Digital Technologies for Railway Electrification

SIEMENS

"

The world is spinning faster and faster and the mobility of tomorrow must keep pace with it today."

Martin Bach
Head of System Engineering & Integration

Content

In commuter and long-distance traffic, more and more people are moving at an ever-increasing speed. Therefore, the requirements for railway network operators are also increasing. Existing infrastructures have reached their limit and need to be expanded.

At the same time, the operation of existing networks must be ensured during increased utilization and changing operational demands.

The digitalization of mobility opens new possibilities to meet this change.
As a team of the System Engineering of Rail Electrification, we have been dealing with the mobility of the future for decades and specifically with the design and planning of railway power supply systems. Thanks to our expertise in the field of railway electrification, we are able to develop holistic solutions for railway-specific issues.

Equipped with this system approach, we accompany our customers worldwide throughout the entire lifecycle of your equipment. We have identified various critical topics that behave similarly in a large number of facilities. To address these challenges, we have developed innovative solutions and incorporated them into a product family of digital solutions.

In this white paper, you have the opportunity to get to know a broad spectrum of our digital solutions. You will also learn more about our novel solutions, tailored to your very specific operating challenges. Start a dialog with us about known use cases and discover the flexibility of our solutions and products that can be easily adapted to your requirements.

Martin Bach
Head of System Engineering & Integration

CHAPTER 1

Modernization **of railway energy supply systems**

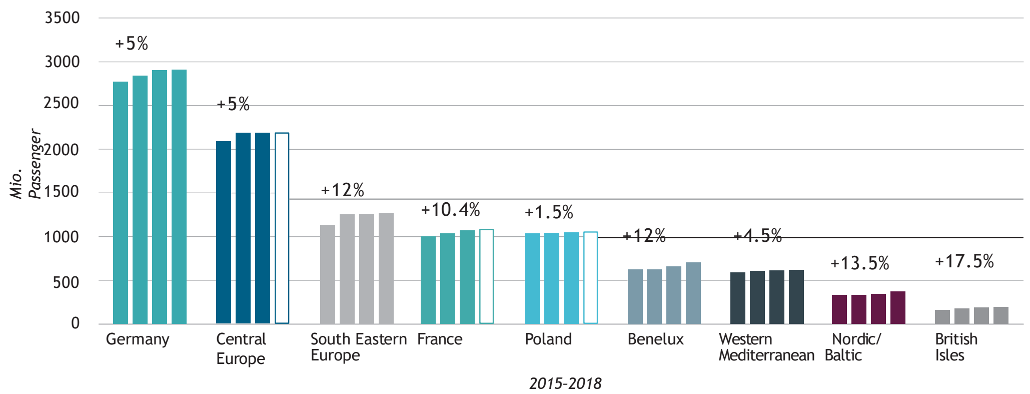
Martin Altmann, Junneng Huang, Tomas Greif

Mobility requirements are strongly driven by the megatrend of urbanization and amplified by the e-mobility revolution in the local electric transport sector. As a result, requirements have grown steadily.

Recent UITP figures on the development of light rail and trams show this growing trend over the past few years through the increasing number of passengers in Europe, see figure 1.

According to the report, more than 10 billion passengers were transported in Europe in 2018 by light rail and tram alone. The addition of new kilometers each year shows regional differences in growth, but also confirms the general growth trend in this sector. However, for Europe and Eurasia, where there is a high number of existing systems, the focus is on modernizing and replacing equipment to keep aging systems operational.

The Covid-19 pandemic has slowed this growth globally, but in the medium and long term, the need to develop efficient urban transport in conurbations remains. The electrical expansion of rail-bound transport and public transport is the backbone of all mobility concepts if environmental objectives are to be achieved and the improvement of the quality of life in urban areas is prioritized.



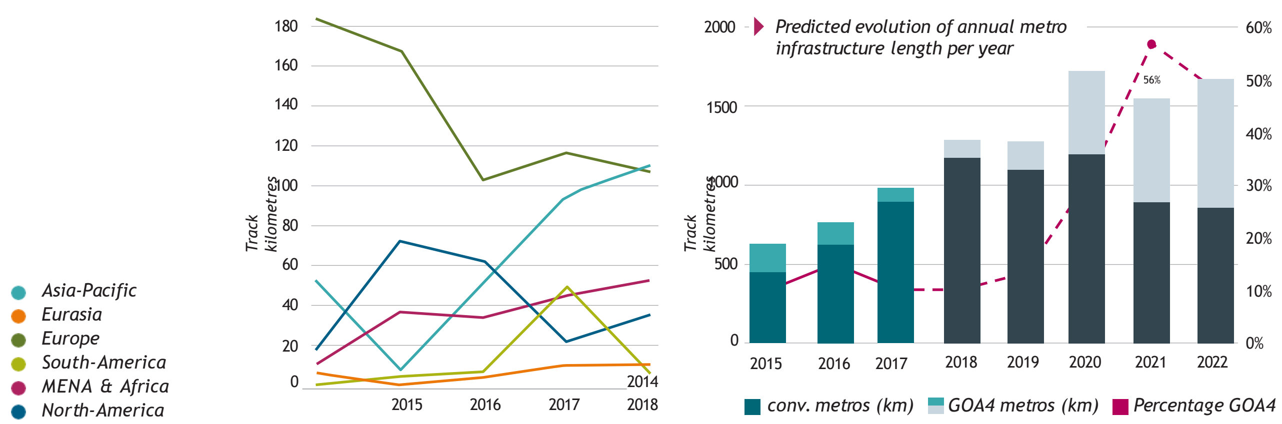


Figure 1: Regional development of passengers in Europe (in million passengers from 2015 to 2018) and of additional track kilometers for light rail and tram systems [2]

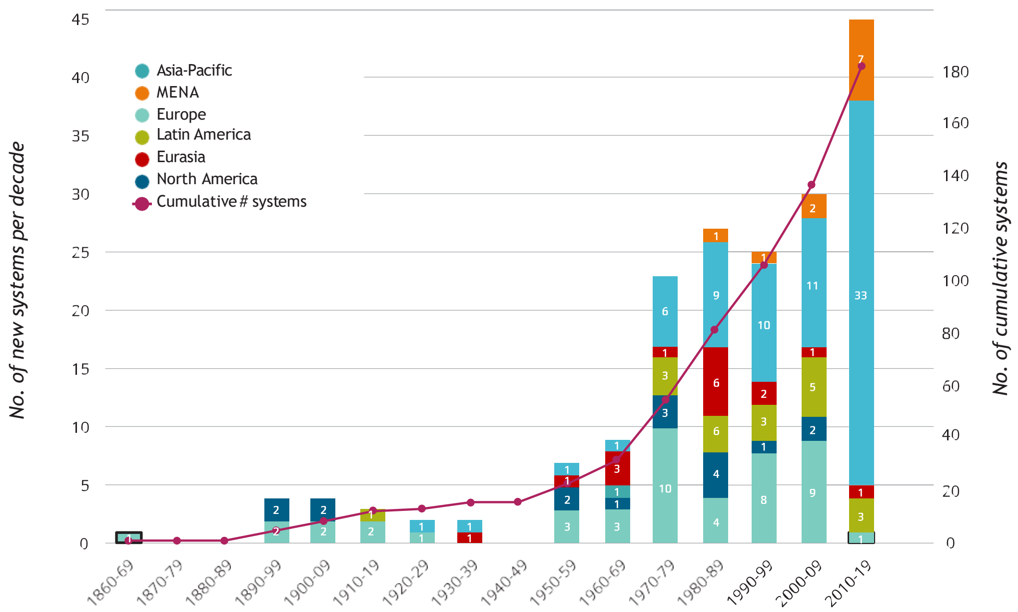
Challenges for rail electrification

The current slump in commuter and long-distance traffic caused by the Covid-19 pandemic gives operators space for the holistic planning of investments and expansion. With the introduction of many economic recovery programs around the world, more plentiful resources are often available for the mobility sector.

Since the power supply infrastructure is typically designed for long operating periods, many systems have been able to manage the growing capacity over many years with selective modernization of equipment or reinforcement of sections. On the one hand, the robustness and longevity of railway energy supply is a major advantage. On the other hand, it also means that the focus on investment has often been shifted to other areas and that the reserve capacities have gradually been depleted. This investment backlog poses increasing challenges for operations and maintenance.

Figure 2: Construction of underground railways per decade from 1860-2017 [3]

Metro system opening (per decade)1860-2017



Total number of metro systems and the location of systems inaugurated each decade

Simulations help with demand analysis

When analyzing demands and designing the necessary modernization measures, it makes sense to carry out a system analysis as a starting point. In doing so, the actual load capacity and the future load requirements for higher transport performance can be assessed.

The analysis leads to milestones for the prioritization of the infrastructure parts which need to be modernized in terms of their performance. This can be done as part of a classic system study. Using multi-train simulation and network planning software, such as Sitras® Sidytrac Designer from Siemens Mobility, the electrical grid can be modeled, and the actual and expected future operation can be simulated while also checking the short-circuit currents and protection concept. At the beginning of such a study, the actual stress situation should always be compared to the simulation.

When facilities are operated close to the load limit, it is important to know these load limits and continuously monitor them during operation – ideally, this happens in a continuous process.

However, the capacity reserve of proven systems operated for decades could be of unknown size. The overload capacity of transformers, rectifiers and other power electronics is highly dependent on former load scenarios. Consistently expand system monitoring

Parts of the overhead contact line system and the return line and its insulation can be overloaded on a point-by-point basis, depending on the operation, without being immediately recognizable.
In older DC systems, in some areas of the world, the return line was not completely isolated, but partly grounded via diodes for stray current measurement.

Modernization measures are an effective way to bring this concept up to date and to support maintenance with appropriate stray current monitoring. Siemens Mobility offers the proven, easy-to-integrate stray current monitoring system Sitras® SMS.

In addition, older systems have hardly any sensors or measurement data acquisition, a prerequisite to allow monitoring of meaningful parameters.
In general, the monitoring of the systems is not consistent and only available for individual components.

For substations, warning messages and live signals of individual equipment such as transformers, rectifiers or switchgear are detected via local protection and control units, and individual sensors are evaluated, such as for the temperature measurement of transformers.

Digital twin increases forecast quality

In some systems, actual values of individual components are measured to be displayed either locally and/or in the higher-level SCADA system. Often, further evaluations cannot be carried out since thresholds or trend analyses are not stored. A valid forecast is therefore rarely possible.

The implementation of a digital twin for power supply could maximize the network utilization for the various operational load requirements. Such a digital twin can use digitized network data for monitoring, data analysis and additional simulation-based load predictions through solutions such as Sitras® Sidytrac Live, and could also maximize plant utilization for the various operational load requirements.

If these options are implemented at an early stage, they will help to optimize the modernization schedule and enable longer operation of the infrastructure.

Focus on system reliability

The reliability of systems typically follows a u-shaped curve which is typical for such technical systems. Whereas sophisticated systems have shown stable behavior for a long time, the risk of failure also increases enormously with age and increased stress. Even if the primary technology is still working reliably, problems caused by failures of the control electronics can increase and lead to an increased maintenance requirement. Therefore, it is important to maintain a high level of availability even with decreasing reliability.

Furthermore, the complexity increases in growing and piecewise extended systems, since different parts of the network or sections of the line can have different operating ages. The topic of maintenance plays an important role in the assessment of needs and the planning of modernization. These measures can significantly reduce maintenance costs.

The maintenance strategy of planned and timed maintenance requires a high personnel effort due to the regular intervals, which must also take into account the age-based reliability of the different equipment. With the digital transformation, the consistent use of all available data and further developments in the field of sensor technology, new possibilities for data-based, predictive maintenance arise.

Maintenance can be tailored to the requirements and lifecycle costs can be optimized. In a first step, data that is already available at the field level should be made accessible for further evaluation. This applies in particular to those parts of the network that remain in operation for even longer and are to be modernized at a later stage.

Modernization effectively planned

All these technical aspects of modernization need to be considered as part of cost-benefit analysis. A significant part of this planning should take into account how the various aspects and benefits of digital transformation can be used in a beneficial way. For this process the connectivity and monitoring of systems, data analysis and load predictions are of essential importance.

If systems and applications of this type are already in place at an early stage, they can bring many benefits and accelerate the entire process of modernization. In order to convert an existing network as smoothly as possible, well-thought-out planning of the processes is the top priority.

Maintaining availability

During the conversion, operation should be maintained with high availability. Therefore, all essential work is carried out during the breaks, at night or on weekends. However, breaks are short, and night work and the many small intervals can cause difficult logistics, additional set-up times, increased set-up costs, longer construction times and high personnel costs, which conflict with the requirements of cost-optimized conversion.

Typically, free space in railway substations is limited and it is very hard to add larger new system parts to the existing ones. In the case of DC systems, these are mainly transformers, DC switching systems and medium-voltage switchgear. The DC as well as 3AC medium-voltage switchgear needs to be taken out of service and dismantled prior to replacement. Subsequently, the new equipment can be installed.

In order to be able to not only use the night breaks, but also to conduct maintenance during the day, an entire substation or a large part of it would need to be taken out of operation. It is helpful to know which train operation is still possible for this network configuration.

Grasp network design and reserves

Traction power supply systems are designed with worst-case scenarios in mind and with reserves always being available. In the case of grown networks, it can be difficult to determine the actual reserves of the network and use the possibilities for the extension of the conversion phases. For example, the train sequence and the average passenger load are lower outside peak hours. In general, the capacity utilization and the auxiliary operations change in daily, weekly and annual cycles and thus the load on all components also changes.

Network simulation software such as Sitras® Sidytrac Designer from Siemens Mobility can take these diverse scenarios into account to support and guide the operator in investigations.

Important criteria to be observed are voltage quality, limits of load capacity, and the guarantee of protection. In the event of a substation failure, appropriate measures to maintain the operation should be defined. Possible operating measures can include speed limits, current limits, or lower accelerations. They should be defined in the planning phase and only be activated in the event of an outage.

Optimize planning and gain flexibility

With complex networks and supply scenarios, it is often difficult to predict whether protection is capable of detecting all failures. Sitras® Sidytrac Designer allows to calculate fault situations for all scenarios and assess protection stability before deciding on the configuration of alternative switching scenarios.

This allows to check the effect on the protection setting for the various planned network configurations during remodeling. If necessary, temporary protection parameter settings should be defined for specific supply configurations during the conversion phase. This can be solved flexibly by modern protection technology.

By analyzing the above aspects, the operator has access to extensive information. This helps to maximize the time windows of the conversion during operation for efficient and cost-optimized performance of the expansion.

Sitras® Sidytrac Designer helps with long-term planning, while Sitras® Sidytrac Live supports short-term operation, spontaneous rescheduling, and operational implementation. Both solutions work with the same data, but Sitras® Sidytrac Live creates additional flexibility, as the operator has the possibility to analyze the short-term desired/ occurring switching states and the planned driving operations for the subsequent days.

Martin Altmann
Senior Key Expert for System Engineering of Traction Power Supply – System Engineering & Integration

Junneng Huang
System Engineer for Traction Power Supply – System Engineering & Integration

Tomas Greif
Principal Key Expert for Traction Power Supply – Lead Engineering

CHAPTER 2

Increasing **the performance of train operation**

**Klaus Müller,
Alexej Halank,
Carolin Seidenberg**

For many years, network expansion was neglected or networks have been completely abandoned, with priority given to motorized private transport. In addition, the last modernization of the infrastructure (routes and electricity) often took place in the 1980s or 1990s or was carried out only in some areas due to scarce financial resources.

Nowadays, the problems of excessive private transport are difficult to solve and the demand for environmentally friendly and energy-efficient transport is increasingly coming to the fore. Therefore, there is clearly an urgent need to modernize and expand public transport networks.

On the one hand, new lines are being built or existing lines are extended, but on the other hand, larger and more powerful trains are also being procured and/or the traffic cycles are compressed.

Growing demands on networks

Today, modern trains can recuperate, which means they largely use electric braking and provides the braking energy in the overhead contact line network.

These measures lead to an increase of the electrical load and consequently to increased thermal loads on the overhead contact line and substations, as the load peaks increase and the “recovery phases” in between become shorter or even disappear.

Railway systems are becoming more complex, assets are getting older and more diverse, and therefore systems are becoming less predictable. Hence, more transparency and connectivity are needed. This can be achieved by digitalization and innovative technology. The new technology should also lead to cost optimization and improved system quality and availability in operation and service.

Improve traffic capacity with reliable operation

Siemens Mobility's digital solutions offer the opportunity to improve the utilization of existing infrastructure while working toward reliable operations. Sitras® Sidytrac Live forecasts the network operation based on train operating data and the switching state of the network. This allows for analysis of the electrical load of the network and its retroactive effect on driving operation as well as on connected systems. Sitras® Sidytrac Live is a simulation program that combines multi-train operation and network calculation algorithms. This means that the highly volatile performance requirements of local and time-changing consumers can be accurately determined in a defined time period by means of forecast simulation in real time.

With Sitras® Sidytrac Live, the operator can get an overview of the impact on the schedule, voltage quality, component load, protection stability and other important system aspects before a switching operation is to be carried out. A dashboard immediately provides all relevant KPIs from the simulation.

If switching operations are necessary due to a substation failure, the effects of the load on the components and the function of the electrical protection can be analyzed quickly before they are carried out. Necessary countermeasures can thus be taken immediately before an overload situation leads to comprehensive operational restrictions. Figure 3 summarizes the broad applications of Sitras® Sidytrac Live.

Even in minimal design, Sitras® Sidytrac Live is an ideal training system to give an operator time to evaluate and show the impact of actions taken. In operational emergencies, Sitras® Sidytrac Live can help the operator to quickly make a meaningful decision by means of What-If simulations.

Archived traffic management system and SCADA data also enable analysis of real scenarios that have occurred in the past. For example, an assessment of measures taken, and of their impact, is possible. This helps to avoid unfavorable operating scenarios in the future.

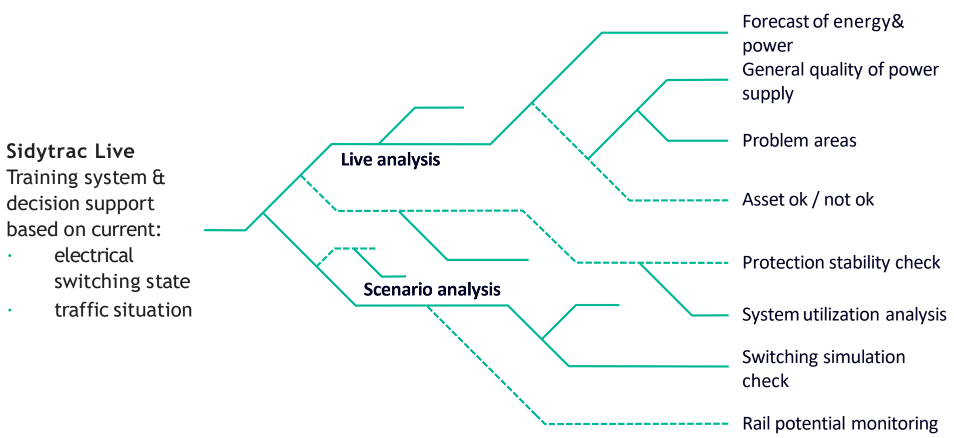


Figure 3:
Applications of Sidytrac Live

A shift of load peaks into more energetically advantageous phases is also feasible (Figure 4). In addition to reducing the maximum required power, the acceleration phase of starting trains can be adapted for the braking phase of arriving trains. This allows the best use of recuperation energy. It is also feasible to improve the predictability of energy demand from the public energy supply network. Sitras® Sidytrac Live supports the operator in decision-making, providing additional security in the long term and increasing network utilization and reliability. Overall, there are significant cost savings for the operator. And yet, the development is far from over: In the future, Sidytrac Live will automatically detect critical situations and immediately propose the right preventative measures to the operator.

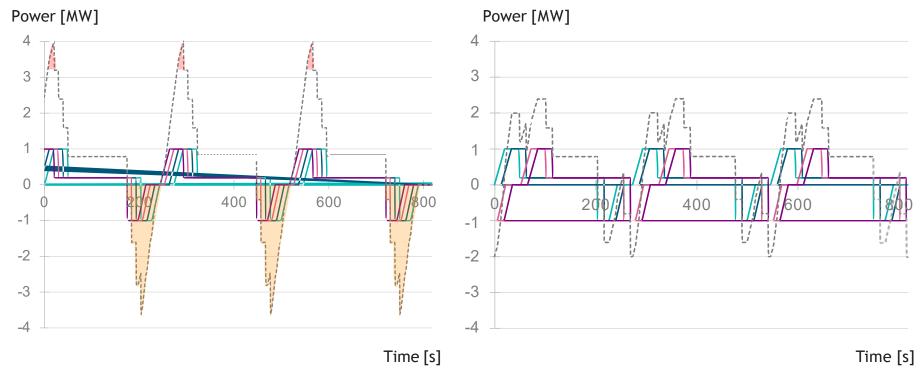


Figure 4: Load peak reduction, normal operation on the left
- all trains operate simultaneously; optimized operation on right

An application for monitoring critical components in substations and for maintenance support is the cloud-related application Substation Analyzer (see schematic in Figure 5). It allows the state of the substation components to be tracked at any time on devices with an internet connection.

The app can support tasks related to failure prevention by providing live and historical data to give a deep understanding of the component's behavior and possible root causes of problems. Furthermore, the ongoing monitoring of substation components with the Substation Analyzer can help to improve the

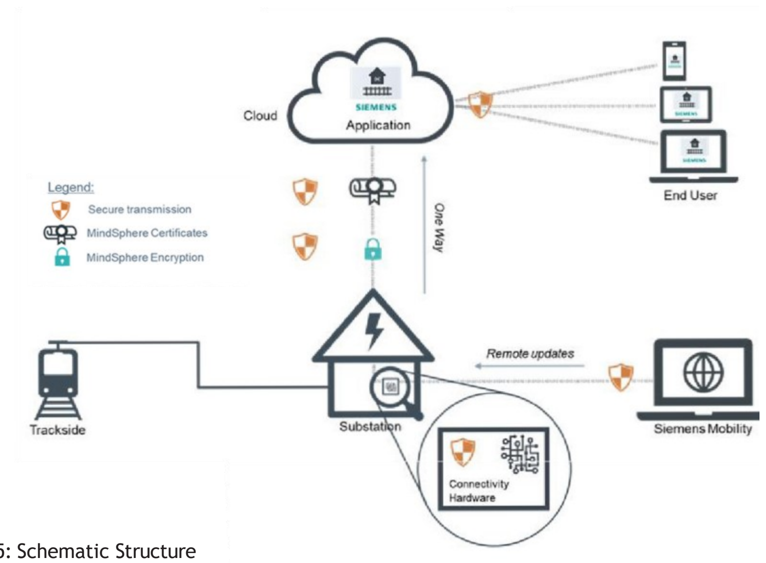


Figure 5: Schematic Structure
Substation Analyzer

preventive maintenance planning of substations, shortening the duration of the maintenance work processes and improving the adaptation of maintenance periods to low-load phases in traffic. The app enables the substations to be serviced only during off-peak times, during which sufficient reserves to the neighboring substations are ensured.

In addition, the response time to certain events can be shortened through personalized rules and associated notifications. These rules can be created, saved, changed and deleted by each user in the application. Fault reports from protection devices can be sent directly to the cloud, without the need to go to the substation, and the cause can be directly analyzed. An asset management system simplifies a document and information overview for each asset, such as maintenance documents and asset-specific data such as serial numbers and installation data.

The tailor-made connection solution for each substation can either be built into existing control cabinets or installed as a compact box. In addition, it meets the latest security standards so that the data is safe at all times – whether when it is transferred to the cloud or in the cloud itself as can be seen in figure 5.

Klaus Müller
System Engineer for Traction Power Supply
– System Engineering & Integration

Alexej Halank
Product Lifecycle Manager Sidytrac Live
– System Engineering & Integration

Carolin Seidenberg
Product Owner Substation Analyzer
– MindSphere Application Center

CHAPTER 3

Maximum energy efficiency for rail operators

Friedemann Koop, Martin Altmann

Electrical transport systems can provide emission-free local operation as renewable energy sources can be used for climate-neutral energy production. In addition, if the energy of the trains in the transport system is provided by a continuous energy supply, an unbeatable high level of efficiency can be achieved. These prerequisites make electric transport the system of the future, which has been and used for electric railways for a long time is also being introduced to road freight transport with the e-Highway.

The energy efficiency of a transport system is mainly determined by its structure, components and operation. Given the wide variety of applications and technical components, the topic of energy efficiency is always network-specific. Energy efficiency can be targeted at different goals, which are to be optimized both in the design of a system and in operation. As a result, it often appears that a combination of many different actions is necessary to achieve maximum energy efficiency, as mentioned in [4] and [5]. There are 250 measures mentioned promoting energy efficiency at the Swiss Federal Railways.

Using new digital solutions, Siemens Mobility offers an extensive, customer-specific analysis of the overall system based on measurements, modeling and simulations. Concrete measures can be derived, leading to a higher level of environmental sustainability and lower energy and operating costs. Climate protection and economic efficiency go hand-in-hand. As described in [4], the price of electricity is expected to rise by about 10% between 2012 and 2030, which in total means additional costs for German public transport of around EUR 350 million for traction energy alone. Energy efficiency measures are an appropriate means of reducing costs.

Simulations create transparency

Many rail operators focus on minimizing the energy costs of the overall system resulting from the overlay of all consumers on the grid. Depending on the tariff, energy costs can consist of different components such as the price of power and energy. Different tariff models are used worldwide, which means that solution strategies will also be different.

Siemens Mobility enables transparency through measurements and with simulations. The multi-train simulation software with coupled network calculation Sitras® Sidytrac Designer [6] represents a digital twin of energy supply including all consumers.

The interaction of both stationary consumers and trains results in the total power demand and energy consumption that is charged to the operator.

Simulations can be used to calculate various alternatives for both design and daily operation and then to select the most suitable ones.
The real-time application of Sitras® Sidytrac Live is connected to adjacent systems and can therefore make precise predictions about the overall system status, energy consumption and power requirements and thus also energy costs in customer-specific tariffs.

Selection of suitable components and system configurations
Comprehensive real-time applications offer a high degree of transparency, especially in special operating scenarios, in the case of faults or any operating cases outside the design conditions. This can increase system availability and at the same time achieve the best possible energy efficiency.

Already in the design process, the best components such as cables and overhead contact line systems can be chosen. In addition, active energy-saving components such as inverters in DC systems and stationary energy storage systems can also be assessed and their most suitable locations and configurations determined.

In addition to the choice of the most suitable components, the parameterization of the various elements has a decisive influence on energy efficiency.

Key aspects are:

- the choice of the appropriate rated voltage and voltage system
- the switching configurations and the resulting protection parameters of the network
- the no-load voltage of the substations
- characteristics of active components

The appropriate selection of measures is customer-specific. Siemens Mobility offers in-depth analyses and subsequent consulting services to determine the suitable measures for both new and existing system.

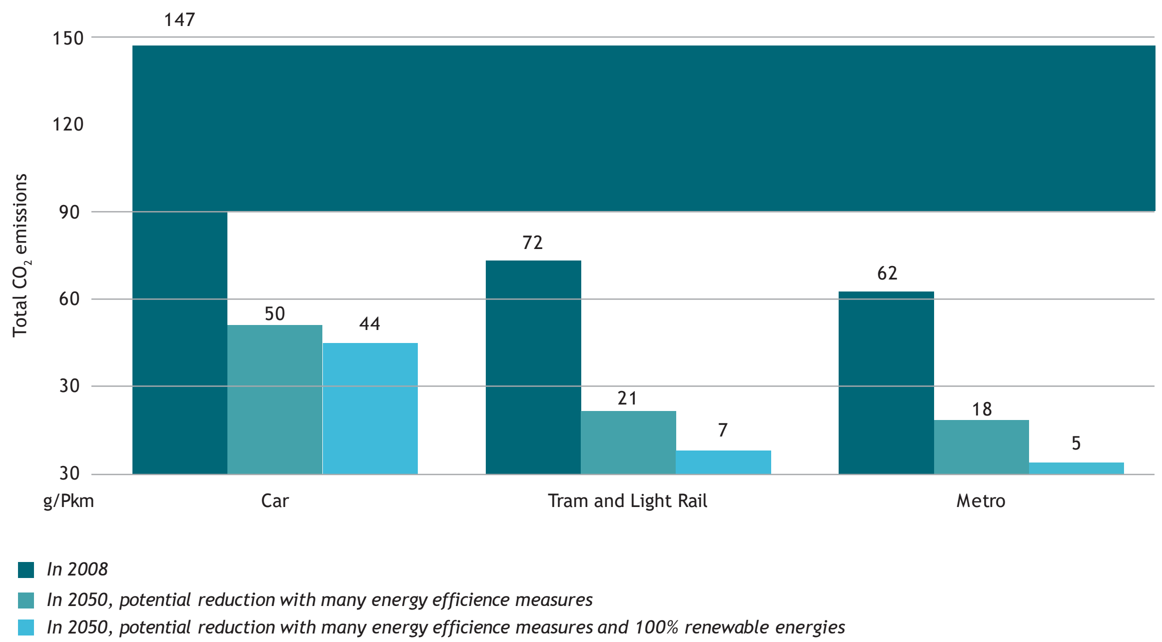
Tailor-made timetables
The timetable and the driving style of individual trains also have a major influence on power and energy and thus on energy costs [4] describes nine general measures for increased energy efficiency in railways, with operational measures such as energy-efficient driving behavior and network optimization bringing the largest savings of up to 15% for traction current.

In the automated interconnection of the digital solutions Sitras® Sidytrac and Controlguide Falko [7], Siemens Mobility offers the opportunity to optimize timetable planning in terms of energy consumption.

The various objectives such as power peaks, total energy consumption and loss minimization are weighted according to customers' requirements and a tailor-made roadmap is determined.

With the real-time application, adjustments to the timetable are made with the aim of increasing energy efficiency during operation. In doing so, the entire system can be operated efficiently even during special situations.

Figure 6: Specific GHG emissions by electric transport for 2050, assuming the implementation of many energy efficiency measures, also with economic risks [4]



Climate protection and climate friendliness
In addition to the multifaceted economic aspects of energy efficiency, the influence of a transport system on the environment is also of great importance. The problems of waste heat and ground temperature increase are becoming increasingly prevalent in the world's metropolises. Particularly relevant are the questions on long-term effects and the impact of global climate change.

With its modern digital products, Siemens Mobility creates transparency by modeling heating and making its effects visible. Based on this, customer-specific solutions with various suitable components are proposed including adaptations of the energy supply system or the efficient, targeted optimization of timetables. The individual solution can be oriented towards different goals. Optimization goals could be, for example, limiting the local heat input in an air-conditioned building, reducing the total energy demand, or maximizing the use of the recuperated energy.

In the field of greenhouse gas emissions, stakeholders and transport companies are required to take measures to reduce air pollution. Siemens Mobility can also advise on this. In general, electrical transport systems are excellently suited to these objectives, as they already have a decisive advantage compared to fuel-powered transport, which can even be expanded in the long term, as figure 6 shows.

Friedemann Koop
System Engineer for Traction Power Supply – System Engineering & Integration

Martin Altmann
Senior Key Expert for System Engineering in Traction Power Supply – System Engineering & Integration

CHAPTER 4

Optimum support for **the maintenance of electrical railway systems**

**Wolfgang Braun,
Christoph Hinze**

The maintenance of electrical railway systems is the basis for high availability as well as fault-free and uninterrupted operation.

In this respect, the rapidly growing demand for rail mobility cannot be met without innovative maintenance. Achieving high availability of the overall system has emerged as an essential cornerstone of modern railway transport systems. The availability requirements are not only based on customer satisfaction and cost reduction, but can also be safety-relevant, for example in metro systems.

In complex systems, high availability with conventional, rigid maintenance intervals can no longer be economically guaranteed. A frequent complication in electrical power supply networks is the lack of maintenance periods for active system components.

As a result, maintenance work must usually be carried out at night outside of active operation. However, even these periods, are increasingly constrained by the continuous expansion of operation time.

Condition-based and predictive maintenance

The development of new digital technologies is geared towards targeted predictive maintenance concepts. Potential failures can be detected and corrected prior to occurrence. An analysis of condition data predictively identifies critical points in the system. In the event of a fault, timely detection and localization of the error can significantly reduce downtime.

The use of digital solutions also enables a reduction in the LCC by reducing the necessary maintenance intervals and the associated maintenance costs. With extensive facility knowledge, operators can classify the measurement values obtained and derive maintenance strategies.

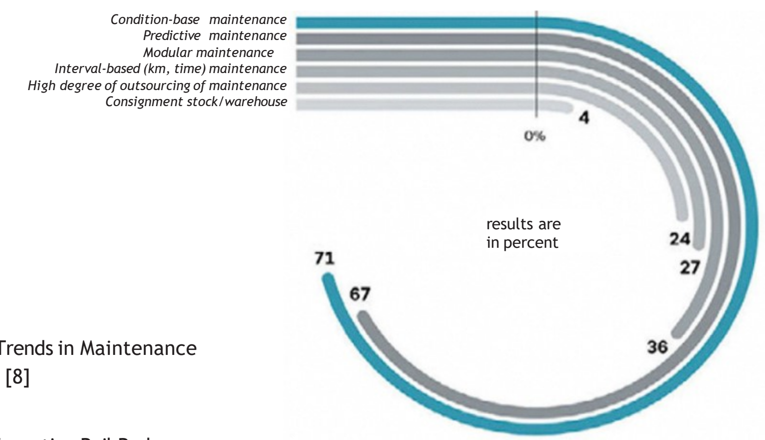


Figure 7: Main Trends in Maintenance Rail Radar 2016 [8]

Source:
Roland Berger Executive Rail Radar

In the context of digitalization, two measures have proved particularly promising in recent years to optimize maintenance activities. These have become the focus of railway operators, as shown in the following survey of managers of European railway systems [8].

1

Condition-based maintenance enables a shift away from fixed maintenance intervals towards targeted maintenance. Based on real-time monitoring of status data of system components, maintenance is performed depending on the current state of a component. This enables the component to be replaced at the most economical time and thus allows for further cost savings.

2

Predictive maintenance identifies potential component failure even before the failure occurs and enables the replacement of the future defective component. Maintenance work can be carried out preventively and without any restriction of operation.

Another measure is to improve the localization of faulty system components to reduce the necessary maintenance costs. By narrowing down the error location, the maintenance can be done in a targeted and fast manner.
The following presents several digital technologies which support different subsystems within the railway power supply based on innovative maintenance concepts.

Monitoring of the overhead contact line

An important component of the power transmission to the trains is the overhead contact line for electrical railway systems. The continuous contact with the pantograph of the trains enables an uninterrupted power supply. To ensure the contact quality between the pantograph and the overhead contact line, the longitudinal conductors are movable and ideally tensioned via weight-based tension wheels. The Sicat Catenary Monitoring System (Sicat CMS), which can be installed on the tension wheel, offers continuous monitoring of the swing lever and the overhead contact line attached. The system monitors the position of the swing lever and derives status information on the overhead contact line. This is depicted in Figure 8.

In addition to the standard version, there is a safety-qualified version that switches off the power supply within a fraction of a second when dangerous system conditions are detected and connects the overhead contact line to the return line. The system is SIL 2-certified and is used for applications in tunnels, stations, rail crossings, etc. However, it is not only the electrical hazard that can be reduced when a fault occurs in the overhead contact line. The detection of contact wire rupture can also support the protection technology since high-impedance faults cannot always be detected by the protective devices. Sicat CMS Safe can therefore be considered as a new protection system for overhead contact line systems.

The corresponding measurement values are transmitted in real time to a central evaluation unit and processed there. Thus, at an early stage, unacceptable deviations of the lateral tensile force become visible and targeted condition-based maintenance is possible. In addition, the location of the fault can be precisely determined.

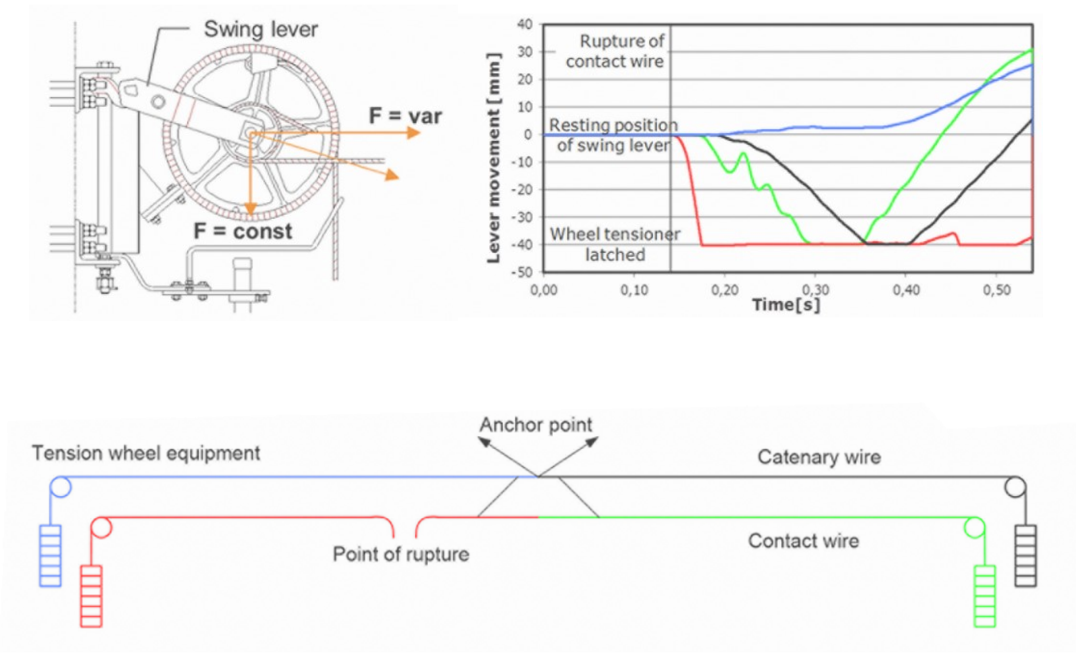


Figure 8: Sicat CMS with example overhead contact line rupture [9]

Monitoring of track insulation

Good longitudinal conductivity of the rails is a prerequisite for low rail potential and thus for compliance with the permissible touch voltages on the track. In addition, good track insulation in DC railway systems ensures that no stray currents leak, and surrounding facilities are not endangered by corrosion.

The track insulation is subject to a continuous, but also occasional deterioration process in the course of its operational life. Maintenance work on the track is often carried out only if there is obvious damage to the operation. A reduction in the insulation quality of the rails is not recognizable from the outside, and detection is only possible through extensive measurements. The measurement requires a break in operation and is therefore carried out only at cyclical intervals of several years. With the Siemens Stray Current Monitoring System (Sitras SMS), continuous monitoring of track insulation quality can be carried out without using valuable operational breaks that could be used for other maintenance work or causing a disruption in operation. Reference values are measured using regularly arranged voltage measuring points at the beginning of operation. Deviating voltage levels on the track during operation indicate a change in the track insulation. The Sitras SMS then issues an alarm that indicates damage or a change in isolation.

In addition to a standard industrial PC, Sitras® SMS utilizes the existing communication network and individual voltage measuring points. These can already be given as components of voltage limiting devices.

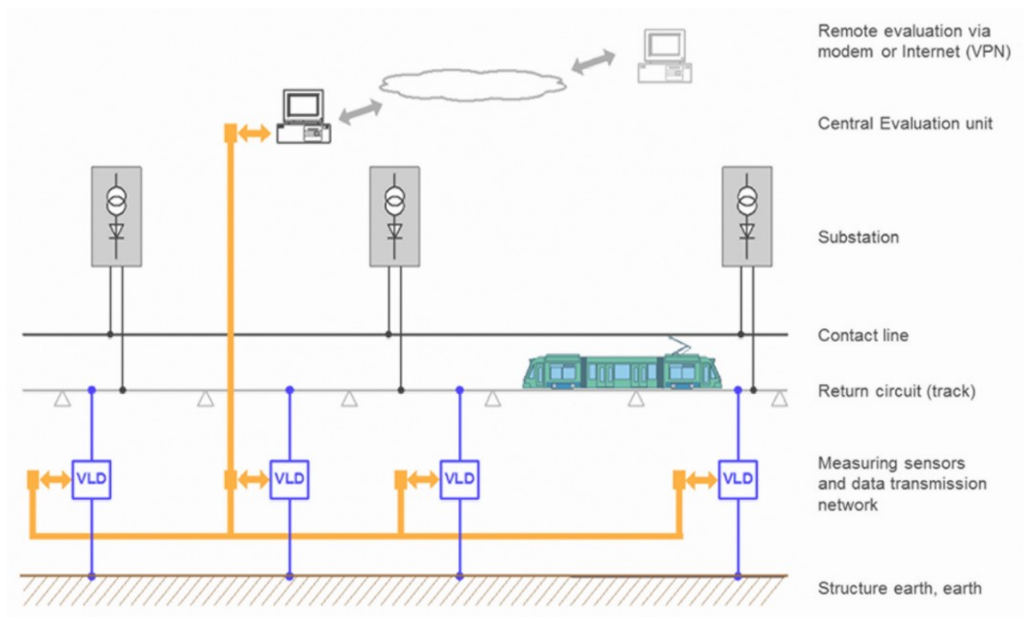


Figure 9: Example track with Sitras® SMS [10]

"During the operation of a metro, there was water intrusion into power cables. The insulation of the non-shielded power cables was faulty. There was a non-metallic, but also not really high-impedance fault. The fault current was not sufficient to be triggered by a protection device. There was a high rail potential. The overlaying of the rail potential due to the fault and the operational rail potential led to a shutdown of the system. Trouble-shooting was difficult. The highest potential does not necessarily occur at the fault location. The additional supply current does not necessarily lead to a protective triggering since there is a great deal of design reserve for substation failures. For long lines, the return conductor-earth resistance is quite low, so that some 100 A error current does not lead to extreme rail potentials. At the point of failure, however, a considerable amount of power is transformed." [11]

Detecting high-impedance earth failure

As the previous example shows, regular faults occur in railway energy supply systems. These cannot be reliably detected by the protection devices and can only be fixed with a considerable amount of maintenance.

An extension of the Sitras® SMS to identify and locate high-impedance insulation faults in power cables or even earth faults in DC railway power supply systems is provided with the Automatic Fault Locator (Sitras® AFL).

The Sitras® AFL monitors the switching state and current flow of the installed voltage limiting devices along the route. Repeatedly closing or permanently closed voltage limiting devices indicate insulation fault. An increased current indicates an earth fault. With an automatic localization algorithm, the individual voltage limiting devices are controlled in a targeted manner and the earth fault can be limited to the area of one voltage limiting device.

The Sitras® AFL significantly reduces the time required to locate and eliminate faults. It can limit the fault location to a single feeding section. This enables a minimum reduction of operation.

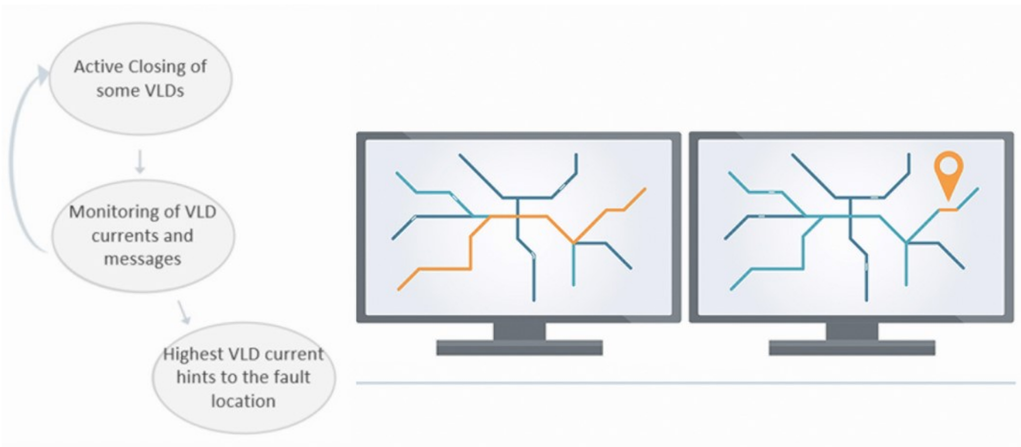


Figure 10: Schematic representation of Sitras® AFL function [10]

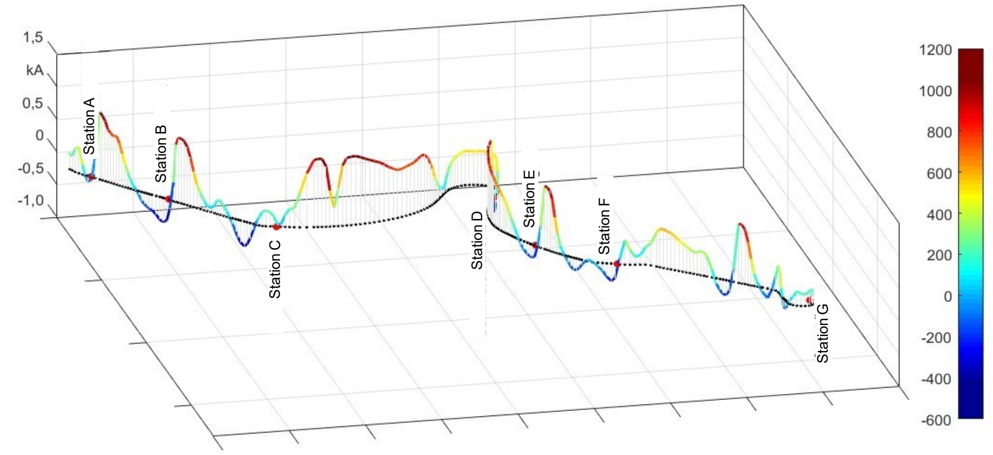


Figure 11: Calculated mean current load on a tram line [12]

Combined data analysis

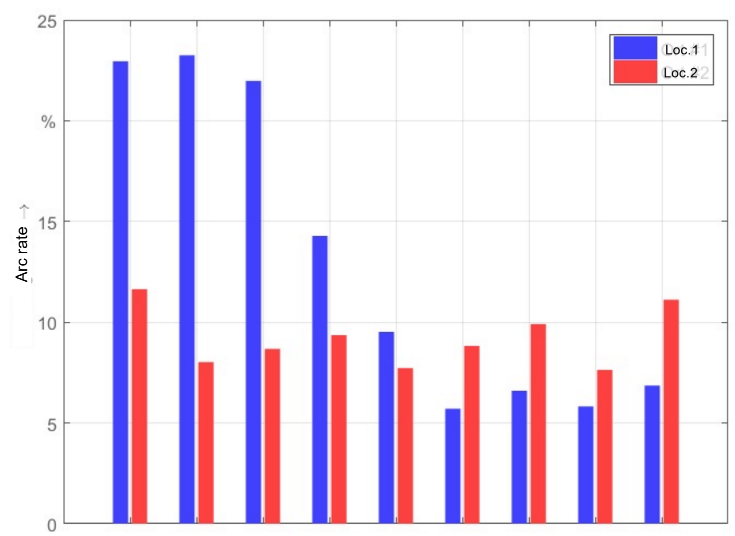
Sitras® CMS, Sitras® SMS and Sitras® AFL each evaluate the data from only one system component. However, the trend is towards a more comprehensive approach with the combination of real-time data from multiple system components.

For example, Sicat Georeferenced Catenary Diagnostic (GCD) combines the recordings of arcs by UV sensors on the roof of the train with continuous measurement of current, voltage and speed of the train along the track. From the data obtained, it is not only possible to derive predictable, condition-based maintenance for locations with high arc frequency, but also a network-wide analysis of the contact line load. The following figure shows the measured mean current load of a tram line and clearly illustrates places with increased load. This enables the operator of the network to take targeted maintenance and improvement measures as well as support manufacturers with wear-relevant field data for product improvement [12].

Once problematic locations in the network have been identified and targeted maintenance measures have been carried out, the continuous evaluation of the field data also allows for the verification of the effectiveness of applied measures. An example is the arc rate of neutral sections with maintenance measures (location 1, time of action: March) and without maintenance measures (location 2), shown in figure 12.

The system is complemented by monitoring of the voltage quality with derived recommendations for action. This enables problematic sites to be identified and localized at an early stage and hence enables targeted maintenance before faults occur and a reduction of the necessary inspection time.

Figure 12: Temporal development of the arc rate, with (location 1) and without (location 2) maintenance [12]



Control system for a comprehensive overview

The Sitras® RSC integrates and merges a wide range of component monitoring systems. The innovative Station Control System clearly displays the processed measurement data of individual monitoring systems and enables the operator to have an overview of both acute needs and long-term analyses in order to plan necessary maintenance work.

There is a wide range of surveillance options. Load and switching processes of circuit breakers can be detected by protective devices or temperature and partial discharge monitoring of transformers. In addition to the monitoring of primary technology, an automatic diagnosis of secondary technology is conducted by means of integrated test routines.

Faulty components are communicated to the operator directly by warning or visualization in a system overview. This is to ensure a quick fix of fault situations as well as condition-based maintenance.

In addition to digital technologies, measures for optimizing maintenance are continuously integrated in other areas as well.

The high level of modularization of systems and structures is an example, increasing the interchangeability of individual components and reducing maintenance costs.

Wolfgang Braun
Senior Key Expert for Traction Power Supply and Earthing & Bonding – System Engineering & Integration

Christoph Hinze
System Engineer for Traction Power Supply – System Engineering & Integration

References

1 R. U. o. t. U. Secretariat, "Statistic Brief - The global tram and light rail landscape", UITP, Brussels, 2019.

2 R. U. o. t. U. Secretariat, "Statistics Brief: Light rail and tram - the European outlook", UITP, Brussels, 2019.

3 U. O. o. A. Metros, "Statistics Brief: World metro figures", UITP, Brussels, 2018.

4 Federal Ministry of Transport and Digital Infrastructure, Unit UI 41 - Energy and Climate Protection, Construction and Transport, Invalidenstraße 44, 10115 Berlin, Germany, "Increasing the share of renewable energy and increasing energy efficiency in public transport", 2014.

5 "Climate-neutral energy for the Swiss railways", Electric railways - electrical engineering in transport, pp. 110-111, 2-3 2020.

6 Siemens Mobility GmbH, "Simulation for Railway Electrification" [Online]. Available: https://www.mobility.siemens.com/global/de/portfolio/schiene/bahnelektrifizierung/beratungplanung.html#Simulation.

7 Siemens Mobility GmbH, "Controlguide Falko - Planning System" [Online]. Available: https://www.mobility.siemens.com/global/de/portfolio/schiene/bahnautomatisierung/betriebsleittechnik/verteilung-planung-disposition.html.

8 Roland Berger GmbH, "Executive Rail Radar 2016", 2016.

9 Siemens Mobility GmbH, Sicat CMS - Catenary Monitoring System for overhead contact lines, Siemens AG, 2016.

10 Siemens Mobility GmbH, Sitras AFL - Automatic Fault Locator, 2019.

11 T. Greif, "Safe detection of faulty food sections with VLD", Electric railways - electrical engineeringin transport, pp. 66 - 71, 02-03 2020.

12 S. Terfloth, "Cating line maintenance through continuous on-board arc detection", in Punktforum Fahrleitungsanlage 2018, Dresden, 2018.

Siemens Mobility GmbH
Otto-Hahn-Ring 6
81739 Munich
Germany
electrification.mobility@siemens.com
www.siemens.com/rail-electrification