Concept of intellectual charging system for electrical and plug-in hybrid vehicles in Russian Federation

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Abstract. Electric vehicles have become the most common solution to improve sustainability of the transportation systems all around the world. Despite all benefits, wide adaptation of electric vehicles requires major changes in the infrastructure, including grid adaptation to the rapidly increased power demand and development of the Connected Car concept. This paper discusses the approaches to improve usability of electric vehicles, by creating suitable web-services, with possible connections vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-grid. Developed concept combines information about electrical loads on the grid in specific direction, navigation information from the on-board system, existing and empty charging slots and power availability. In addition, this paper presents the universal concept of the photovoltaic integrated charging stations, which are connected to the developed information systems. It helps to achieve rapid adaptation of the overall infrastructure to the needs of the electric vehicles users with minor changes in the existing grid and loads.

1. Introduction
Ecology of the vehicles has become the main concern of the engineers and researchers in the last twenty years. The sustainable electric vehicles (EV) and plug-in hybrids have become the key solution to meet the strict ecological requirements with reasonable cost and technical development. Zero emission vehicles improve the air quality of the cities as well as reduced noise level.

However, modern EVs still face the problem of limited driving range on a single charge and availability of the charging stations within the driving distance. Long charging time has also become an issue for the users.

Developed countries have improved their infrastructure to meet the novel challenges in the power consumption and its distribution. In addition, several countries have introduced special tax exemptions and specific changes in road rules for the users of EVs. It allows them to rapidly increase the number of sustainable transport on the roads.

Nowadays, official electric vehicles market in Russia is limited to a single brand Renault. Another manufacturer of EVs, Mitsubishi, has left the market after four years of presence. The main reasons were the low development of the infrastructure and the absence of the special taxation polices for EVs and their users.
As it can be seen on figure 1, Nissan Leaf and Tesla Model S are the leading EVs in terms of sale, but they have been imported unofficially or as second-hand vehicles. The only available new EVs are Renault Twizy and Renault Kangoo ZE.

According to the proposed plans, PJSC “Russian Grids” has started Russian-wide program of infrastructure development and adaptation to meet EVs requirements. In addition to the program, Minister of Energy of Russia, A. Novak, announced in 2016, that the number of EVs in Russia will reach 200 thousand units by 2020. As a part of this development, wide integration of EVs is assigned to the private and commercial transport.

Past researches have shown that the charging infrastructure in Russia is located in the large agglomerates and it is not presented in local centres. In addition, existing charging solutions are provided by various companies. That situation leads to the lack of unified information supply for the drivers and customers.

This paper presents the initial analysis of the existing infrastructure in Moscow regions, as the region with wide adaptation of Electrical transport. Next section presents the developed information system for information collection and sharing within the concept of Connected Car system. Next part of the paper discusses the design and implementation of the universal charging station for EVs based on photovoltaic (PV) system with integration of the solution in the existing electrical grid and developed information solution. It also presents the preliminary results of the system integration. Last section discusses the main results of the developed system and shows the key direction of the future work.

2. Analysis of the existing infrastructure solutions in Moscow region

Moscow region is known as a region with the most developed infrastructure for EVs due to the high number of vehicles-in-use and existing intelligent transportation solutions. Due to these factors, Moscow region was analysed to see the available charging solutions for EVs.

Currently, there are three providers of the charging stations for EVs in Moscow region: PJSC “Mosenergo”, PJSC “RUSSIAN GRIDS” and LLC “Revolta”. They have different charging standards, different combination of the charging cables and accessing polices. These differences create a challenging environment for the drivers of EVs. In addition, charging access card is different for all three solutions, as it can be seen in table 1.
Table 1. Comparison table of charging companies in Moscow region.

| Company Name          | Number of Charging Stations | Access Card Type          | Cost of Charging, Rub/hour | Web-service |
|-----------------------|----------------------------|---------------------------|-----------------------------|-------------|
| LLC “Revolta”         | 25                         | «EMI» Card                | 10                          | Yes         |
| PJSC “RUSSIAN GRIDS”  | 11                         | «MOESK-EV» Card           | Free                        | No          |
| PJSC “Mosenergo”      | Unknown                    | «Troika» Card             | Free                        | No          |

Current number of charging stations creates several problems. First problem is availability of the charging ports due to the high demand. Second problem is distance between charging stations, which leads to the overrun of EVs, higher power consumption and, as a conclusion, lower satisfaction for the users. Third problem is availability of the specific charging plugs on the specific stations.

Because of these issues, a typical EV driver in Moscow has to spend more than half-an-hour to find suitable charging station. It leads to the decreased sustainability of the overall transportation system and low satisfaction rate.

Based on the observation and analysis, couple more challenges have been identified:
- Hard to identify location of the charging stations;
- Impossible to identify availability of the charging ports;
- Various charging providers have different access cards;
- Pricing and payment for the specific company;
- Availability of a specific charging plug on the nearby station;
- Absence of the centralised information centres for EVs.

3. Developed centralised information platform based on connected car concept

Connected car concept includes all possible connection between a specific vehicle and its environment. The initial connection protocols combine two key channels Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I). Further development of the Internet of Things and smart devices, provided another communication channel Vehicle-to-Portable Device (V2D).

In addition, EVs can be used as an energy storage. Due to the rapid integration of unreliable renewable distributed generators, EVs have become elements in the power distribution network through the protocol Vehicle-to-Grid (V2G). This protocol allows EVs to create bidirectional power flow. Within this protocol, EV can get the energy from the grid, if the excess if presented in the distribution network, or operate as an external battery storage for the peak-consumption times.

Developed solution is based not only on the technical ideas and existing solutions within the concept of Connected Car, but also based on the discussions with EV-users. New system combines the demand from individual vehicles and creates a general pattern of the electrical demand within specific regions and matches it with the combined supply. Centralised nature of the solution allows to get information about charging capacity from all providers and supply it to the users.
Intellectual charging scheme is shown on figure 2.

![Figure 2](image.png)

**Figure 2.** Connection scheme of developed solution with infrastructure elements and EVs; where 1) Navigation satellites; 2) Charging stations with Internet connectivity (4G/5G, ZigBee); 3) EVs with V2V and V2D connectivity; 4) Traffic Management Centre; 5) Navigation Service Provider; 6) Centralised Data and Control Centre; 7) Mobile devices with installed application from centralised service provider; 8) In-car information system with GPS and Centralised system connectivity.

Developed solution is based on intellectual data analysis concept. It analyses the data about available charging stations, vacant stations and number of EVs in the designated area. At the same time, each car supplies information not only about current destination and optimal route, but also about remaining charge in the battery and charging technical information. Charging information includes model of the car. Required charging port and availability of fast charging technologies. These parameters are sent to the centralised control centre by the owner, when he registers his EV for the first time in the system. In addition, key parameters for the most common EVs can be assigned automatically, based on the manufacturer’s data, supplied to the centre.

Collected data can adjust the routes, according to the availability of the charging stations on the route, traffic congestions and planned arrival time. These algorithms help to achieve higher efficiency from individual vehicle as well as decrease the load on the selected charging stations and spread the load evenly between all charging stations, as system can analyse and predict demand for the stations, based on the current shared routes.

Furthermore, developed system constantly monitors state of charge of the battery due to the V2D protocol. It helps to analyse the state of health of the battery (SoH), detect the issues with temperature or degradation and supply technical data to the manufacturers for further improvements. Optimisation algorithms in the route planning allows users to charge their EVs in scenarios, when the traffic congestions are heavy, so the battery can be drained fast and not efficiently, which mean more benefits for the users.

4. **Design of universal charging station for intellectual system**
The main problems with rapid integration of fast charging stations in current grid is the peak load, which is created by these stations. Outdated grid cannot handle high power charging in the peak loading times, which leads to the slower charging time, decreasing of the power quality and even power outage in the selected regions. As a result, it slows the integration of EVs in the society.
On the other hand, the outdated infrastructure with limitations in the powerflow directions also limits integration of sustainable energy sources, such as photovoltaic systems (PV). The key challenge in integration of PV systems is inoptimal generation time, when the peak of generation for the households is not matching the period with the peak demand. As a result, many researchers have proposed to use additional energy storage systems to store generated energy for later use.

Similar concept was proposed in the design of the universal charging stations. Solar energy allows to increase the capacity of the power generation with limited interventions to the grid due to the applications of the energy storage system, associated with the generation unit. Current power capacity of powerplants cannot meet increasing demand of power by EVs. In addition, long distribution and transmission lines decreases the sustainability of the integration processes of EVs.

Developed solution is shown on figure 3.

Figure 3. Developed architecture of charging stations.

Developed solution includes set of solar panels (1). Power generation capacity of the solar panels can be calculated based on the current demand in the area and number of registered EVs in the neighbour area. Inverter (2) operates as charge controller for the energy storage elements (battery (3) and ultracapacitors (4)). In addition, charge controller plays the role of maximum power point tracking (MPPT) unit for solar generation under partial shading conditions. Integrated MPPT unit operates with the PV panels based on the partial swarm optimisation concept to achieve immediate response and high possible variables.

State of charge of energy storage devices and generation capability of the system is continuously monitored by centralised control centre (7). This centre communicates with vehicle via V2D and V2I protocols to exchange information about charging demand of the vehicle and provide information about power supply in the nearby stations for further analysis by driver, if required. AC/DC inverter (4) allows charging station to take power from the main grid and, if the infrastructure allows, send extra generated power back to the grid.

In addition, developed solution powers the local light system (10) to improve safety of the areas and increase efficiency of the solution. In Russia, the requirements for the street light varies from 5 to 16 hours per day depending from the season.

Initial calculations were performed based on the assumption, that charging station will accommodate parking space for one car. As a result, the area of PV panels in the calculations was limited to 20 m². In the analysed solution, monocrystalline PV elements were used due to the high performance in high range of weather conditions. Analysis showed, that developed solution can generate up to 16kWh per day and 4007 kWh per year, as can be seen in figure 4. Generated energy provides the distance of 24000 km for an average EV. At the same time, it allows to decrease the amount of CO₂ emissions by 1963 kg.
5. Conclusion and future work

This paper presented and discussed the concept of the intellectual information solution for the drivers of EVs. Developed solution helps to combine power requirements from the drivers and charging infrastructure elements and create sustainable environment. The foundation of the developed solution comes from the concept of Connected Car.

Second section of the developed solution allows to update the charging infrastructure using small investments. Separated self-powered solar-based charging stations were designed and analysed as a part of developed infrastructure concept. Monocrystals PV panels allows to generate enough energy throughout the year in the middle part of Russia for an average EVs. This solution helps to further improve sustainability of the electric grid and EVs integration policies.

As a future work, the research will lead to the hardware manufacturing of the system and implementation in several regions for further testing of the system.

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