withstand these increased voltages.
If persons are to be protected against electric shock, an additional or double insulation is required. Here, the safety margin is ≥100%.
DC sensors such as the P40000 from Knick are designed for application in railway systems according to IEC 61992 / EN 50163. They cover all voltages up to U_n = 3000 V DC and ensure continued isolation up to a maximum non-permanent voltage U_{max2} of 3900 V AC/DC.

Interference-free operation even with fast voltage fluctuations

According to IEC 60850 / EN 50163, fast voltage fluctuations are to be expected as an inherent part of railway systems. They act as a common-mode interference on the current measurement and have a notable effect on the safety relay. DC sensors with poor common-mode rejection may cause an increased number of accidental activations of the safety equipment with the corresponding disruption of the rail traffic (standstill).
In principal, undesired common-mode voltages influencing the signal output (common-mode interference) exist in every DC sensor. A suitable design, however, can reduce this effect so that proper functioning is not impeded.

The conditions of railway applications often account for high common-mode interferences, i.e. the required common-mode rejection ratio for the DC sensor must be correspondingly high. Common-mode interferences result from voltage fluctuations, which are caused by alternating loads and switching processes, among others, and can spread throughout the supply network via the busbar. The abrupt voltage change as a common-mode load generates a pulse artifact in the output signal of the current sensor which then may cause an erroneous activation of an emergency shutdown. For assessing the suitability of a transformer for a DC current sensor, special attention must be paid to the common-mode rejection ratio. The quantitative specification of the common-mode rejection ratio is not stipulated by the railway applications standards.

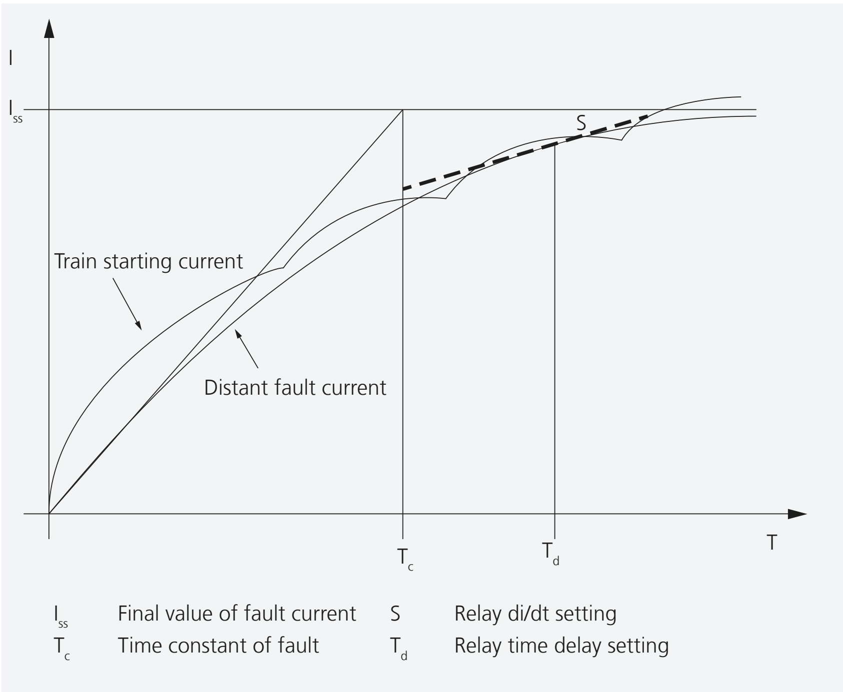


Figure 6: Example for determining the rate of current rise (IEC 61992-7-1 / EN 50123-7-1)

When these specifications are missing in the product documentation, it is difficult for the system designer to select the suitable product.

Knick transformers of the P40000 series have been optimized for these applications and their product specifications include the common-mode rejection ratios for slow and fast common-mode loads. DC or 50Hz common-mode interferences are suppressed with150 dB (CMRR), and still 115 dB are achieved for fast 1000V/1µs pulses (T-CMRR). These products have proven their suitability in thousands of applications in traction power supply systems. With their low common-mode interference, they ensure interference-free operation.

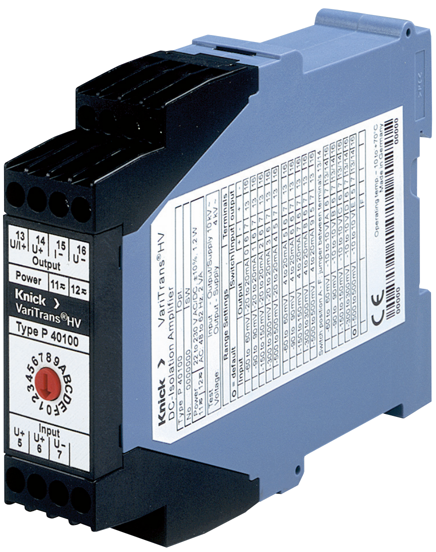


Figure 7:
DC sensor with calibrated switch selection of input and output ranges

Precise signal reproduction for error-free monitoring

To discriminate between fault conditions (short circuit) and normal railway operation (starting current), the monitoring system for the emergency shutdown evaluates the rate of current rise dI/dt to detect the different current shapes. As the differences are very small, an undistorted signal reproduction also during fast changes is essential. That means that the current shape from the input must be reproduced at the output without distortion. To achieve this, it is not sufficient to transmit a DC signal. The higher frequencies which represent a change must also be reproduced at the output. IEC 61992-7-1 / EN 50123-7-1 specifies this characteristic of the current sensor as upper cutoff frequency, which should be at least 1kHz according to the standard. In practice, slightly higher values are required to allow exact reproduction and unequivocal evaluation of typical current shapes.

The P40000 DC sensors have an upper cutoff frequency (-3 dB point) of 5 kHz, thus meeting the requirements for quality of reproduction of the current shapes occurring during railway operation. Short-circuit faults can be safely detected. Normal current changes, which occur when the train starts or the load changes, are recognized as such and do not cause an emergency shutoff. Regular rail traffic remains undisturbed.

High accuracy requirements for precise analysis

The critical parameters, current, rate of current rise and voltage, shall be evaluated with the smallest possible measurement error. Only this ensures that the evaluation algorithms of the monitoring system detect an error with high sensitivity and specifity.
When selecting a product, attention must be paid as to how measurement errors are specified. Maximum values and typical values of the error may differ significantly. In practice, the temperature coefficient may cause a notably larger error than the error specified for normal operating conditions. According to IEC 61992 / EN 50123 a possible offset occurring after measuring a (high) primary current must be specified. Here, remanences may lead to errors. As a basis for making appropriate decisions, manufacturer's specifications should be thoroughly examined. Partial errors in bold print should not distract from assessing the total error. The measuring features must prove their worth in practice.

With a gain error < 0.1% of the measured value and an offset < 0.1% full scale, the P41000 is very well suited for this application. With 0.005%/K, its TC is low compared to typical devices.

Simplified stock-keeping due to flexible multi-range sensors with universal power supply

Depending on the measuring task and on boundary conditions of the specific application, different demands are placed on input ranges, output signals and power supply for the DC sensors. Here, DC sensors which provide several switchable input/output signal combinations in one device are of special advantage for suppliers and operators of public transportation systems. That means the products do not have to be ordered when a specific need arises, but that a small number of models can be kept on stock with little effort. Depending on the application, the product is switched to the required range. This is only a real advantage if the switching is calibrated, i.e. no adjustment is required after range selection and accuracy is maintained. An integrated broad-range power supply, which allows operation with almost every supply voltage, provides even more flexibility and further reduces the number of models kept in stock.

The P40000 series provides such products for application in traction power supply systems. Up to 16 calibrated input and output ranges can be selected in one product. The ranges can be specified by the user. Every device accepts supply voltages between 20 and 253 V AC/DC so that the number of product variants is reduced. This makes stock-keeping very simple. Systems production is not delayed by delivery times.

Summary

An always safe railway operation with a minimum of disruptions also depends on perfectly working monitoring systems. Evaluations performed in the safety equipment are based on current and voltage measurements in the traction power supply system. Analyzing this information is a demanding task and its evaluation is critical. Errors or mistakes can endanger persons or equipment if a fault condition remains undetected. On the other hand, a mistakenly identified fault has considerable effects on the rail traffic. Therefore, high sensitivity and specifity are required for fault detection.

The special conditions of railway applications place high demands on the technology used. High-quality devices which are specially designed for the application meet the normative and functional requirements. Here, isolation properties, common-mode rejection, accuracy and cutoff frequency are of special importance. Each individual characteristic must be perfectly suited for the measurement application to ensure that the overall task is reliably performed. The series P40000 transformers from Knick meet the high technical demands in every aspect. They have been specially designed for railway applications and have proven their suitability in thousands of applications.

In addition, their high cost-effectiveness makes the products economically competitive. Their universal design with range selection and broad-range power supply drastically reduces the required product variety and simplifies stock-keeping. Thanks to the advantages concerning planning, scheduling and logistics, the devices can be integrated in the different projects with significantly reduced effort.

[1] Press release from SCI Verkehr, November 16, 2009

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Knick
Elektronische Messgeräte
GmbH & Co. KG
Beuckestraße 22, 14163 Berlin
Phone: +49 (0)30 - 801 91 - 0
Fax: +49 (0)30 - 801 91 - 200
knick@knick.de · www.knick.de