Alternative Possibilities of Using Electric Cars in Siberia

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***Abstract* — The ever-increasing demand for electricity requires constant expansion of generation facilities capable of providing the quantity and quality of energy supplied to the consumer. The search for highly efficient and more productive technological solutions in the field of electricity production and storage through distributed generation is one of the main lines in the development of the electric power sector. In turn, the wider use of such technologies, their advancements and improvements in their quality create the need to assess the potentialities and prospects for the use of various types of electrical energy storage and the related technologies required. The paper addresses the possibility of using electric vehicles as a battery for a small solar power plant.**

Index Terms: **electric power industry, solar power plants (SPPs), renewable sources, electric vehicle, battery.**

I. Introduction

Nowadays, there is a steady upward trend in the number of private power generation facilities. A direct consequence of this is an increased interest in various storage devices that can boost the productivity and efficiency of solar power plants (SPPs). The possibility of regulating and controlling electricity consumption rates can lead to a sharp increase in prices for electricity, which may result, for example, in its unavailability for private households, which use electricity to meet most of their needs.

One should also consider the possibility of levelling tariffs with the removal of the regions with low electricity costs from their preferential position in the field of electricity supply, which will also negatively affect the private sector, which, owing to low prices, makes maximum use of electricity supply resources. The problems with gasification are also worth mentioning. For example, the Irkutsk region, being one of the main gas suppliers, does not have access to this resource and has to use electricity for heating purposes. Any changes in this area can be disastrous for most of the population [1].

One of the best solutions to smooth out possible energy shortages is self-generation, for example, with SPPs placed in the territories of private households, which will enable them to compensate for the lack of «centralized» electricity. Thus, the use of solar power plants by the private sector in most regions of Russia can not only improve the environmental situation but also help balance the consumption behavior or make it cost-effective. This solution can be very promising for the territories where tariffs currently allow the installation and operation of SPPs with a payback period of up to seven years for objects of about 100 m^2 of living space.

However, due to the vast territory of our country, the distribution of the solar energy across it varies greatly. The territories with the highest insolation indicators and relatively high daylight hours in the Russian Federation are the Republic of Buryatia and the Irkutsk Region, which theoretically allows the efficient operation of the SPP. Thus, one of the most common electricity generation solutions for private households in these areas is solar power plants.

With the insolation data taken into account when planning the infrastructure changes, a significant increase in generating capacity directly at consumers can be achieved. Analysis of potential efficiency, development and modernization of SPPs in the future may lead to an increase in their number in the region, which will reduce the negative effect of electricity generation at its constantly increasing values.

However, one of the main obstacles to commissioning solar power plants in the territory of private households is the need to store electricity due to the variability of solar insolation.

Problems arise in the energy storage technology due to the uneven energy reaching the solar panels. Therefore, solar panels are used either in conjunction with energy

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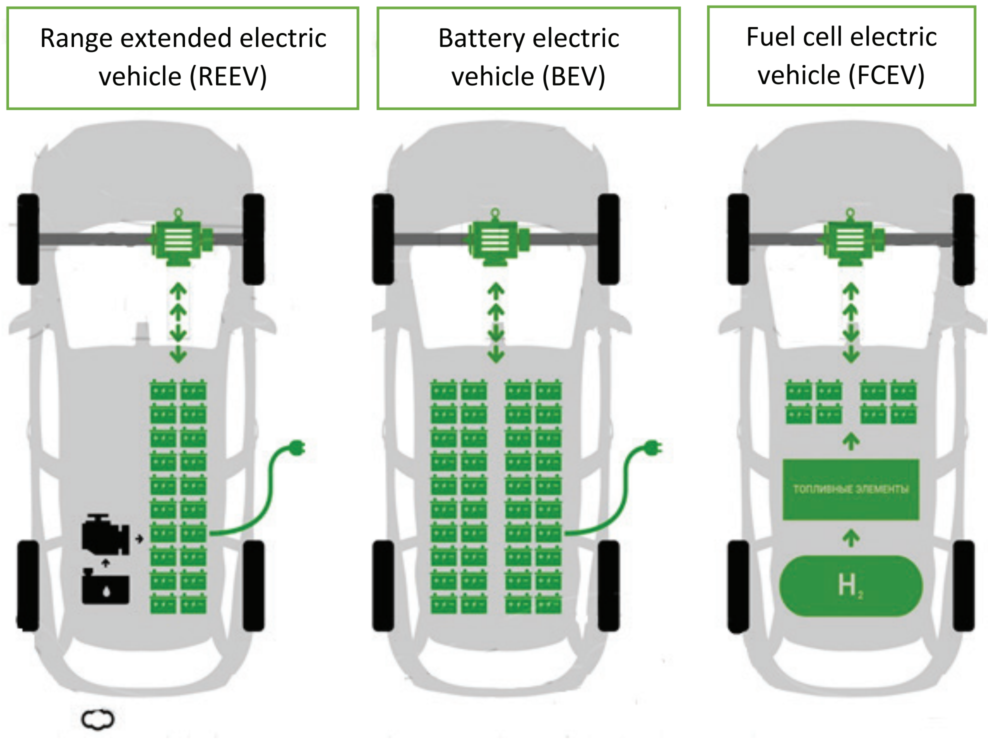


Fig.1 Types of electric vehicles.

storage or as an additional source of power supply for the main power plant.

II. Electric vehicles and their characteristics

In parallel with the ever-growing interest in various renewable energy sources, the demand for more environmentally and cost-effective modes of transport is increasing. Such types of transport include hybrid cars or electric vehicles, which are completely independent of traditional fuels and use electricity as the main energy resource for movement. The storage system of electric vehicles can be used for the accumulation and storage of electric energy in the sector of private households.

The mass use of electric vehicles, due to the need to resolve the environmental issues in large cities by reducing the harmful emissions from vehicles, could contribute to coping with the night-time dips in the electrical load curves.

Currently, the automotive industry tends to switch from internal combustion engines (ICE) to an electric motor. In October 2016, the German Bundesrat adopted a resolution banning the production of cars with internal combustion engines from 2030 [8]. Such a ban is also discussed in Norway and the Netherlands. This initiative can change the attitude of the world to harmful emissions and reduce the greenhouse effect in the future. In this regard, the development of ground electric transport and the use of cars with an electric motor instead of an internal combustion engine are relevant issues.

Therefore, the improvement in the battery charging process in ground electrically driven vehicles is relevant. Currently, there are six main engine systems:

1. A gasoline car runs on the fuel burnt in an internal combustion engine, which is followed by conversion of chemical energy into mechanical energy, which makes the car move.
2. A hybrid electric vehicle (HEV) operates using an electric motor powered by batteries in parallel with a gasoline engine receiving fuel from the gas tank. Batteries cannot be charged from external sources, and the mileage of a car using electric traction is extremely limited.
3. A plug-in hybrid electric vehicle (PHEV) has several types:

- Parallel PHEV, which combines the operation of electric and gasoline engines, allowing battery charging from the grid and traveling a sufficiently long distance with electric traction motor solely.
- Series-parallel PHEV, which is capable of operating either as a series or a parallel hybrid vehicle with an electric motor being the main drive.

4. Range-extended electric vehicle (REEV) known as series HEV with all the motive power provided by an electric motor, but with a small ICE present to generate additional electric power. The battery of this type of cars can be charged from the power grid.
5. Battery electric vehicle (BEV) is driven by an electric motor, which is powered by the energy of rechargeable batteries charged from external energy sources.

Table 1. Technical characteristics of batteries for leading manufacturers

Make/Model	Technical specifications				
	Number of charge cycles	Power reserve, km	Battery capacity, kWh	Maximum speed, km/h	Engine power, hp
Tesla Model *	10 000/15 000	644	100	267	362
Nissan LEAF E	5 500	550	60	156	217
Renault Megane E-Tech Electric	6 000	450	60	160	218
Ford Mustang Mach-E	8 500	450	75.7	180	258

* averaged data on Tesla models developed in 2016-2021 (100D, P100D, Performance, Long Range Plus, and Plaid).

6. Fuel cell electric vehicle (FCEV) converts hydrogen into electrical energy, which makes the car move. This happens in a stack of fuel cells, each of which is an electrochemical generator inside which a reaction occurs in which hydrogen is oxidized and generates energy. The electric energy produced feeds the electric motor and other systems of the car, and the battery pack is charged through regenerative braking.

For a long time, the development of electric vehicle transport has been hindered by the lack of suitable batteries (cheap, reliable, capacious, and environmentally friendly). Widespread sulfuric acid batteries, having a large mass, reduce the payload capacity of an electric vehicle, and an increase in their production and the need for recycling increases the environmental impact.

The weakest link is the number of charge/discharge cycles of electric vehicle batteries. This is due to their limited resource and increased charge/discharge-related load compared to the normal mode of operation.

Therefore, to assess the possibilities of battery charge/discharge cycles, a sample of the newest models of the major representatives of the electric car manufacturers (Tesla, Nissan, Renault, and Ford) was considered. These automakers conduct numerous studies on the development areas and innovative technologies, which contribute to the development of the automotive industry.

The main criterion for selecting the models of electric vehicles was the use of the battery as the main source of energy. For the selected models (Table 1), the technical characteristics and features of the charge system operation were analyzed [2-5].

A distinctive feature of the Tesla Model * electric car is a relatively large battery capacity, thanks to which it has a maximum power reserve. This is a significant competitive advantage because the main disadvantage of electric cars is their long charging time and small power reserve.

The Nissan Leaf is built on the new Nissan V platform, which is also used in the Juke crossover and the subcompact Micra 2011. An electric motor with a capacity of 80 kW (about 109 hp) and a torque reaching 280 Nm is located under the hood.

The electric vehicle has a front-drive wheel. The low location of the heaviest component (the battery) of the car provides better stability compared to traditional cars of this class. In addition, the battery also ensures higher structural rigidity for five-door hatchbacks of such a design.

A full cycle of charging batteries from a utility grid with a voltage of 220 V and a current of 12 A lasts about 9 hours. A special Nissan charger replenishes 80% of battery's charge (480 V — 125 A) in 30 minutes. The car can be equipped with two sockets for chargers in the front of the car: one for standard and the other for accelerated charging [6].

Currently, batteries are assembled at Nissan's facilities in Japan producing annually about 65 thousand sets. In 2012, as part of its project to start mass production of electric vehicles, Nissan opened a battery plant in Smyrna (Tennessee, USA) with a design capacity of 200 thousand sets per year.

Most cars, even hybrids, generate tons of CO_2 emissions every year. The Nissan Leaf is a fully electric car producing no harmful exhaust emissions. This electric car is not designed for long trips, but it has proven itself to be efficient in a megalopolis. Nissan has developed its application for mobile telecommunications devices, which finds the nearest charging station and filters out the stations that are already occupied or have high-power DC charging devices.

The next electric car included in the sample is the Renault KANGOO Z. E. This model was created mainly for the business environment. Several types of cargo bay partitions make it easy to transport loads of various sizes.

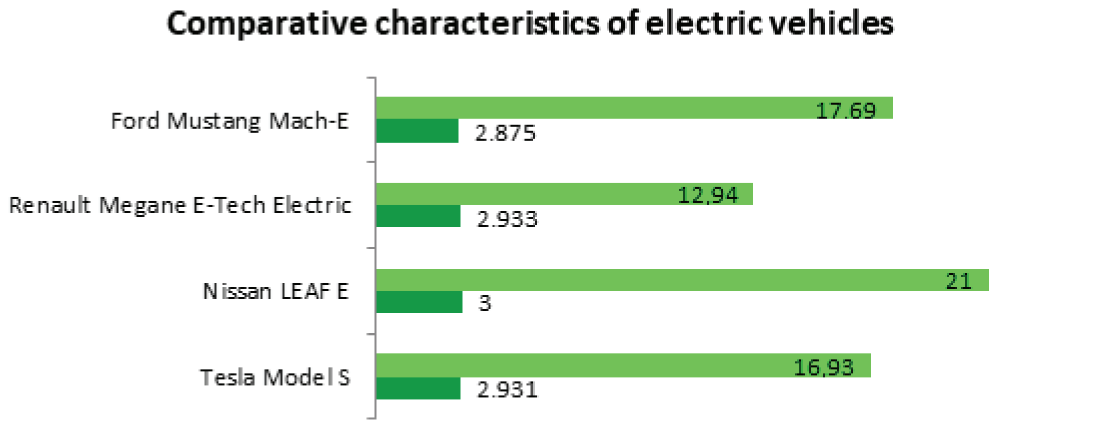
A distinctive feature of Renault is the «Chameleon» smart charging system, which allows charging the car from sockets of any power.

Ford Focus Electric was chosen as the latest model to be analyzed. The electric car is distinguished by its reliability and practicality. Ford prefers to use a battery with active liquid cooling and heating, which ensures stable battery operation over a wide range of temperatures.

The electric vehicle can be recharged from a DC power source at a voltage of 120 V, 240 V. The model is equipped with a 6.6 kW charger, which allows charging an electric car faster than the main competitor, Nissan Leaf. With the DC used, the charging power can reach up to 50 kW [5].

Nissan Leaf 2020 is the most popular electric car in Russia. It was chosen by 83% of Russian electric motorists. To date, the number of the cars used in Russia is 5.2 thousand.

The analysis focused on electric vehicles with the best characteristics, which were selected from different segments. Since electric car models are in different price



	Tesla Model S	Nissan LEAF E	Renault Megane E-Tech Electric	Ford Mustang Mach-E
Electricity consumption per 100 km, kWh	16.93	21	12.94	17.69
AB charge rate, kW/h	2.931	3	2.933	2.875

Fig.2 Comparative characteristics of electric vehicles from different segments.
The analysis of the diagram presented in Fig. 1 suggests the following conclusions:
- ***the most economical electric car is Renault KANGOO Z. E.;***
- ***the electric car with the highest charge rate is Nissan Leaf;***
- ***the electric car with a maximum battery capacity is Tesla S 85.***

categories and are designed for different tasks, comparison by absolute values of indicators cannot be objective. To ensure the objectivity and visibility of the study, a system of generalized relative indicators was proposed (Fig. 1). The following main indicators were considered for comparison:
- electricity consumption per 100 km in [kWh];
- battery charge rate in [kW/h].

The expansion of a set of tariffs and services mutually provided by the energy system and consumers requires the specialized recording equipment, i.e., advanced technologies for metering electricity consumption. Apart from the stricter requirements for metering devices, requirements are also increasing for systems for collecting, transmitting, and processing information obtained with their help (speed, accuracy, visualization, etc.). Technologically, the process of load management is in many ways akin to modern technologies providing communication services. It also requires consideration and establishment of tariffs for the minimum possible time intervals, instant information exchange between its participants (subscribers) and the availability of opportunities to provide related services in terms of the main objectives.

In general, the serial electric car of the future is a direct analogue of a modern city car, i.e., a comfortable vehicle with an average engine power of about 50 kW and a price of about USD 15 thousand or RUR 450 thousand (exchange rate of October 2021). The unit cost of power of the electrical vehicle will be about RUR 9 thousand/kW (USD 0.3 thousand/kW). The mass introduction of electric vehicles will be facilitated by such factors as the price of fuel for internal combustion engines and the environmental situation in places of compact and crowded residence. This suggests that autonomous electric transport will be recognized and widely developed and, possibly, by 2030, will account for a significant part of the total vehicle fleet.

Based on the studies of the technical characteristics of modern electric vehicles and their batteries, we will consider the theoretical possibility of their introduction and use as intermediate storage devices for SPPs in Siberia.

III. Alternative ways of using electric vehicle batteries

Solar power plants (SPPs) can be considered the most promising and evolving energy source in the territory of Siberia. This renewable source has several advantages. One of them is environmental safety at the place of generation, which is an important factor when choosing this type of generation from all possible renewable energy sources currently on the market. Geographical location and climatic features also play an important role when choosing a source of generation. The picture of the solar energy distribution is very diverse due to the vast territory of our country. The areas with the highest insolation indicators and relatively high daylight hours in the Russian Federation are the Republic of Buryatia and the Irkutsk Region, which implies efficient operation of the solar power plants here.

Thus, due to the favorable geographical location, the sunshine duration in the area at issue is 2000-2400 hours per year and the solar radiation intensity varies from 4 to

Table 2. Daily energy consumption in the household.

Power consumer	Quantity	Power, W	Operating time	Electricity consumption, kWh/day	Daily consumption total, kWh
Energy-saving bulbs	20	15	6	1.8	1.8 (1%)
Electric stove	1	8000	2	16	19.8 (9%)
Refrigerator	1	350	6	2.1	
Kettle	1	1500	0.4	0.6	
Microwave	1	1500	0.2	0.3	
Kitchen appliances	1	1600	0.5	0.8	
TV	1	100	5	0,5	5.85 (2%)
Computer	1	250	5	1.25	
Iron	1	2400	0.143	0.34	
Washer	1	1500	0.215	0.32	
Vacuum cleaner	1	2000	0.07	0.14	
Charging the phone	1	300	8	2.4	
Hairdryer / electric shaver	1	1800	0.5	0.9	
Electric boiler	1	8500	24	204	204.6 (88%)
Circulation pump	1	50	12	0.6	
Total volume per day	232.05 (100%)				

4.5 kWh/m2 a day.

Given the received insolation data when planning the infrastructure changes in construction and electricity generation, a significant increase in generation capacity for consumers or in so-called distributed generation can be achieved. Analysis of potential efficiency, development, and modernization of SPPs in the future may lead to an increase in their number in the region, which will reduce the negative effect of electricity generation at its constantly growing values.

After analyzing the insolation data obtained from publicly available sources, an abstract electricity consumer was taken as a basis for the research to theoretically design and calculate the number of necessary SPPs in the selected area and possible power to be generated from them.

A household with an area of 100 m2 was taken as a calculation unit, which was determined based on the ever-growing demand for residential facilities in the private sector. The calculation of the electricity consumed considered both the minimum required set of electrical appliances used by an electricity consumer and their approximate operating time (Table 2). The study relied on the averaged values considering the changes in the consumption depending on the change of the season. The electricity consumed to boil water and heat the room, as well as the operating time of electrical appliances are also taken into account.

The total daily volume of electricity consumed by a household with an area of 100 m2 is approximately 232.05 kWh, of which 204.6 kWh is used for the needs of the boiler and pump. The electricity consumption for household needs amounted to 25.65 kWh, and about 1.8 kWh of electrical energy was used for lighting. Thus, when using an electric vehicle as a backup battery device, some household needs can be covered or EV power reserve can be used as a power source in case of emergency disconnection of the main battery.

The highest load values are associated with the operation of the boiler. This load requires the investment in storage and is a variable value depending on the season. The load corresponding to lighting and household needs, being a relatively constant, is flexible and is most subject to modernization through the introduction of SPPs.

The conducted studies confirm once again that it is impossible to fully provide the household with electrical energy from a SPP without using a battery. Since the average vehicle is not used around the clock and not every day, electric cars can be used as a backup storage device capable of supplying power at least for lighting and some other household needs, and even for some household electrical appliances, under optimal operating conditions of SPP panels and rational and economical energy use.

The main parameter, which affects how the planned loads are covered, is the solar panel capacity to be chosen. Thus, the calculation used the average amount of electricity generated for the Irkutsk region and the Republic of Buryatia, considering the choice of three different solar panels with the same coverage area of 10 m2. When installing solar panels at an optimal angle for the area or models of the panels that adjust the tilt angle automatically, it is possible to fully cover the electricity used for lighting or even have more electricity than the lighting needs. Thus,

Table 3. Data on power generation for solar panels of various capacities.

Solar battery SilaSolar, W	250	350	450
January	4.02	4.69	6.03
February	5.67	6.62	8.51
March	7.68	8.96	11.52
April	7.59	8.86	11.39
May	7.28	8.49	10.98
June	6.75	7.88	10.13
July	6.34	7.15	9.20
August	5.99	6.98	8.98
September	5.84	6.81	8.75
October	5.07	5.92	7.61
November	3.92	4.57	5.87
December	3.30	3.85	4.95
Average annual electricity generation, kWh/day	5.77	6.73	8.65
Total electricity generation per year of operation, kWh	2 104.44	2 455.18	3 156.66

it can be assumed that the panel with the highest calculated output will generate electricity to cover not only the lighting needs, but also the load of some electrical appliances. The calculation data are shown in Table 3.

The values obtained from [7] were used to calculate and obtain the predicted values of the required additional generating capacities.

The calculation results included the values of the total amount of electricity consumed, the amount of electricity consumed for lighting needs, and their overall annual values.

One of the main conclusions of this study is that the proposed solution to the problems may be partial replenishment of electricity from renewable resources, which will mitigate the economic and environmental situation. SPP as a source of additional generating capacity, used to partially meet the needs of private sector, can become one of the promising and efficient solutions. Despite the low electricity tariffs in the Irkutsk region and the Republic of Buryatia, their territories are favorable for the introduction of SPPs due to their geographical location.

When determining the effectiveness of load management, one should avoid its direct opposition with the increase in generating capacity and consider both of these measures as a reasonable and balanced complement to each other. The construction of new generating capacities and load management, when considered jointly, allow:

optimizing the degree of loading, extending the service life of the existing generating and power grid equipment, and reducing the construction costs of new one;

- optimizing the energy equipment repair schedules;
- reducing the cost of maintaining inefficiently loaded generating capacities in good operational condition;
- optimizing the number of production personnel;
- increasing the stability of the electric power system in the case of external disturbances and accidents;
- allocating funds for technical re-equipment of the electric power industry instead of forcibly applied half–measures (upgrades and repairs).

In the event of a change in the initial prerequisites or economic situation, the timely application of load management can reduce the risks of investment in the development of the electric power industry. This is because the optimization of power consumption schedules due to the capabilities of consumers reduces the likelihood of a shortage or lack of demand for newly introduced power capacities in case of unexpected, relative to forecast, changes in power consumption.

Conclusion

The analysis of the capabilities and characteristics of the updated models of electric vehicles from several largest manufacturers and calculations made for a private household, whose energy needs are fully or partially met with the help of solar electric panels suggest the conclusion that it is advisable to use an electric vehicle storage system as an additional or backup battery. The energy stored in this way will be enough to meet the needs of lighting. The ever-growing competition between manufacturers of electric vehicles accelerates the development of methods for increasing the capacitance characteristics of batteries, engine power, charge rate and mechanism, power reserve, and the number of charging cycles. There are very few studies in this area in our country at present, which makes it more difficult to incorporate modifications into existing projects or those under development.

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