Stationary Hybrid Renewable Energy Systems

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The energy storage system is one of the key elements in a hybrid renewable energy system. Systems with kinetic storage, electrochemical storage batteries, supercapacitors, hydrogen energy storage are considered.

Keywords: railway electrification ; renewable energy sources ; energy storage system ; hydrogen energy

1. Introduction

To date, rail transport is one of the largest users of electricity, both in Russia and in other countries with developed and actively developing economies (USA, France, Spain, China, and a number of other countries).

According to the strategy of scientific and technical development of the JSC Russian Railways [1], the goal of the transport sector by 2030 is to reduce greenhouse gas emissions to 20% below the level of 2008, which corresponds to the Resource Efficient Europe roadmap set out in the Europe 2020 Strategy.

The commitment of the Netherlands Railways to provide all-electric trains with 100% renewable energy (RE) was achieved in 2017 ahead of schedule [2].

It is planned that by 2021, the national rail transport of India will use up to 1 GW of solar energy [3]. Work is underway on projects to create complexes of solar panels installed on roofs, which will have a total capacity of up to 500 MW. Currently, a significant number are in operation, including at 900 railway stations. Their total capacity is 100 MW. In the future, Indian Railways can use 51,000 hectares of unused land to build solar power plants (SPPs) with a total capacity of up to 20 GW. Recently, Indian Railways announced their plans to use up to 200 MW of wind energy on the railways of India by 2021. The theoretical potential of solar energy capacity at India's rail transport facilities is estimated at 266.034 GW [4].

One of the main disadvantages of RE is the instability of its generation, which leads to the inability of the power system to meet the consumer's demand at any time. A way to solve this problem is to use various energy storage devices, for example, batteries, flywheels, electric double-layer capacitors, etc. The excess of energy generated by the RE power system can be stored and then supplied back to the grid when the energy generated at a certain moment from renewable sources is not enough to meet the demand.

In addition to various physical and electrochemical storage systems, energy can be stored in the form of hydrogen produced by water electrolysis using renewable sources. When the demand for electricity arises, hydrogen is supplied to a fuel cell (FC), where electricity is generated because of the electrochemical reaction of oxygen reduction from the air with hydrogen [5][6]. According to the *Technology Roadmap—Hydrogen and Fuel Cells* by the International Energy Agency [7], by 2025, hydrogen technologies should penetrate all energy sectors, CO_2 capture technologies in hydrogen production should be improved, and the number of hydrogen storage systems suitable for integrating into energy systems based on RE sources should be increased. Thus, the importance of introducing hydrogen energy into the transport sector and, specifically, the electrification of railway transport is recognized by the world community [7].

2. Renewable Energy Systems for Railway Transport Electrification

The most used renewable energy systems (RES) are SPPs based on photovoltaic converters and wind farms. Most hybrid systems consider these types due to their greater versatility compared to other RE sources. Micro-hydro turbine power plants can also be used as an energy source. This type of RES is the most cost-effective, which was clearly demonstrated in [8][9], but the use of micro-hydro turbine power plants is strongly limited by the geographical peculiarities of the area.

Among the possible options for introducing RE sources into the electrification systems of railway transport, the following groups of design solutions can be defined by the type of RE source:

- Power generation systems based on photovoltaic converters;
- Generation systems based on wind power plants;
- Hybrid generation systems.

Depending on the region and climatic conditions of the area, it may be economically acceptable to use systems based on one energy source or a combination of several sources. According to the report [10], the use of solar energy conversion systems is relevant for countries such as India, Saudi Arabia, Egypt, and Argentina, but not for the countries of northern Europe, for example, Sweden, Norway, and Finland. At the same time, some regions with low solar radiation can use wind energy quite efficiently. As a rule, these are countries with coastal territories and highlands or states located near the Arctic Circle.

In accordance with the recommendations of the International Union of Railways [11], the following options for the location of RES at railway transport facilities can be defined, presented in **Figure 1**.

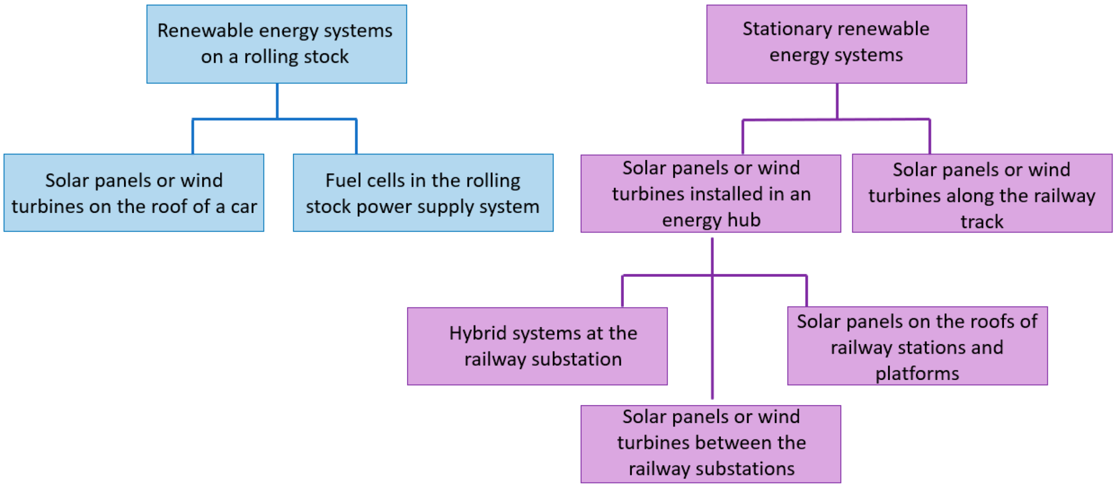

Figure 1. RE sources classification for the railway transport electrification systems.

3. Stationary Energy Storage Systems for Electrified Railways

ESSs are one of the fastest-growing sectors of the electric power industry actively implemented in various areas, including the electrification of railway transport. This is especially influenced by the recent wide development of RE sources [12]. Due to the stochastic nature of RES generation, an additional means is required to ensure a balance between the generated and consumed energy; therefore, ESS is a widely recognized part of the RES integration into any energy system. This problem is especially relevant for railway transport since the train schedule, and therefore the load on the grid, is strictly regulated. ESS in the transport sector as on-board (mobile) or stationary (wayside) systems are becoming more widespread throughout the world.

Flywheels, electric double-layer capacitors (EDLC), and electrochemical batteries are usually used in railway electrification [13].

4. Hydrogen Technologies

In a number of works devoted to ESSs, FCs are presented as such systems. However, it should be noted that these devices themselves are only capable of producing electricity, not storing it. Therefore, FCs are always used in conjunction with a hydrogen storage system, which is actually an ESS. FCs are currently the most promising and safest devices for generating electricity from hydrogen. Depending on the size and type, they can be used both in “on board” and stationary modes. FCs are notable for their noiseless operation, stability of power generation provided that hydrogen is continuously supplied, and the ability to use one device to produce heat and electricity at the same time [5]. In the case of RE power systems, electricity generated from RE is used for water electrolysis, as a result of which hydrogen is formed. Further, hydrogen is placed in storage, and in case of demand for electricity, it is supplied to the FC.

5. Conclusions

Renewable energy sources are increasingly being introduced into all sectors of the economy, and rail transport is no exception. To date, engineers from different countries have already developed and continue to develop many technical solutions based on renewable energy sources and energy storage systems to improve the efficiency and environmental friendliness of railway transport.

- The analysis of the publications allowed defining the main groups of technical solutions for the integration of renewable energy systems into the railway infrastructure. Their advantages and disadvantages were described. Examples of the implementation of these systems in various countries were given. The analysis identified the main criteria for the feasibility of using various options for renewable energy systems at the design stage.

- Various types of energy storage systems that play a key role in integrating renewable energy with rail electrification systems were also considered. A comparative analysis of the technical and economic characteristics of various types of storage devices has been carried out.

- In this review, special attention was paid to works describing the configuration of hybrid energy storage systems based on hydrogen storage, electrochemical storage batteries, and supercapacitors. Optimally selected characteristics of the storage system make it possible to compensate for the shortcomings of each individual element, providing both high-speed performance and high peak power values in the event of sudden changes in the mode, and a large capacity of stored energy, which allows using renewable energy systems with maximum efficiency.

- The analysis of publications showed that at present, the greatest interest from researchers is shown to hybrid microgrid systems, which include various generation systems based on renewable energy sources, as well as energy storage systems of various types. This option is the most effective from the standpoint of reliability and quality of power supply since it reduces the likelihood of imbalances between the generation and consumption of electrical energy caused by the variable operating mode and significant fluctuations in the output power of renewable energy systems.

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