The use of vehicle-to-grid technology for the integration of electric vehicles in the power system of the city

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Abstract. This paper analyzes the possibility of using electric vehicles as a controlled distributed generator. Aggregation of demand and supply for electric power with the participation of batteries allows us to solve the problem of the development of the electric grid infrastructure of megacities. The absence in some areas of the city of opportunities for technological connection of consumers and significant deterioration of the network infrastructure is solved by the integration of electric vehicles in the city’s power system. The article shows that information technology allows you to control the energy curve over time. At the same time, the power schedule in the loaded power centers will be deprived of pronounced highs and lows, which favorably affects the loading of generating capacities. Informatization of electric transport and the use of a digital platform will eventually become part of the concept of "smart city".

1. Introduction

The problem of overloaded networks has received considerable attention in the research of scientists since the electric grid complex of large cities is significantly worn out [1-3]. The global challenge of urbanization and the migration of people to cities is becoming a problem for the entire global community. Modern industrialization trends, the introduction of digital technologies and the growth of the population of large cities by 2.5 billion people by 2040 will cause an increase in electricity demand by 50% compared with 2017 [1, 6]. The transition to information technology will improve efficiency in those areas of life where a certain limit has already been reached and a further increase in operational efficiency is a complex task [3, 4]. Energy refers to such areas. Power processes and new information technologies will improve the efficiency and stability of energy systems in large cities [6].

In this work there is the research of a possibility of use of electric vehicles for the purpose of elimination of one of the main power problems – problems of the overloaded networks. In the research the following technologies were used: Smart Charging, Smart Grid, digital «doubles», Demand Response, blockchain, machine learning, neural networks, Big Data, Vehicle-to-Grid.

Today modern technologies of the industrial Internet of things (Industrial Internet of Things, IIoT) and the Comprehensive Internet (Intenet of Everything, IoE) is one of the most discussed trends in the world [7, 8]. Things of new generation (smarts things – clever things) will be not only clever, but also integrated into the network, they will be able to interact with each other or with the external environment [9, 10].

The main idea lays in the organization of the computer network of real physical objects: cars, electric engines, unmanned aerial vehicles, robotic knots, "smart counters", etc. The number of the connected
devices exponential increases. IBM, Gartner, Cisco, Siemens predict 50 billion connected devices till 2020. Examples of introduction of IoT in an initiative both the state, and business are known. For example, with the state support in the countries of the European Union, South Korea, China and India technologies of "the smart city" which allow to increase management efficiency, consumption of energy and traffic flows take root [11-14].

In the territory of St. Petersburg and the Leningrad region, the generation capacity in certain periods exceeds the power consumption by 3,000 MW. After putting into operation LNPP-2, the capacity of which is 4680 MW under the project, the situation with the discrepancy of generation and consumption capacities may worsen. At the same time, most power centers in the city are overloaded and it is not possible to connect new consumers to them. Introduction of the provided decision will allow one to minimize a divergence between the developed power and consumed, to smooth differences between power consumption in certain timepoints and also, will allow one to lift without construction of the new network infrastructure and expansion existing to avoid limits for technical connection of some closed power supplies in the territory of the megalopolis [14].

![Figure 1. Daily diagram of generation and consumption according to the system operator of the unified energy system.](image)

Having developed and applied this sort of technology, we will be able to organize in the future similar implementation of innovative technologies of intellectual networks at first in the large cities. Integration into the system of the smart city will lead to increase in efficiency of power production, and, of course, to improvement of an economic component of this process [15-17].

2. The problem of overloaded grids

Owners of construction companies who are building residential or commercial complexes are faced with the problem of lack of capacity for technological connection. Lack of power for technological connection is the root of the problem of overloaded networks in large cities [18, 19]. The similar example can be given from any sort by a production object or other large consumers.

Specifically in St. Petersburg and the Leningrad region there are many areas where it is impossible to build new residential complexes or accommodate large consumers. Some feeding substations are only entered into network infrastructure and only to cover the current requirements, but not to expand the horizons for future buildings.

Construction of new, and reconstruction of existing power centers in the city does not allow to keep
up with the growing demand for electricity consumption by the population. The study examined areas of the city where there is a local shortage of additional capacity for technological connection. It is planned to equip parking stations with charging stations that are sufficiently filled during the working day. Also, based on data from the Yandex.Probki and Yandex.Maps service, an analysis was made of the migration of road transport throughout the day, areas of the city were identified, in which large concentrations of vehicles were recorded. Thus, “favorite” places of motorists were designated and, obviously, charging stations should be located in these places. It should be noted that on weekends the geography of the movement of cars varies slightly, other "favorite" places are added including local supermarkets, shopping and entertainment centers.

In this section there was a review and the analysis of the districts of St. Petersburg where connection of large consumers is impossible. Let us go from the Southwest, to the city centre and on the Northwest.

![Figure 2. Distribution map of overloaded catering centers in St. Petersburg during the morning maximum.](image)

3. Solution based on Vehicle-to-grid technology

To charge electric vehicle batteries, alternating (single or three phase) and direct current are used. The AC network is generally available, but for recharging it is necessary to straighten it and lower the voltage to the voltage of the electrical vehicle electrical system [20-22]. Rectifying devices are bulky, heat up during operation, requiring additional cooling. Therefore, their power has to be limited. The low power of such chargers significantly increases the charging time.

In the world there are many private companies that produce special charging stations for electric cars. An important function is “Fast Charging”, which can charge your car for 60–80% within 0.5–2 hours, approximately 90% of the stations have this function.

Vehicle-to-grid (further V2G) is the concept of bilateral use of electric vehicles and hybrids meaning connection of the car in the general power network for recharge of the car and return of the excess electric power back. Owners of cars with V2G technology will have an opportunity to sell the electric power to power engineering specialists in hours when the car is not used, and to load the car in hours when the electric power is cheaper since in many countries the price of the electric power depends on time of day. For example, the Nuvve company is a supplier of the platform which controls an energy stream. The platform which is initially developed at the University of the State of Delaware optimizes the power available to the network.
Denmark example shows that this technology works (the large companies are ready to cooperate and introduce this decision) and the fact that it can be realized also in the form of the commercial project. In the USA the V2G-technology is realized by the GOOGLE Company together with the America government.

For a full-fledged “connection” of an electric vehicle and its integration into the city’s power system, consistent steps are needed:

- On the basis of in-depth analysis of the movements of cars, places of accumulation of cars and zones of overloaded power centers, to identify the most suitable places for building wired (classical gas stations and V2G charging stations), wireless (based on magnetic resonance communication and self-induction) charge of the electric car in motion.

- To implement a cloud platform (fig. 3) based on the “Internet of things” technology to organize the management and interaction of electric vehicles with each other, the energy system of St. Petersburg and the Leningrad region, owners of charging stations and other interested participants.

- To develop algorithmic support for analyzing the state of batteries in order to ensure the safety of operation in the charge-discharge system at filling stations. The algorithm will analyze a group of batteries and manage them at the gas station. Since the machine itself already has a program on board that analyzes the state of the battery, our algorithms go on top of this, they collect statistics, interrogate the onboard systems, and actually need to know about the state of the battery before it gets to the gas station. The fueling algorithm sends a request for a level up, another algorithm is even higher into a common base, where there is information about how an electric vehicle was charged, when, where, how many years it has been running. We need this information to compare and select from a variety of such batteries in the parking lot.

- To create social and incentive programs to promote the widespread use of electric cars.

- To develop the structure and launching a mobile application to interact with the cloud platform, which will implement information and control exchange between platform participants.

Figure 3. The concept of a cloud platform for the integration of electric vehicles in the cyber-physical system "smart city".
Discharging and charging of car batteries will have a detrimental effect on batteries. That is why a control program is needed that will automatically analyze the batteries available for use in demand management and make conclusions whether the battery is capable of operating in this mode. At the same time, electric vehicles with batteries, whose residual life is in a certain range, are excluded from the possibility of participating in demand management.

4. Location of charging stations

The introduction of technology is successful, and it is necessary to work on geographic location of charging sets competently. A main objective of this section will be the analysis of readiness of city infrastructure for development of V2G technology. The card of approximate location of large filling stations / parkings will become result of work.

For assessment we will use hereinafter the following basic data: week day, 30 kW charging sets, average power capacity of batteries of the electric vehicle of 23.63 kWh. Thus, we receive that the total number of parking spaces 825, from them 363 places (44%) are filled. And if all these cars were connected to charging sets with V2G technology, then the peak generating station would turn out on 10.89 MW. The volume of available energy (provided that all cars are loaded by 100%) is equal. Approximately, it is worth increasing the value by decreasing coefficient, there is 3431.1 kWh of available energy. For comparison, consumption of the one room apartment for day of 6.67 kWh, the office for 100 people per day "will burn" about 338 kWh. It is easy to notice, that the attitude of number of cars towards available energy and also the relation of number of cars to peak generating loading is identical (linear dependence) and therefore for simplification of calculations we will use the following formula:

\[ W = C \cdot N \cdot \alpha, \]

where \( W \) is the volume of available energy (the confidant to real conditions), \([W] = \text{kWh}\); \( C \) - the average power capacity of rechargeable batteries, \([C] = \text{kWh}\); \( N \) - total number of cars in this or that process area. The coefficient \( \alpha \) is responsible for the average level of a charge of the car, during connection to the charging set.

By results of the subsequent calculations of the table for process areas (the process area includes several areas) of the cities of St. Petersburg was made.

**Table 1.** Approximate data

| Technological zone        | Approximate number of parking places | Peak power generating station, MW | Peak power generating station, kW*h |
|---------------------------|--------------------------------------|----------------------------------|-------------------------------------|
| Southwestern              | 5590                                 | 195.65                           | 52834.68                            |
| Moskovsko-Nevskaya        | 7700                                 | 269.5                            | 72780.4                             |
| Central                   | 6840                                 | 239.4                            | 64651.68                            |
| Northern and Northwestern | 6350                                 | 222.25                           | 60020.2                             |

In addition, there is reason to believe that the graph of power consumption will take the following form:
5. Conclusions
Thus, during the work a problem was identified, an analysis of a possible solution was carried out and further activities on this research work were identified.

The introduction of information technology will optimize the production and consumption of electricity. Integration into the «Smart City» system will improve not only the quality, but also the competent distribution of the supplied electricity. Integration based on digital technologies, demand management systems for electricity and the cloud platform of a distributed generator of electric vehicles create a synergistic effect that allows you to:
- lift, in some areas, restrictions for technological connection of consumers under contracts and bids;
- satisfy a portion of the potential demand of the projected capacity;
- reduce the load on medium voltage networks of 6-35 kV in areas of significant power overload;
- reduce the load in areas with a significant amount of electrical equipment in the power supply system of the exhausted resource;
- increase the number of users of electric vehicles;
- develop a network infrastructure for gas stations.

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