1. Jozef KIRÁLY[1], 2. Dušan MEDVEĎ[2]

Technical University of Košice, Faculty of Electrical Engineering and Informatics (1),(2)
ORCID: 1.0000-0002-3429-8656; 2. 0000-0002-8386-0000

doi:10.15199/48.2023.04.41

Electromobility in smart grids - simulation of V2G charging influence on grids

***Abstract**. The article deals with introduction to electric vehicle 2 grid operation in smart grids from view of contribution of these devices (chargers) to smart grid as a battery energy storage systems. In the beginning of article is described overview of charging technologies and potential influence to distribution grid. The whole topic is described on the experiment (simulation) of a distribution network with connected nanogrids consisting from renewable resources, usual residential load and vehicle 2 grid DC chargers.*

***Streszczenie.** Artykuł dotyczy wprowadzenia do pracy sieci pojazdów elektrycznych 2 w sieciach inteligentnych z punktu widzenia udziału tych urządzeń (ładowarek) w sieci inteligentnej jako akumulatorowe systemy magazynowania energii. Na początku artykułu opisany jest przegląd technologii ładowania i potencjalnego wpływu na sieć dystrybucyjną. Cały temat jest opisany na eksperymencie (symulacji) sieci dystrybucyjnej z połączonymi nanosieciami składającymi się z zasobów odnawialnych, zwykłego obciążenia domowego i ładowarek DC do sieci pojazdów. (**Elektromobilność w inteligentnych sieciach - symulacja wpływu ładowania V2G na sieci**)*

Keywords: electromobility, vehicle 2 grid, DC charging, smartgrid
Słowa kluczowe: elektromobilność, sieć pojazdu 2, ładowanie DC, smartgrid

Introduction

The perception of electromobility only from the point of view as the load in the distribution network is changing with the advent of the deployment of charging stations with the vehicle-to-grid or vehicle-to-load mode. Currently, when there is a massive deployment of hybrid photovoltaic systems with a battery, electric cars are one of the options for storing energy in a decentralized network. It is important to note that the fundamental difference from standard decentralized sources in the distribution network is that the supply of energy to the network from the vehicle battery is even more difficult to predict. From the perspective of the perception of the topicality of this topic, it is also important to note that the increase in the number of vehicles in the European Union has an exponential character.

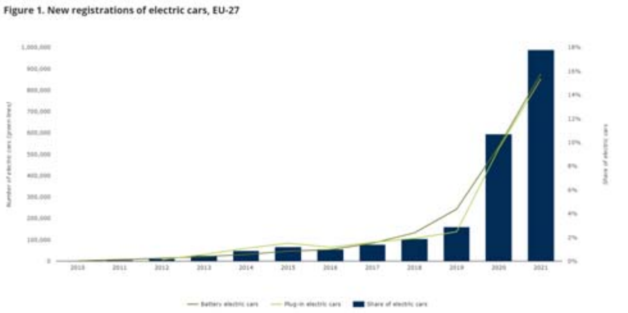

Fig.1. Number of EV and PHEV in European Union [1]

Currently, we can assume that most of these vehicles are charged with standard AC, or DC charging stations. The increase in the number of charging stations, also taking into account the type of chargers, is shown in the figure below.

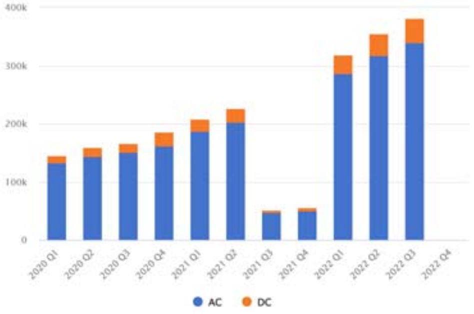

Fig.2. Distribution of EV chargers in time

As can be seen from the given figure, the dominant increase is precisely in AC charging, which is most often represented by residential charging stations. In this case, the above-mentioned method of supplying electricity to the network from EV depends on the connected vehicle and its on-board charger, which must support this operation mode.

The another case is DC charging, where the type of charging station used is decisive, since the charging station in this case directly accesses the vehicle's battery - while the limits of charging and delivering energy are the limitations of the thermal management of the EV battery.

Considering the mentioned facts, one of the main tasks in the operation of smart grid networks is the establishment of communication between this charging infrastructure and other energy sources, or significant loads in the grid.

Components of smart grid networks related to EVs

As mentioned in the introductory chapter, the most important feature of devices in these grids is their communication. In the case of nano grids, which are most often represented by residential areas, the following components are involved [3]:

- Smart electricity meter at the interface with the distribution network
- Decentralized renewable energy source (photovoltaics in hybrid mode)
- Battery storage, most often LiFePO4
- Optional charging station with V2G, or
- Electric vehicle connected to the grid

The listed components are determined by the parameters listed in the following table:

Table 1. The components of smart grids

Device	Usual communication protocol	Measured parameters
Smart metering system	RS485/ M-BUS/ Mod BUS/ TCP/IP	A+/A-, P+/P-, Q+/Q-
Decentralized PV energy source	TCP/IP, RS485	Delivered power
Battery energy storage system	RS485/ M-BUS/ Mod BUS/ TCP/IP	Battery capacity min/max/remaining, A+/A-, P+/P-, Q+/Q-
Charging station (V2G)	TCP/IP, OCPP, OSCP, OCPI	Charging power, delivered power
Battery of electric vehicle	ISO 15118	State of charge

Considering the parameters listed in table no. 1, we can say that the most suitable interface can be either the TCP/IP technology or a combination of industrial protocols connected through a concentrator and subsequently through TCP/IP technology.

In the case of decentralized sources such as photovoltaic power plants, where the performance of the inverters and possibly the capacity of the battery storage is important from the point of view of operation. The secondary component of these systems can be a separate battery storage (BESS) or just a charging station with support for the vehicle 2 grid/load mode. Considering this, it is just important to know and predict the behavior model of these vehicles connected to the grid.

Electric vehicles connected to nanogrid

The interface between the connected electric vehicle and the distribution network, or nanogrid is a charging station. As mentioned above, one of the most widespread charging methods is AC charging using the vehicle's on-board charger. Charging is carried out either by using wall chargers with a power of up to approx. 22kW. AC charging is also possible using external chargers powered from 230V sockets. The limit of this type of charging is the vehicle's on-board charger, which determines the maximum battery charging capacity, which is usually up to 22kW for purely electric vehicles and up to 3.6kW for hybrid vehicles. A risky influence precisely for the operation of the electrical grid, or on a smaller scale, the electrical installation of a household with an installed renewable energy source, e.g. a photovoltaic power plant is precisely the application of these chargers, which can load only one phase in certain configurations, and therefore represent a potential problem from the point of view of load asymmetry.[4]

In AC charging installations in households, another problematic effect can be the use of power management of the charging station, taking into account the use of the entire maximum reserved capacity of the electrical delivery point (defined by the main circuit breaker), where with such controlled charging in several households, the provision of a superior fuse element on at the distribution substation level. Therefore, from the point of view of the future development of the network, it is also necessary to take into account this phenomenon, which can largely affect the value of the considered simultaneity coefficient β.

Vehicle-to-grid mode is a less common solution for AC charging, since in this case this mode must be supported directly by the vehicle's on-board charger.

In contrast to AC charging, DC charging is characterized by rectification of alternating current and direct charging of the vehicle battery with a power from approx. 50kW to 350kW. Unlike AC charging, however, it is a symmetrical load in most cases. The course of the charging itself is controlled and influenced in principle only by the thermal management of the battery, in order to achieve the least wear and tear on the battery together with the shortest possible charging time.[5]

In general, we can describe the efficiency of the power supply from the battery with respect to its temperature according to the graph shown in figure no. 3. As is obvious from the above, the ideal temperature range is between approx. 0°C and 40°C, which is not achievable from the point of view of year-round operation. In that case, it is possible to increase the temperature of the battery externally, but from the point of view of the overall efficiency of the nanogrid as a whole, it is not an economical solution. A similar phenomenon is also the effect of battery temperature on its ability to be charged – i.e. limitations of the charging performance on the part of the thermal management of the battery of an electric vehicle.

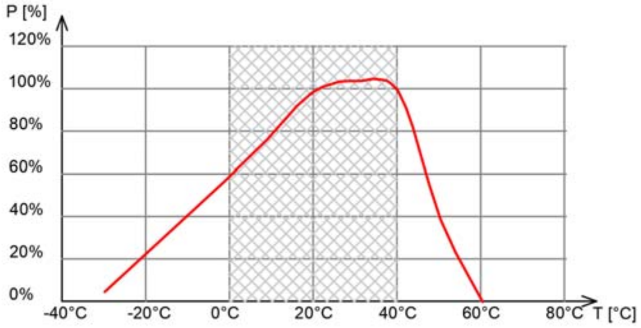

Fig.3. Dependence of battery power and operation temperature

Since DC charging is concentrated in most cases in charging hubs, the course and rate of load in the grid is essential. The solution is the installation of battery storage for managing the flow of energy from the distribution grid and batteries in order to optimally use the available capacity at a given point in the grid. This fact is also supported by the fact that the location of these charging points is precisely in places with a requirement for fast charging on transit routes, near highways, etc. Such a position often limits the possibility of installing devices with such a high performance together with the simultaneity coefficient β=0.8 - 0.9.

One of the options for energy management, in addition to installing battery storage, is the use of vehicle 2 grid systems or vehicle 2 vehicle. The installation of this technology generally assumes installation in smart grids, where communication between individual elements in the distribution grid is enabled, and thanks to this communication, electricity is also supplied in the reverse direction from the batteries of electric cars connected to the grid in order to compensate for insufficient capacity in a certain point. In addition to the available capacity of electric energy in vehicle batteries, it is also important in this case to know, or to predict the behavior model of individual cars connected to the distribution grid, which provide the mentioned functionality. In addition to the above behavioral models, it is equally promising from the charging point of view to consider the vehicle 2 everything model, which can serve not only for mutual data sharing for energy flow control, but also, for example, for use in traffic management, parking, etc. The general mechanism of V2X is shown in the following figure:[6][7]

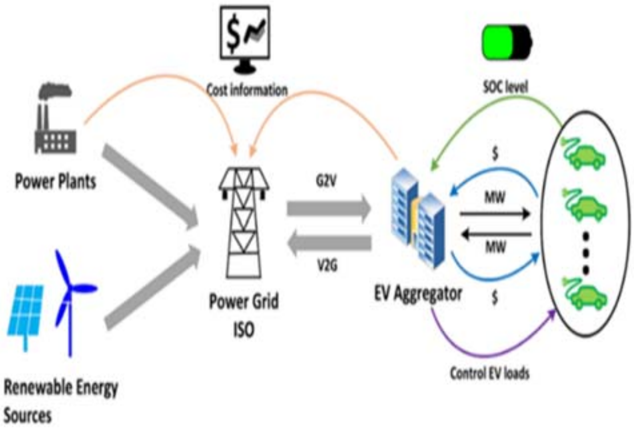

Fig.4. V2X Topology [6]

Model of simulated network

From the point of view of the operation of the distribution grid and the impact of the supply of energy by vehicles to the network, it is important to determine the connection interface of this nanogrid. In the case examined by us, it is a electrical delivery point, which consists of an electricity meter provided by a distribution company.

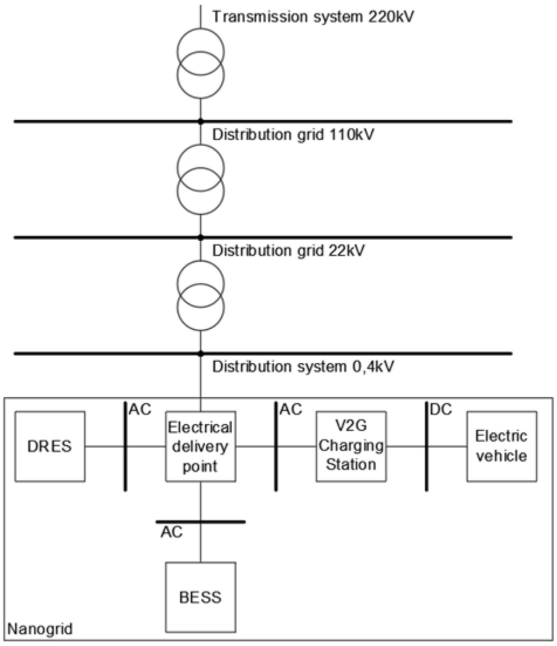

Fig.5. Topology of simulated network

The topology of the investigated nanogrid is shown in Figure 5. From the point of view of using an electric vehicle as a decentralized resource, it is important to describe the behaviour cycle of this vehicle after connecting to the network. This vehicle behaviour is determined by the initial parameters of the connected vehicle. So we can include among the initial parameters:

- Initial state of charge of electric vehicle SOC_I
- EV Battery limit states (minimum state, maximum state of charge) SOC_{min}, SOC_{max}
- Nominal power that can be delivered to the grid P_{EV}

From a grid management perspective, it is important to communicate:

- Number of electric vehicles n_{EV}
- Predicted vehicle connection time t_{EVch}

Based on the above data, it is possible to build a grid model taking into account the contribution of these vehicles to the grid as a decentralized resource. A prerequisite for the reliable and safe operation of such a grid may be, in addition to the above, the coordination of not only the supply of electricity to these vehicles into the grid, but also the maintenance of the connected vehicles to the required SOC_D charge value. In such a case, we can partially talk about the so-called Vehicle 2 Vehicle operation.

The initial parameters in the case of the grid simulated by us from the point of view of connected vehicles are listed in table no. 2. In order to determine the impact of such connected vehicles, it is also important to determine the daily load diagram. For the needs of the model, we considered the flow as shown in fig. 6.

The contribution from DRES was represented by a photovoltaic hybrid system with a battery with a usable capacity of 10kWh. The examined sample was 30 listed nanogrids with the following schedule of connected vehicles:

Table 1. The components of smart grids

Parameter	Unit	Value
SOC_i	kWh	40
SOC_{min}	kWh	10
SOC_{max}	kWh	80
P_{EV}	kW	25
n_{EV}	-	30
t_{EVCH}	h	8

Simulation

The simulation of the smartgrid with the parameters defined in the previous chapter was performed for two cases. The first was grid operation with standard operation of electric vehicles without vehicle 2 grid mode, in the second case it was operation in vehicle 2 grid mode (AC, 25kW).

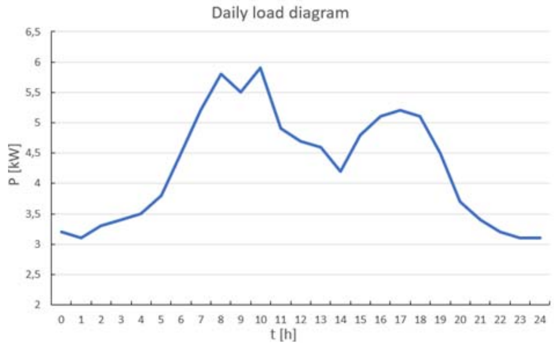

Fig.6. Daily load diagram for simulation

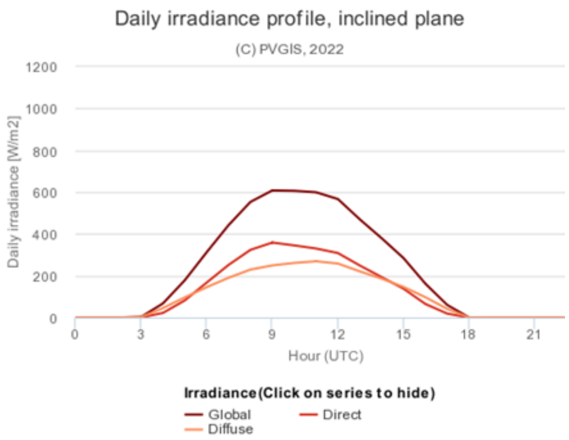

Fig.7. Daily Irradiance profile in simulated place (month - may)

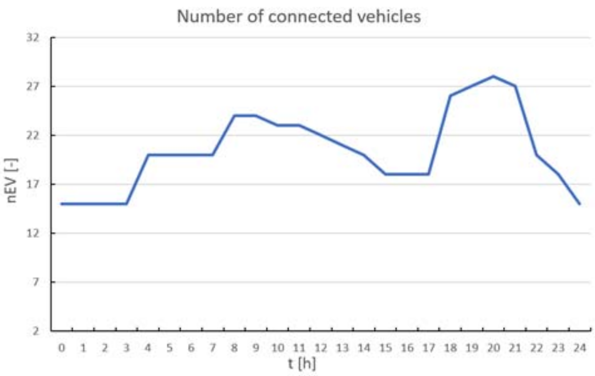

Fig.8.Number of connected electric vehicles

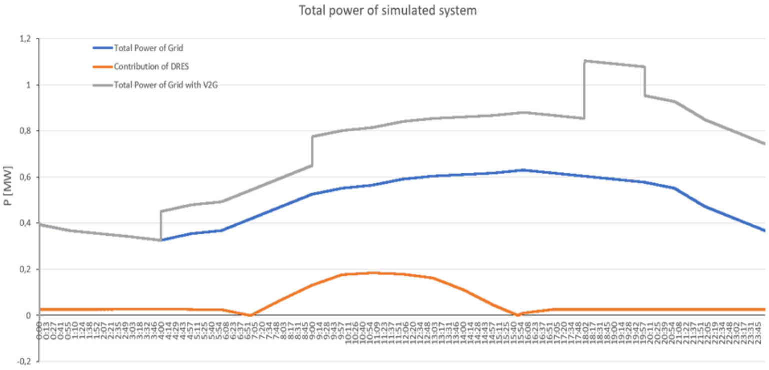

Fig.9.Simulated grid from view of total power

As is evident from the curves, the contribution of vehicles to the distribution grid was not negligible and overall increased the performance balance of the simulated network. The most significant were the contributions from connected vehicles at 4:00 a.m., 8:00 a.m. and 6:00 p.m., where the system recorded significant contributions from these sources. The total contribution from DRES affected the system to a lesser extent, but its contribution was just compensated by the increase in consumption in terms of the daily grid load diagram. Since the simulation assumed SOC_i at the level of 50%, from the point of view of further research, it would be appropriate to simulate the same in addition to the daily load diagram, as well as different initial charging levels of the vehicles.

Conclusion

The topic of charging electric cars in the V2G mode and the impact of this charging on the operation of the distribution network is highly actual, and from the point of view of the trend of the development of the number of electric cars due to the environmental reduction of the traffic load, we do not expect a reversal in the near future.

The aim of this article was to provide a general overview of the pitfalls of individual types of charging and to provide an introduction to the possibilities of simulating consumption and production processes in certain distribution networks.

As was demonstrated on the time course of consumption and production, charging, or the supply of electricity to the grid from the point of view of the chargers can, together with decentralized sources, significantly affect the course of the supply of electricity from the distribution system. For this reason, it is important for practice in the future not only to obtain real data about areas and networks where such systems are operated, but also to create functional models of the behaviour of the distribution network, thereby ensuring the prediction of transient phenomena associated with charging and thus increasing the quality and stability of the electricity supply energy.

This work was supported by Technical University of Košice, Faculty of Electrical Engineering and Informatics from Young scientist grant No. FEI-2022-85.

Authors*: Ing. Jozef Király, PhD., Technical University of Košice, Department of Electric Power Engineering, Mäsiarska 74, Košice, SK 04210, Slovak Republic, jozef.kiraly@tuke.sk*
Doc. Ing. Dušan Medveď, PhD., Technical University of Košice, Department of Electric Power Engineering, Mäsiarska 74, Košice, SK 04210, Slovak Republic, dusan.medved@tuke.sk

REFERENCES

[1] New registration of electric vehicles. European Environment Agency [online]. [cit. 2022-10-01]. Available on: https://www.eea.europa.eu/ims/new-registrations-of-electric-vehicles
[2] Total number of recharging points, according to the AFIR classification. European Alternative Fuels Observatory [online]. [cit. 2022-10-01]. Available on: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/infrastructure
[3] B. Wang, J. Hernandez Fernandez and A. Massoud, "A Wireless Battery Temperature Monitoring System for Electric Vehicle Charging," 2019 IEEE SENSORS, 2019, pp. 1-4, doi: 10.1109/SENSORS43011.2019.8956733.
[4] H. M. Khalid and J. C. . -H. Peng, "Bidirectional Charging in V2G Systems: An In-Cell Variation Analysis of Vehicle Batteries," in IEEE Systems Journal, vol. 14, no. 3, pp. 3665-3675, Sept. 2020, doi: 10.1109/JSYST.2019.2958967.
[5] A. A. Abdullah Al-Karakchi, G. Putrus and R. Das, "Smart EV charging profiles to extend battery life," 2017 52nd International Universities Power Engineering Conference (UPEC), 2017, pp. 1-4, doi: 10.1109/UPEC.2017.8231961.
[6] C. Corchero and M. Sanmarti, "Vehicle- to- Everything (V2X): Benefits and Barriers," 2018 15th International Conference on the European Energy Market (EEM), 2018, pp. 1-4, doi: 10.1109/EEM.2018.8469875.
[7] A. Gupta, H. O. Bansal, P. Jaiswal and R. Kumar, "Modeling and Analysis of a V2G Scheme: A Concept in Smart Grid," 2020 International Conference on Emerging Trends in Communication, Control and Computing (ICONC3), 2020, pp. 1-6, doi: 10.1109/ICONC345789.2020.9117408.