MODERN METHODS OF RAILWAY ELECTRIFICATION

Djabbarbergenova Aygul Maxsetbay qizi
Teacher at the Aral region medical and transport technical college
Kosbergenova Sabina Rustam qizi
Teacher at the Aral region medical and transport technical college
Turdibaeva Lalaxan Adilbaevna
Teacher at the Aral region medical and transport technical college
https://doi.org/10.5281/zenodo.20840133

Abstract. This thesis discusses modern methods of railway electrification and their role in the development of efficient, safe and environmentally friendly transport systems. Railway electrification is one of the main directions of modern transport modernization because it reduces the use of diesel fuel, decreases harmful emissions, increases train speed and improves energy efficiency. Today, railway electrification is developing through the use of high-voltage power supply systems, regenerative braking, smart substations, renewable energy sources, energy storage technologies and digital monitoring systems.

Keywords: railway electrification, electric traction, energy efficiency, regenerative braking, smart substations, renewable energy, digital monitoring.

Railway transport plays an important role in the economic and social development of every country. It provides the transportation of passengers and goods over long distances at relatively low cost. However, traditional diesel-powered railway systems have several disadvantages, such as high fuel consumption, air pollution, noise and dependence on petroleum products. For this reason, railway electrification has become one of the most effective solutions for modernizing the railway system. Railway electrification means supplying trains with electrical energy through overhead contact lines, third rails or other power supply systems. Electric trains are more environmentally friendly, more powerful and more economical than diesel locomotives. They can accelerate faster, carry heavier loads and operate with lower maintenance costs. Today, railway electrification is developing together with digital technologies, automation and energy-saving systems.

One of the most widely used modern methods of railway electrification is the **25 kV alternating current system**. This system is commonly used on main railway lines because it can transmit electricity over long distances with relatively low energy losses. The 25 kV AC system is suitable for high-speed trains, freight trains and intercity passenger transportation. It allows railway companies to operate more powerful locomotives and increase the capacity of railway lines. Another modern method is the **2x25 kV autotransformer system**. This method

is considered more efficient than the traditional 25 kV system because it reduces voltage drops and energy losses. In this system, autotransformers are installed along the railway line to balance the power supply. As a result, trains receive more stable electrical energy, and substations can be placed at longer distances from each other. This method is especially useful for high-speed railways and long-distance heavy freight lines. A very important direction in modern railway electrification is the use of **regenerative braking technology**. When an electric train slows down, its traction motors work as generators and return part of the energy back to the power system. This energy can be used by other trains or stored in energy storage systems. For example, when one train is braking and another train is accelerating nearby, the recovered energy can be transferred to the accelerating train. This reduces total electricity consumption and increases energy efficiency.

Modern railway electrification also includes the introduction of **smart substations and digital control systems**. Traditional substations only supplied electricity to trains, while modern substations can monitor voltage, current, energy consumption and system faults in real time. Digital control systems help railway operators quickly detect technical problems and prevent accidents. For example, if the voltage level decreases or a contact wire overheats, the system can automatically send a warning to the control center. Another effective method is the integration of **renewable energy sources** into railway electrification systems. Solar panels and wind power stations can be used to supply electricity to stations, depots, signaling systems and, in some cases, traction networks. This method reduces dependence on fossil fuels and supports environmentally sustainable railway development. In sunny regions, solar energy can be especially useful for powering auxiliary railway infrastructure. The use of **energy storage systems** is also becoming more important. Batteries and supercapacitors can store excess energy produced during regenerative braking or from renewable sources. Later, this stored energy can be used when trains need additional power. Energy storage systems are especially useful in areas where the electricity supply is unstable or where railway traffic is very intensive.

In addition, modern railway electrification involves the improvement of **overhead contact line systems**. New materials, stronger wires, automatic tensioning systems and weather-resistant components increase the reliability of the contact network. Modern catenary systems are designed to work safely at high speeds and under different climatic conditions. This is important because any failure in the contact line can stop train movement and cause economic losses. For

non-electrified or partially electrified railway lines, **battery-electric and hybrid trains** are considered modern alternatives. These trains can operate on electrified sections using overhead wires and continue their journey on non-electrified sections using batteries. This method reduces the need to electrify every kilometer of railway line immediately. It is especially useful for regional routes where full electrification may be expensive. Railway electrification also requires **modern maintenance and diagnostic technologies**. Special measuring trains, drones, sensors and artificial intelligence systems can be used to inspect contact lines, substations, rails and electrical equipment. These technologies help identify defects before they become serious problems. As a result, maintenance becomes more accurate, faster and less expensive.

The advantages of modern railway electrification are very significant. First, it reduces harmful emissions and improves environmental conditions. Second, it lowers operating costs because electricity is usually cheaper and more stable than diesel fuel. Third, electric trains have better acceleration and can increase the speed and capacity of railway transport. Fourth, electrification supports the development of high-speed rail and modern logistics systems. However, railway electrification also has some challenges. The initial construction cost is high because it requires substations, contact lines, signaling adaptation and power supply infrastructure. In addition, qualified specialists are needed to operate and maintain electrified railway systems. Therefore, successful electrification requires long-term planning, investment, technical training and government support.

In conclusion, modern methods of railway electrification are an essential part of sustainable transport development. The use of 25 kV AC systems, 2x25 kV autotransformer systems, regenerative braking, smart substations, renewable energy sources, energy storage technologies and digital monitoring systems makes railway transport more efficient, safe and environmentally friendly. Railway electrification not only improves the technical capacity of railways, but also contributes to economic growth and ecological stability. Therefore, the modernization of railway electrification systems should be considered one of the priority directions in the development of future transport infrastructure.

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