Recent Topics on Power Supply Technology

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In order to ensure that the railways remain a sustainable transport mode into the future, it is essential to improve the reliability and stability of train operations and railway systems. Functional failures in power supply systems significantly affect train operation: the RTRI has therefore been tackling the issue of improving reliability of power supply systems. This paper describes recent power supply technology research focusing on research geared to contribute to reducing failures and accidents on the railway system.

Keywords: electric railway, power supply system, traction power system, contact lines, maintenance, availability

1. Introduction

In recent years, the influence of climate change and extreme weather associated with global warming have increased the urgency for a low carbon society. Railway transport is known for its high energy efficiency and low carbon emissions. In order to ensure that the railways continue to be a sustainable mode of public transport into the future however, its energy saving performance must be improved. At the same time, the productive age population in Japan has now fallen to 87% of its peak reached in 1995. Consequently, although proper maintenance and management of infrastructure is indispensable for the safe and stable operation of railways operation, it is predicted that finding highly skilled personnel with the necessary skills to carry out this maintenance, will become increasingly difficult. It is therefore essential to advance infrastructure inspection and diagnosis technologies and improve the efficiency of maintenance work. In addition to the long-term perspective, it is also important to reduce transport disruptions due to delays and accidents as far as possible, and achieve more stable operations, in order to ensure that railways continue to be a reliable transportation mode.

Based on this analysis, the research division involved in electric power supply technologies at the Railway Technical Research Institute (RTRI) set itself the goal of improving reliability of electric power supply systems. This paper introduces and highlights RTRI activities aimed at improving reliability of electric power supply systems.

2. Electric power supply system multiple protection layers and factors contributing to failures

Electric power supply systems require permanent maintenance to be kept in normal operational state because one fault has the potential to create serious transport disruptions. However, because a fault may stem from a variety of causes, electric power supply system failures may result in prolonged transport disruptions. Hazard sources of an electric power supply system fault can be classified into “external anomaly,” “long-term deterioration,” “operation-al/executional error” and “protective equipment failure.”

External anomalies include severe weather conditions such as strong wind, heavy snowfall, etc., an earthquake, lightning stoke, fallen trees/ flying objects, wayside fire, etc., that are basically considered at the design stage, but also include exposure of equipment to conditions that exceed what was envisaged during the design phase. Long-term deterioration, includes abrasion, fatigue, corrosion, etc., of components making up the electric power supply system. It is not realistic to completely eliminate them. A fault occurs if deterioration continues beyond the allowable limit. Operational and executional errors occur during usual operations or during maintenance work. Again, it is difficult to completely eliminate this type of problem whilst there is a human factor involved. If one or more of these hazard sources exceed the allowable level, some sort of fault will occur at component level. Then, if the fault progresses and causes functional loss, this will lead to serious transport disruption. Protective equipment is installed to prevent the effect of a fault in the electric power supply system from spreading and to ensure the lost function is restored promptly. If however, the protective equipment itself fails, then it becomes the hazard source leading to propagation of the failure.

![Fig. 1 Chain reaction from power supply system hazard sources to serious transport disruption](image-url)
Such situations can be summarized in the manner shown in Fig. 1. In order to stop such serious disruptions, it is important to prevent the hazard sources from occurring as far as possible, and put multiple safeguards in place, so that should a failure occur, it can be contained. This idea is shown in Fig. 2. The protection layers consist of multiple safeguard measures, which can be roughly classified into three categories, as shown below.

1) Measures to build the safest possible electric power supply system
2) Measures to improve inspection and maintenance technologies
3) Measures for supporting secure maintenance works

RTRI has been actively researching and developing technologies aimed at building a more stable electric power supply system, by establishing these kinds of protection layers. Details of this work are introduced in the following chapters, in the order presented above.

3. Strategy to build highly-safe electric power supply system

In order to build a highly-secure electric power supply system, it is important to design the system with sufficient safeguards against external anomalies so that it can maintain the required performance. For this purpose, it is essential to quantitatively assess the condition of the system when affected by a complex combination of such anomalies. Numerical simulations are very effective for this type of assessment. Accordingly, a Train Operation Power Simulator [1], Pantograph/Catenary Simulator [2], etc. are being developed, to be used in the design of electric power supply facilities.

The Train Operation Power Simulator is a tool for precisely estimating the traction power consumed during train operation. As shown in Fig. 3, this simulator consists of the calculation components for train operation control, for feeding circuits, for rolling stock, and for the speed profile. Since it can handle detailed information regarding vehicle performance, operation, and train operation control as input data, accurate evaluation of electric energy consumption is possible. Current work is focused on improving calculation speed, along with promoting V&V of this simulator. As this simulator is capable of very detailed evaluations of the load capacity required for the substation according to train operating conditions (train schedule, vehicle performance, outside air temperature, etc.), it is very useful for determining suitable traction power system specifications. Furthermore, it can be utilized for quantitative evaluations of the energy-saving effect of installing/ introducing power storage equipment and assessing variations in electric power consumption due to train timetable revision, etc.

The Pantograph/Catenary Simulator is a tool for accurately evaluating the dynamic behavior of pantograph/catenary systems. It is being further developed to evaluate the dynamic behavior of the pantograph/catenary not only in straight sections, but also in curved sections, which is still impossible to do in Japan with existing simulation tools. At present, it is possible to calculate the static geometry of the overhead contact lines installed above an arbitrary track. The static geometry of overhead contact lines in curved sections with strong radial forces acting on the wires at each support can be accurately evaluated (Fig. 4). This simulator is also able to consider elongation of wires due to temperature change. Therefore, it is expected that this tool will be used for the design of overhead contact lines to take into account certain external conditions, such as strong wind, temperature change, etc.

In parallel with the development of these design/evalu-
ation tools, research and development is also being carried out to improve electric power supply system safety itself. Protective equipment is installed in every substation to be able to detect ground faults immediately and stop power feeding in order to prevent serious damage to the electric power supply system. However, there is a lack of suitable countermeasures for high-resistance ground faults, where ground faults occur via supports with large electric resistance such as concrete poles. RTRI has already developed a high-resistance ground fault detection system for DC feeding circuits using protective wire with discharge gaps [3]. However, there is also a need to develop protective devices for high-resistance ground faults with no additional electric wire. RTRI is now therefore developing a new type of high-resistance ground fault detection system through evaluation of fluctuating feeding currents when a high-resistance ground fault occurs with the aid of the Train Operation Power Simulator, shown in Fig. 5.

In addition, RTRI is developing a compound overhead contact lines for insulated overlaps [4] in DC feeding sections where contact wire ruptures tend to occur due to trains stopping. It is hoped that this type of contact line will offer a low-cost means to prevent contact wires breaking, even when trains stop in these sections.
4. Strategy to improve inspection and maintenance technologies

Inspection and diagnosis are important for preventing serious transport disruption due to electric power supply system failures, as shown in Fig. 2. However, electric power supply equipment is energized using high voltage, and therefore, the maintenance staff usually only have a limited window of time for close-range inspection. Visual inspection of electric power supply systems is therefore inefficient and requires substantial human resources, especially in the case of the long and large scale infrastructure installations such as overhead contact lines. In order to improve overhead contact line inspection efficiency, and raise the quality of the inspection itself, RTRI is developing a contactless overhead contact line measurement device.

The device, shown in Fig. 6 (a), consists of a laser sensor and line cameras, which are mounted on the roof of a vehicle to take images of overhead contact lines at commercial line running speed. Soundness of the overhead contact lines is diagnosed through the captured images using image processing technologies [5, 6]. One of the key features of this device is that it not only measures the geometry of the contact wire but also the messenger wire, and the auxiliary messenger wire. It can also check the position and condition of droppers, electrical connections, etc. Another key feature is that it can obtain purely static geometry of the overhead contact line with the aid of contactless measurement. Currently-used measurement systems installed on inspection cars measure dynamic height of the contact wire by evaluating vertical movement of the pantograph. Hence, RTRI expects that estimation of the dynamic behavior of overhead contact lines under various conditions will be possible by combining the measurement results with the aforementioned dynamic simulation of the pantograph/catenary system. So far, it has been confirmed that this device can obtain the static geometry of overhead contact lines during operation at 130 km/h which is the commercial maximum speed for conventional lines in Japan (except for partial lines) (Fig. 6 (b)). Furthermore, we have also confirmed that the positions of clamps and other fittings for overhead contact lines can be automatically identified by using images captured at 130 km/h (Fig. 6 (c)).

Hereafter, RTRI will focus on creating an algorithm for the automatic diagnoses of the soundness of components such as droppers, electrical connections, clamps and fittings on overhead contact lines by using captured images, and develop a technique for monitoring the progress of erosion on overhead contact lines.

5. Strategy to develop more secure maintenance work techniques

Since maintenance work on electric power supply system relies on actual people working under severe time constraints, strategies to minimize faults due to human errors (incorrect operation, errors, etc.) is also important.

One example of the work being carried out by RTRI to do this, is the development of a maintenance scheduling system for overhead contact lines. This system assesses the probability of a failure based on the outcome of inspections carried out on overhead contact lines, then qualifies the risk of the failure in consideration of the potential cost of an accident occurring, and indicates when maintenance work should be carried out before the risk reaches an inadmissible level (Fig. 7). This procedure also takes into account the life cycle costs of the equipment. Data gathering and data assessment as the basis of risk assessment are indispensable for the establishment of such a system. Therefore, RTRI has already started to gather and analyze vast volumes of failure data.

In addition, RTRI is planning to develop a follow-up
inspection system for checking the installation of overhead contact lines using the contactless overhead contact line measurement device mentioned above. A downsized and simplified version of this device is required to apply the system to the maintenance vehicle (Fig. 8).

6. Conclusions

This paper outlines research and development carried out by the RTRI railway system power supply technology division, which focuses on improving power supply system reliability using three approaches. The environment and operating conditions of the railway system are constantly changing. Accordingly, in order to prevent serious transport disruptions due to electric power supply system faults, understanding where weak points lie in the system’s protective layers and remedying these shortfalls, are indispensable. Others involved in this field may therefore be asked by the authors to contribute to this work by answering surveys regarding the state of the type of railway equipment mentioned in this paper.

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Research Areas: Dynamics of Pantograph-Catenary System, OCS Maintenance, Reduction of Pantograph Noise