Charging stations for electric cars using hybrid energy storage systems

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Abstract. In this article, it is proposed to use energy storage devices as a part of charging stations to reduce the powerful load for the power system during the hours of the greatest energy consumption. This is due to the analysis results for the growth trends of the electric vehicles. By the example of the city Novosibirsk, according to the forecasts of analytical companies about the trend of increasing the number of electric cars (ECs) in Russia, the average energy consumption per day for charging ECs has been calculated. Based on the calculation results, the influence of charging stations on the daily schedule of the active load for the industrial power grid is shown and the capacity lack problem is identified. The experimental measurements results at traction substation No. 29 in Novosibirsk are presented.

1. Introduction

In Russia, the development of electric cars is becoming noticeable: their purchased number has been growing annually. According to the innovative development scenario laid down in the Transport Strategy of the Russian Federation, the share of hybrid and all-electric cars can reach 30% by 2030.

Electric cars from several hundred to several thousand will be operated in each region of the country in the future for several years according to forecast estimates and a large share of their fleet will inevitably be concentrated in the regional centers. In order to stimulate the intensive growth of this industrial segment and energy markets, proactive measures are needed increasing its attractiveness to the consumer with minimal investment in infrastructure. Of course, one of the key factors influencing the decision to purchase an electric car is the availability of charging stations. The presence of specialized charging stations becomes especially important in the conditions of Russian cities, where the high density of multi-storey residential and household buildings does not allow connecting chargeable electric cars directly to household networks. It is worth noting that the charging stations are designed to be connected to AC networks (single-phase with a voltage of 220V or three-phase with a voltage of 380V).

Energy companies can deploy more local solutions, such as co-locating an energy-storage unit with the transformer that charges the unit during times of low demand. The storage unit then discharges at times of peak demand, thus reducing the peak load. Several factors can drive the business case for installing energy storage. These include shaving peak loads to reduce demand charges (extra fees based on peak loads) and avoid grid upgrades as well as taking advantage of lower power prices at certain times (by charging the battery when energy prices are low). Energy users can also potentially
seek compensation for offering flexible services. As the cost of batteries continues to decline rapidly, using energy storage to smooth load profiles will become increasingly attractive.

Thus, the electric car market analysis in Russia with the forecast for the next 5 years is proposed and to calculate the capacity spent on charging individual electric cars. It is necessary to consider one of the solutions to the capacity lack problem, to create a topology of the hybrid charging system for electric cars with energy storage devices.

2. The Infrastructure Development Problem
Currently, there is a growing trend in the number of individual and public types of electric vehicles. According to the analytical company Canalys [1], global sales of electric vehicles in 2020 increased by 39% compared to 2019 and reached 3.24 million units of electric cars. Electric car sales will continue to grow throughout the decade. Canalys predicts that electric cars will account for about 34 million units, or 48% of all new automobiles sold in 2030, as shown in Fig. 1.

In Russia, the market for electric cars is not as developed as in the rest of the world. Still, the number of electric cars is increasing significantly every year. For example, in January 1th, 2021, 10,836 passenger electric cars were registered in Russia. 83% of all electric cars in the country account for one model—the Nissan Leaf. In Russia, there are just over 9 thousand copies of this model. It is also worth noting that about 60% of electric vehicles are registered in the Far East and Siberia, in particular in the city Novosibirsk. In total, there are 18 models of 14 different brands in the Russian fleet of electric cars [2]. Over the past year, the volume of this fleet has grown by 71%, which was facilitated by the abolition of import duties on electric vehicles for the countries of the Customs Union.

![Figure 1. Worldwide electric vehicle sales [1]](image1)

![Figure 2. Number of electric cars registered in Russia](image2)
According to the forecast of PricewaterhouseCoopers [3], the average annual growth rate of the electric car market in Russia can reach 30%, which is equivalent to sales growth from 2.6 thousand units to 17 thousand units throughout the Russian Federation. This forecast corresponds to an optimistic scenario for the electric car market development and is shown in Fig. 3. It is assumed that Russia will take into account international experience and will provide state support.

As an example, we will estimate the amount of required capacity for electric car charging stations, taking into account the existing trends of increasing the number of electric vehicles in the city Novosibirsk.

In Novosibirsk, at the beginning of 2021, 330 electric vehicles were registered. According to the forecast of “PricewaterhouseCoopers” in 2025 [2, 3], the number of electric cars will be:

\[
N_{2025} = N_{2020} + n \cdot (1,3 + 1,3^2 + 1,3^3 + 1,3^4 + 1,3^5) = 1858
\]

where \(N_{2020}=330\) is the total number of electric cars in the city Novosibirsk by the end of 2020; \(n=130\) – the number of purchased electric cars in Novosibirsk in 2020.

According to the website "Cenamashin", the average car mileage for a year in the city Novosibirsk is 11305 km [4]. Therefore, the average daily mileage of the car is \(L_{av,d}=30\) km.

Since the Nissan Leaf makes up about 90% of the electric car fleet in the city Novosibirsk, the characteristics of this electric car were taken as the basis for the calculation. From the average daily mileage, the energy consumption of the Nissan Leaf, with a battery capacity of \(Q_{24}=24\) kWh and a range of \(L=160\) km, per day is:

\[
A_{av,d} = \frac{L_{av,d} \cdot Q_{24}}{L} = 4.48 \text{ kWh}.
\]

There are several battery capacities available on the market as part of the Nissan Leaf: 24 kWh, 30 kWh, 40 kWh and 62 kWh. According to formula (2), similar calculations were made for the remaining battery capacities with a range of 160 km, 172 km, 243 km and 364 km, respectively. The average power consumption of the Nissan Leaf per day is calculated:

\[
A_{av,d} = 5 \text{ kWh}.
\]

The average energy consumption per day for charging electric cars in the city Novosibirsk in 2020 is:

\[
A_{2020} = N_{2020} \cdot A_{av,d} = 1624 \text{ kWh}.
\]

By 2025, the average energy consumption per day for charging electric vehicles in the city Novosibirsk will be:

\[
A_{2025} = 1866 \cdot 5 = 9183 \text{ kWh}.
\]
In the future, the growth in sales of electric cars will be due to the infrastructure development, in particular, charging stations. By the end of 2019, there were about 7.3 million charging points in the world (6.5 million frequent), where public chargers increased by 60% in 2019 [5].

Currently, there are 3 types of charging stations for electric vehicles in the world: ultra-fast stations, fast stations and slow stations. The slow ones are designed for power up to 3 kW and there are some models that can produce 6 kW. Fast charging stations deliver single- or three-phase alternating current to the electric car. They come with the power of 7-22 kW. The ultra-fast stations group includes both DC and AC charging stations. There are three large groups: DC charging stations with the power of 50 kW (62.5 kW); AC charging stations with the power of 43 kW; DC charging station with the power of 120 kW. The class of ultra-fast charging stations is rapidly developing and it is expected to increase the power of the stations next 3-5 years, firstly to 150 kW and then to 350 kW, which will significantly reduce the total charging time [6, 7].

Figure 4 shows the experimental measurements results has been carried out at the existing traction substations of UEV city Novosibirsk using the FLUKE 1760 electric power quality indicator recorder.
Soon the cities will face with the lack capacity problem. As a rule, to increase capacity, it is necessary to carry out the expensive upgrade of the network and substations. Now, one of the most important areas of energy development is to increase the energy efficiency of the consumer and it is more correct to contribute to this direction of development. Therefore, the stationary energy storage installation in the charging station can solve this problem.

3. The Power Supply System

There is a positive experience of integrating rechargeable batteries (RB) together with double-layer capacitors (DLC). The obtained results of measurements and calculations allow us to evaluate the efficiency of working with double-layer capacitors (DLC) in the process of starting the starter electric motor of shunting diesel locomotive of the «TEM-2» model together with batteries (RB). When using batteries (RB) and capacitors (DLC), it was possible to reduce the peak loads on the batteries [12].

The solution of the identified problem should be carried out with new capacities, taking into account the positive world experience. And here the projects of distributed power systems consisting of various types of energy sources and energy storage are of considerable interest [8, 9, 10]. Wood Mackenzie’s latest report shows global energy storage capacity that could grow at a compound annual growth rate (CAGR) of 31%, recording 741 gigawatt-hours (GWh) of cumulative capacity by 2030.

![Figure 6. Cumulative global energy storage deployments](image)

Taking into account the real nature of the instantaneous current values in the network [11, 12] and the results of studies on the degradation rate of lithium batteries [13], it seems appropriate to use the hybrid storage unit based on lithium batteries and capacitors. The use of the hybrid energy storage unit will ensure the quality of voltage in power supply systems, as shown in Fig. 7, by compensating for peak loads and will increase the controllability, reliability and efficiency for the operation of storage systems.

![Figure 7. Regular daily active load schedule with the use of energy storage at charging stations](image)
4. Results and Discussion
Experimental measurements have been carried out at the existing traction substations in Novosibirsk, temporary peaks that revealed the maximum power. With the intensive electric vehicles development, these peaks will be even higher. One of the solutions to the problem is the installation of hybrid energy storage devices as a part of charging stations.

There are two possible directions for the development of the charging station:

a) 3x380 system. Joint work of the energy storage system and the power supply system to meet the power demand for fast (high-power) charging stations;

b) traction power supply system for city electric transport. Based on the performed investigations of the electro-technical complex department we argued that the increase in the constant component of the load power and the decrease in its "unevenness" will favorably affect the energy performance of traction substation units.

In view of this, it is relevant to assess the potential technical and economic effects when using energy storage of different types in charging stations and with a different combination of their properties (hybrid storage power plant).

One of the solutions to reduce the need for cities to introduce new capacity into the energy system is to install energy storage units in charging stations. This will not only provide the necessary energy when charging electric vehicles during peak hours of the power grid, but also provide load balancing in the contact network for urban electric transport. The example of the electric filling station structure with the energy storage system is shown in Fig. 8.

The presented structure of the charging station assumes a separate location of connection points for electric cars for charging and power converters. Each charging cabinet has bi-directional power converters to provide power to 2-4 charging terminals and exchange energy between the energy storage system and the grid. Charging terminals include only the charging cable and protective devices.

The charging station can be connected to the AC network, as shown in Figure 6, and to the power supply system of urban electric transport.

5. Conclusion
It should be noted that the growth rate of the number of electric cars is significantly limited by the infrastructure development and given the wide availability for charging points. The forecast indicators may change significantly. In this case, an avalanche-like process of increasing the number of individual electric cars is possible. According to the forecasts of one of the companies that produce charging stations in Russia, if the planned infrastructure development is achieved, the average annual growth rate of the electric car market in Russia can reach 50%. This is equivalent to an increase in sales from 2.6 thousand units for 2020, up to 94.2 thousand units for 2025 on the entire territory of the
Russian Federation. In addition, it is necessary to take into account the municipal plans for purchasing passenger electric buses.

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