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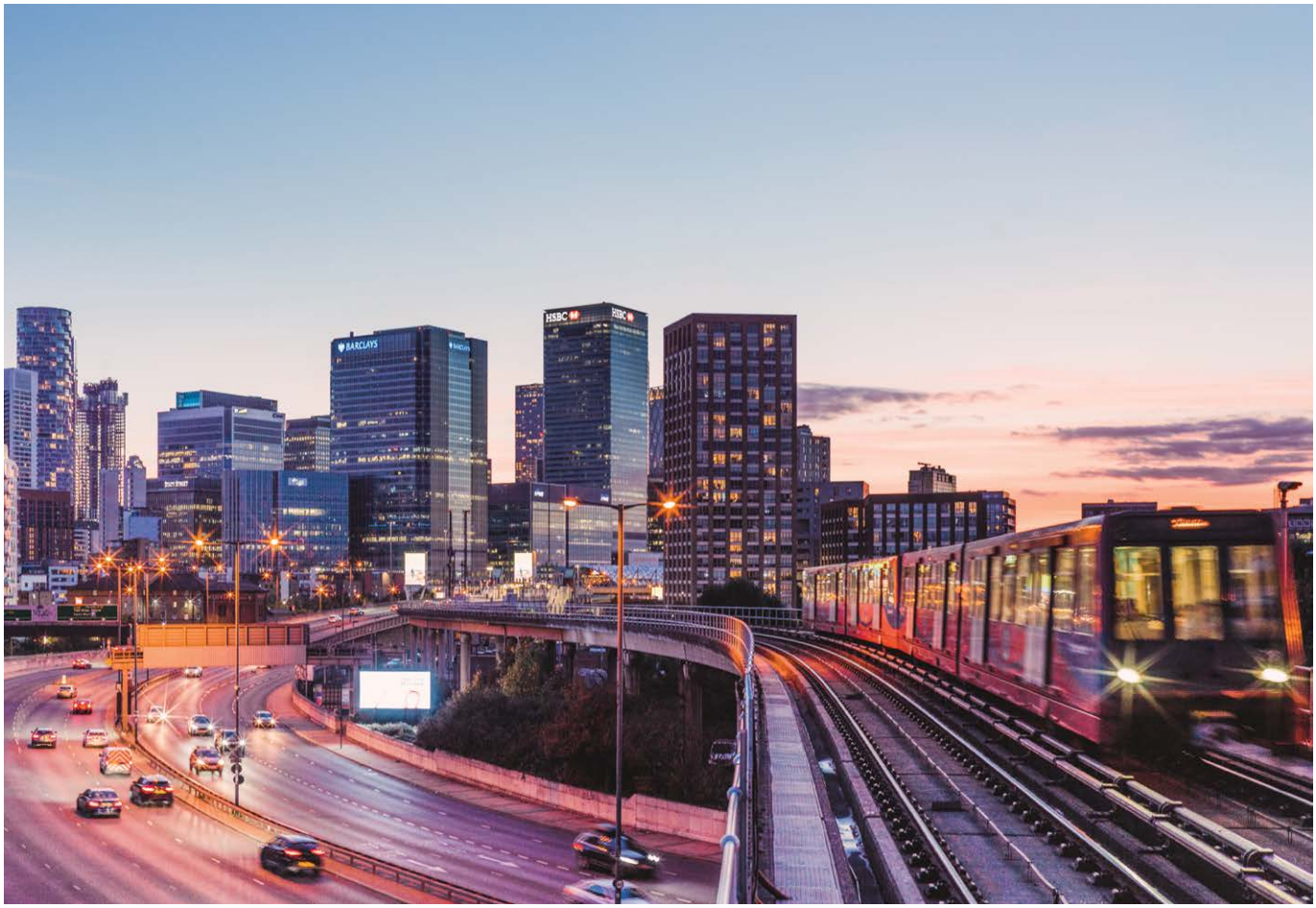
The hidden infrastructure powering the future of rail mobility

A Hitachi Energy perspective on the evolving role of transformers in the railway energy systems

Around the world, governments, infrastructure owners, and operators are investing heavily in rail as a strategic response to some of society's most pressing challenges. Rapid urbanization, growing freight demand, decarbonization targets, energy security concerns, and the need for more sustainable transportation systems are driving renewed investment across metro networks, commuter rail, high-speed corridors, and freight routes. Rail continues to demonstrate a unique ability to move large volumes of people and goods efficiently while supporting economic growth and reducing environmental impact.

The industry's growth trajectory remains strong. While new railway construction continues across many regions, particularly in Asia-Pacific and emerging economies, mature markets are increasingly focused on infrastructure renewal, digital modernization, operational efficiency, and electrification. By 2035, much of the value creation within the rail sector is expected to come not only from new assets, but from improving the performance, resilience, and sustainability of existing networks.



The future of rail will be shaped not only by mobility infrastructure, but by the electrical systems that power it

Yet beneath this transformation lies a reality that receives far less attention than new trains or signaling technologies. Every railway ultimately depends on energy.

The future of rail will be shaped not only by mobility infrastructure, but by the electrical systems that power it. At the center of these systems stands one of the industry's most enduring and essential technologies: the transformer.

For more than a century, transformers have enabled the conversion, distribution, and management of electrical power across railway networks worldwide. Today, as railways become increasingly electrified, interconnected, and digitally managed, their role is evolving from a supporting component to a strategic asset that influences reliability, energy efficiency, resilience, and sustainability across the entire transport ecosystem.

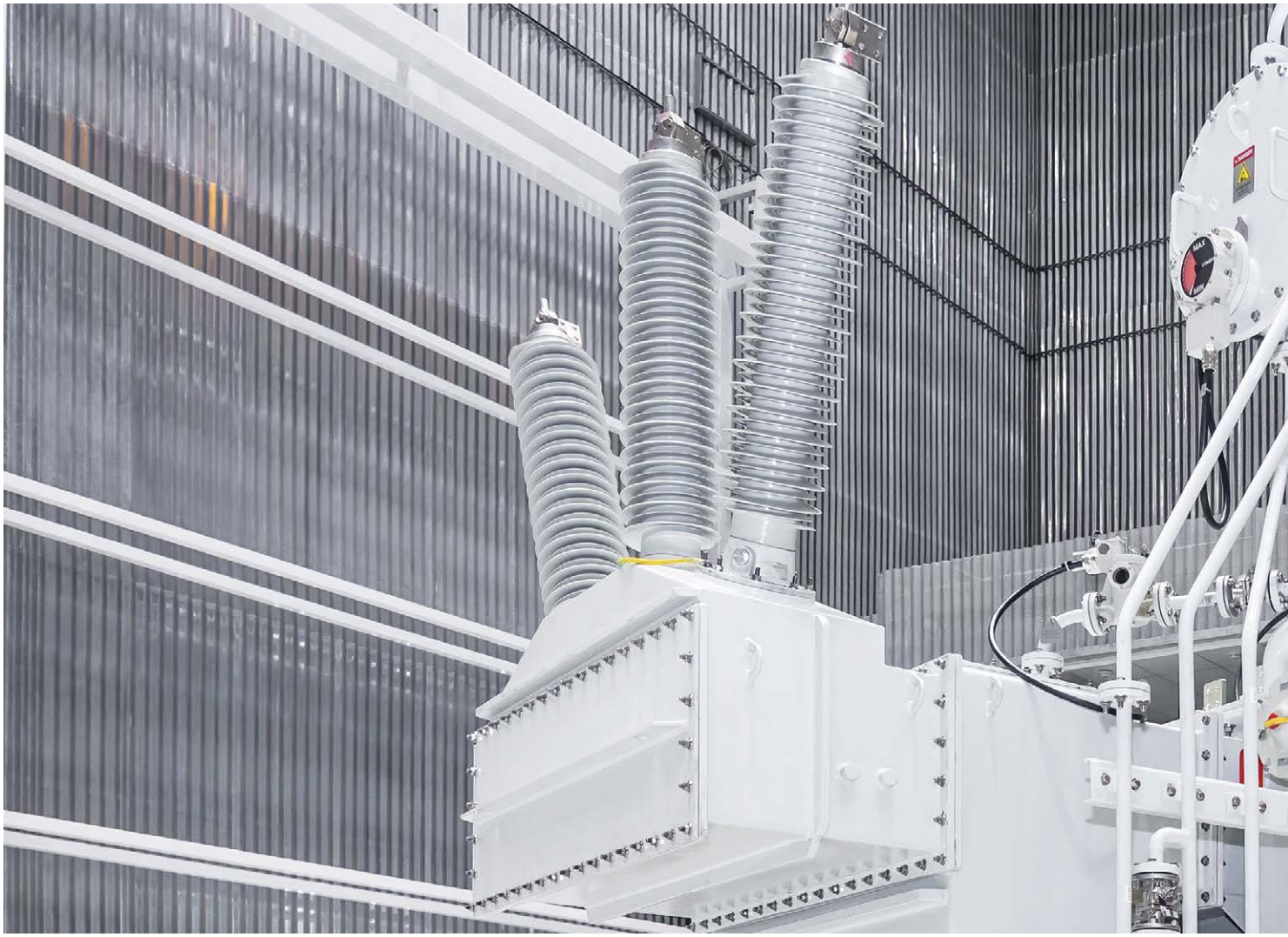
Why electrification matters more than ever

Long before climate change became a global priority, railway electrification was recognized as one of the most effective ways to improve railway performance.

Electric railways provide significant advantages over traditional diesel-based systems. They offer higher energy efficiency, lower operating costs, stronger acceleration, increased network capacity, improved reliability, and reduced maintenance requirements throughout their lifecycle. Electric traction also enables regenerative braking, allowing trains to recover energy and return it to the network rather than dissipating it as heat.

For densely utilized passenger and freight corridors, these benefits create a compelling long-term business case. Electrified railways not only reduce direct emissions but also improve operational economics, support capacity growth, and enhance service reliability. As electricity generation itself becomes increasingly renewable, the environmental benefits continue to increase.

This is one of the reasons why railway electrification continues to expand globally. Industry forecasts project significant growth through 2035, supported by high-speed rail development, metro



expansion, fleet modernization, and decarbonization initiatives across multiple regions. The percentage of electrified railway infrastructure worldwide continues to grow as operators seek to balance sustainability objectives with operational performance and long-term economic value.

However, electrification also introduces new challenges. The more electrified a railway becomes, the more dependent it becomes on the quality, reliability, and resilience of its power infrastructure.

Railways are becoming energy systems

Historically, railway operators and energy operators largely worked within separate domains. Today those boundaries are disappearing.

Modern railways must operate within increasingly complex energy environments

Electric railways provide significant advantages over traditional diesel-based systems

shaped by renewable generation, fluctuating demand patterns, energy storage technologies, digital control systems, and growing electricity consumption across society. As a result, railway performance is becoming intrinsically linked to the availability, stability, and flexibility of electrical power.

This convergence is changing the nature of railway infrastructure planning.

Expanding rail networks require more than tracks, signaling equipment, and rolling stock. They require grid capacity, traction substations, power quality management, load balancing, renewable integration, and energy management strategies capable of supporting increasingly demanding operating environments. In many regions, rail operators are working more closely than ever with utilities, regulators, and grid planners to ensure that future transportation growth can be supported by corresponding energy infrastructure investment.

Transformers sit at the center of this transition. Whether installed in substations, stations, depots, or onboard trains, they provide the essential interface between the electrical grid and railway operations. They connect transmission and distribution networks to traction systems, adapt voltage levels to different operational requirements, and

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enable the continuous flow of electricity throughout the railway ecosystem.

As railways become increasingly complex, the transformer's role extends far beyond power conversion. It becomes a critical enabler of system performance.

The invisible backbone of railway electrification

Railway electrification has always depended on transformers, but today's operating environment places new demands on these assets.

Urban transit systems require compact, efficient solutions capable of supporting high passenger volumes and dense service schedules. Mainline railways demand reliable operation across long distances and varying load conditions. Rolling stock manufacturers seek equipment that can deliver high performance while optimizing weight, space utilization, and lifecycle costs.

Across all these applications, transformers serve as the physical connection between energy systems and transportation systems. They link transmission networks to traction substations, support station operations, supply onboard propulsion systems, and help maintain the continuous flow of electricity that keeps railways moving.

What makes them particularly important today is not simply their electrical function, but their contribution to broader system objectives. Reliability, efficiency, safety, maintainability, and sustainability increasingly depend on infrastructure that can perform consistently over decades while adapting to changing operating requirements.

For many operators, the challenge is no longer building additional infrastructure alone. It is maximizing the value and performance of the infrastructure already in service while preparing networks for future growth.

As operators seek greater value from their infrastructure investments, reliability and lifecycle performance have become as important as initial capital expenditure. The industry's focus is increasingly shifting from simply purchasing equipment to maximizing asset performance throughout its operational life. This places transformers among the most strategic long-term assets within the railway ecosystem.

Stories from the world: A global perspective on railway energy infrastructure

The importance of transformers becomes evident when examining railway systems operating under vastly different conditions around the world.

Mumbai provides a striking example of railway electrification at megacity scale. The city's suburban railway network supports more than six million passenger journeys every day, operating across approximately 450 kilometers of corridors and around 150 stations. More than 2,300 train services run daily, creating continuous demand on the supporting electrical infrastructure.

Supporting an ecosystem of this scale requires far more than reliable trains. It requires a resilient energy architecture capable of supplying power across rolling stock, traction infrastructure, stations, depots, and substations. Today, more than 850 onboard traction transformers and more than 140 dry and power transformers from Hitachi Energy contribute to keeping Mumbai's mobility network operational.

The significance of the example lies not in the number of assets deployed, but in what they represent: reliable mobility for millions of people depends on electrical infrastructure performing continuously behind the scenes.

At the other end of the spectrum, **Sweden** illustrates a different dimension of railway electrification. Operating across vast geographical distances and often under demanding climatic conditions, Swedish railways demonstrate the importance of long-term infrastructure reliability. Here, transformers must support passenger transportation, freight operations, and regional mobility systems while delivering consistent performance over decades of service.

Operating across vast geographical distances and often under demanding climatic conditions, Swedish railways demonstrate the importance of long-term infrastructure reliability

Such networks highlight a critical reality of modern rail infrastructure: transformers are among the longest-lived assets within the railway ecosystem. Their importance extends beyond day-to-day operation. They form part of the strategic foundation upon which future capacity expansions, efficiency improvements, and sustainability initiatives depend.

Whether supporting high-capacity metropolitan transit systems, national rail corridors, freight operations, or rolling stock applications, the underlying requirement remains the same: ensuring that electrical energy can be delivered safely, efficiently, and reliably wherever rail mobility demands it.

Sustainability begins with infrastructure

The environmental benefits of rail transportation are widely recognized. Yet as

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operators pursue increasingly ambitious decarbonization objectives, attention is shifting beyond the trains themselves toward the infrastructure that powers them.

The industry is increasingly evaluating assets through a lifecycle lens, considering factors such as energy efficiency, material selection, maintenance requirements, safety, operational longevity, and end-of-life impact. Infrastructure decisions are becoming sustainability decisions.

This shift is driving interest in technologies such as dry-type transformers, biodegradable ester-based insulating fluids, and higher-efficiency transformer designs that can reduce environmental impact while maintaining operational performance. These innovations support the broader goal of sustainable mobility not only by enabling electrified transportation, but by reducing the footprint of the infrastructure behind it.

As railway operators increasingly seek to balance performance, resilience, and sustainability, transformer technology will continue to play a central role in achieving those objectives.

More than equipment: Connecting energy and mobility

The future railway will be defined by the convergence of mobility, energy, and digital technologies.

As networks become more interconnected, operators will require greater visibility into asset performance, improved energy management capabilities, predictive maintenance strategies, and infrastructure that can adapt to evolving operational demands. The focus will increasingly shift from individual products to integrated systems capable of delivering long-term value.

This is where the broader capabilities of Hitachi Group create unique opportunities. Across rail transportation, digital solutions, operational technologies, and energy infrastructure, Hitachi companies are helping customers navigate the growing complexity of modern mobility systems.

Within this broader ecosystem, Hitachi Energy contributes with the expertise required to design and deliver the electrical foundation that enables railway networks to perform. But the ultimate objective extends beyond electrification itself.

It is about connecting energy and mobility in ways that make transportation systems more resilient, efficient, sustainable, and future-ready.

Because while passengers experience rail through the journey they take, the future of mobility will increasingly be determined by the infrastructure they never see. Transformers may remain hidden from view, but their role in shaping the present and next generation of rail networks has never been more visible.