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VGI: smart grid integration of electric vehicles

MARINESCU ANDREI*, **NICOLAE GOLOVANOV**

Technical Sciences Academy of Romania

Abstract. The integration of electrified vehicles (EVs) of any kind (electric or hybrid) into the power grid (VGI) has become necessary with the significant increase in the number of such vehicles. The charging of their batteries in the smart grid becomes “smart charging” where the charging level and charging duration are controlled by the grid operator so as not to affect the grid’s operational reliability. VGI now combines battery charging (G2V) with the bi-directional transfer of electricity stored in the EV battery, known generically as (V2G). VGI is rapidly gaining popularity because it offers both the EV owner / the company with a fleet of commercial EVs and the grid the possibility to use the energy stored in the EV battery for other purposes when the EV is not in use. This paper is an introduction to the analysis of the VGI system with direct application in the private and industrial economy.

Keywords: electrified vehicles, EV charging, grid operator, smart grid, system services.

1. Introduction

In the coming years, the energy systems will undergo major changes, due primarily to the need for decarbonisation. Three main areas are expected to be the focus of attention:

- decarbonisation of fuels;
- increasing energy efficiency;
- promoting renewable energy sources.

The electric mobility contributes in all three areas to the reduction of pollutant emissions through the highly efficient use of energy from “clean” sources.

In new grid-connected configurations, the electric vehicles (EVs) can become an important support for ensuring the functionality of the electricity system by being able to generate system services especially in the event of disturbances which could

∗Correspondence address: andrei.marinescu@ieee.org

affect the quality of electricity supplied to users. In this way, electric vehicles become components of the power system with an impact on its stable operation.
The paper examines the practical possibility of using the energy available in the batteries of electric cars to cover some system services, especially in distribution systems.

2. Connecting electric vehicles to the grid

The electric vehicles (EVs) are becoming more and more widespread as electricity receivers in electricity systems and are showing a strong upward trend (Fig. 1) [1].
The more than 16,5 million vehicles today use, triple the amount in 2018. The success of the EV determined that in 2021 nearly 10% of global car sales were electric [2].
As the number of electric vehicles has grown, so has and will the number of battery charging stations. (fig.2) [3].
It is considered that electric cars are only used about 5% of the time and, the rest of the time, the energy stored in the batteries could be used for other services, provided the battery is recharged before using it for driving the vehicle [4]. In order to enable the use of the energy stored in EV batteries without affecting the owners expectations of the availability of the means of transport, it is necessary to develop a structure in which the vehicle is permanently connected to the electricity grid and provided with the possibility of bidirectional energy transfer, with a monitoring and control system to indicate the battery's state of charge, the level of energy transferred during the two operating modes (receiver, source), the program for the utilization of the electric car.

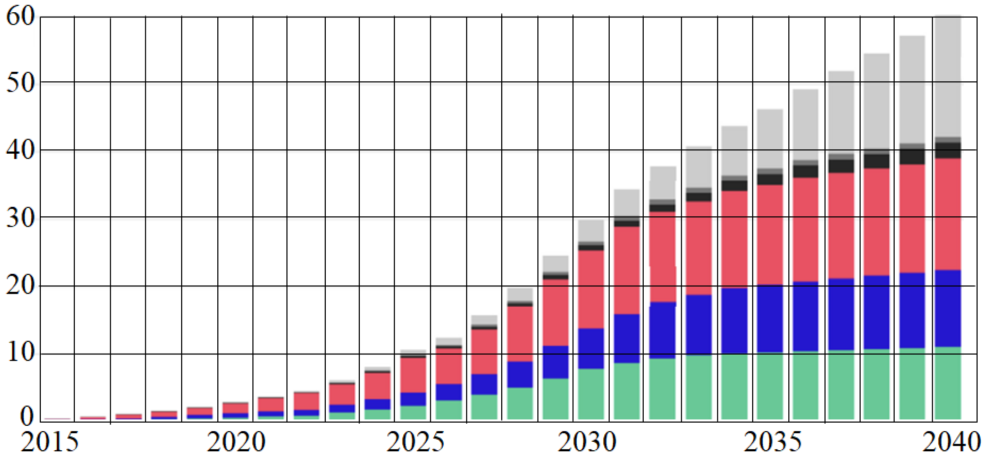

Fig.1 – Evolution of the number of EVs worldwide (in million units/year):
Europe; USA China Japan; South Korea; Other

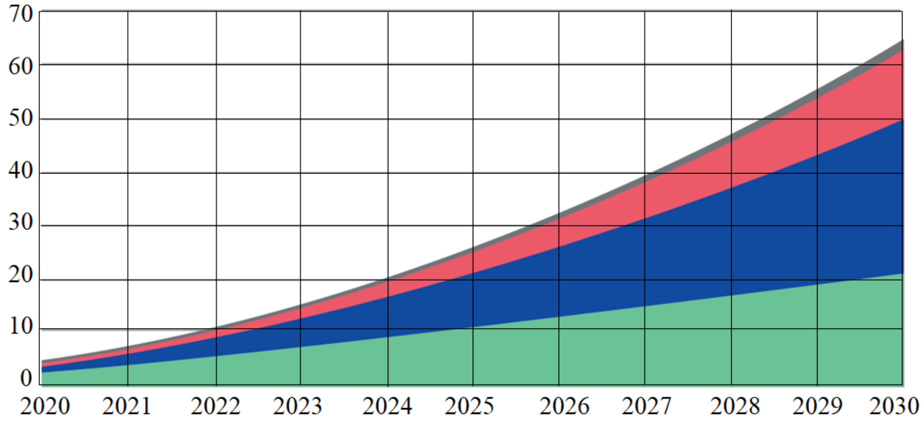

Fig. 2 – Evolution of the global number of EV charging stations (in million units/year):
Europe; China; USA; Japan & Korea.

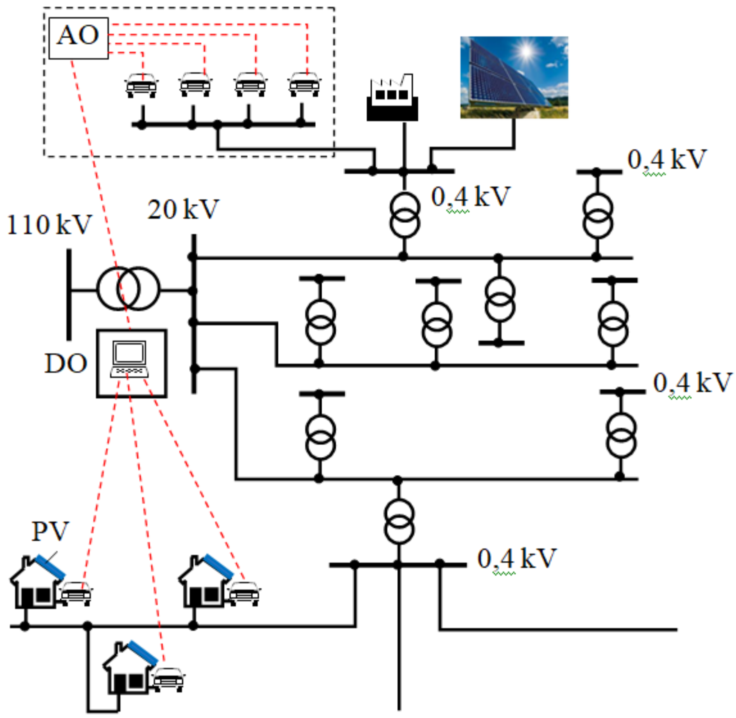

Fig 3 – Diagram of a low-voltage network supplying individual VGI systems and aggregate VGI systems:
—— electrical connection; ---- computer connection.

For the transfer of individual or aggregate data for several EVs to the electricity grid operator, communication channels between each EV and the grid operator or aggregation operator are required.
The energy available in EV batteries can provide some of the energy services necessary for the operation of the power grid: providing input to frequency regulation during grid events, voltage regulation in power grid nodes, covering short-term loads, limiting congestion, limiting voltage dips and short interruptions in power supply to users, correction of the shape of load chart, limiting peak load, storage of excess energy caused by intermittent renewable energy sources [5]. In this way, grid-connected EVs become components of the power system and will be included in a communication, measuring, control, monitoring, and security architecture specific to power system components. It is considered that they will become VGI *(Vehicle-Grid Integration)* structures by merging G2V *(Grid-to-Vehicle)* and V2G *(Vehicle-to-Grid)* systems specific to the smart grid.
In principle, the EV charging systems are specific to low voltage networks where, depending on the actual on-site conditions, EVs can be connected individually or as part of a parking lot with multiple charging system (Fig. 3).
The aggregate systems can be built in the parking lots of apartment blocks or in the parking lots of institutions and companies, and the individual systems can be built in areas with single-family dwellings. The aggregate systems require specific management and an aggregator manager as the "customer" of the distribution system operator.
The advantages and disadvantages of individual and aggregate systems are shown in Table 1.

Table 1. Advantages and disadvantages of VGI systems

Structure	Advantages	Disadvantages
Individual supply	- simple connection diagram; - circuit for direct communication with the distribution system operator; - direct control by the EV owner; - possibility to use the energy stored in the EV to supply the individual user in the event of power outage; - improvement of power quality in case of voltage dips and short interruptions	- extensive radial network of communication with each EV; - difficulties in choosing and synchronising EV units to cover system services; - complex data processing circuit installed at the network operator's location.
Aggregate supply	- the possibility of aggregating significant powers for system services; - coordinated access of EV charging process and input to system services; - contribution to the control of the voltage profile in the distribution network by controlling the power input; - support for the control of flexibility in the distribution network.	- peer to peer communication network between the aggregator and the distribution operator and a radial local area network between the aggregator and each EV; - investments in the EV charging stations aggregation system

The role of the OA aggregator, as the person in charge for managing the EV charging processes and the use of the energy available in their EV batteries is to ensure that the EV batteries are charged so that the car can be used by its owner at the designated time, to organize and optimize the participation of the EV on the electricity market and to contribute, in an intelligent way, to covering the requirements of the system services based on the energy available at a given time in the EV batteries in the aggregated system. The aggregator's activity simplifies the actions of the grid operator and makes an important contribution to ensuring the quality of electricity supplied to users.

Any EV can operate in the VGI system provided it fulfils the following three conditions:

- it has a power connection to the grid for the bi-directional power flow;
- it has a control system or a logical connection for the communication with the grid operator or aggregation operator;
- it has an accurate on-board metering system for the transferred energy. At the moment, none of these conditions is fulfilled by the EVs sold in Europe,with a few exceptions (Nissan Leaf, Mitsubishi Outlander) and in preparation for VW ID in 2023, but due to the possibilities offered by the VGI solution, this solution will become a requirement for the energy system. The solution may be simpler if battery charging is done with DC voltage.

If we consider a 40 kWh traction battery for each EV, the energy available today for the 10000 EVs in Romania in theory is of 400 MWh and if only 10% of the Romanian EV owners would participate in a national VGI implementation project, this would represent a theoretical contribution of 40 MWh in case of failure in the distribution grid (practically only 20 - 30 MWh if we take into account the transfer efficiency and the residual energy needed to ensure the functionality of the batteries).

The presence of the energy source stored in the accumulator batteries of EVs connected to the power system can act as a source for secondary regulation in case of events in the electrical network that must be activated for no more than 15 minutes after the occurrence of the event [6].

It would be possible, throughout the country, to have an input of approx 100 MW, which would be particularly useful to overcome major system disturbances (especially in the distribution systems).

As the number of vehicles increases, the input of the energy stored in EV batteries can make an important contribution to limiting events in the power system.

Studies are underway, as part of a complex project called "*V2G Romania*", to develop a minibus and charging station compatible with international VGI recommendations.

3. EV with integrated uni- or bi-directional inverter

Most EVs today have one-way on-board chargers (OBC) [7] which allow battery charging from the low voltage, single or three-phase AC network, with power ratings ranging from 3.7 to 22 kW as shown in Figure 4 a). They have simple hardware construction and offer high battery reliability.

In VGI systems used in the smart grid, charging an EV with a standard uni-directional charger is called G1V; in this case, the charging level and duration of this process is set by the grid operator depending on the condition of the power system, regardless of the power displayed on the charging station.

By installing a bi-directional charger in the EV as in figure 4 b), the energy transfer is provided in both directions: the charging of the G2V battery is identical to the G1V and the energy transfer from the battery to the grid or micro-grid (V2G) is carried out as necessary (e.g. in case of power failure in homes).

The difference between the diagrams in Figures 4 a) and 4 b) is that the diode rectifier bridge is replaced by a controlled bridge on the battery side. The change of the power flow direction is determined by the grid operator on the basis of the existing supply contract; it is done by controlling the two controlled rectifiers from the grid and from the battery, both transformed into inverters by application software according to the IEC/ISO 15118 standard presented in paragraph 5.

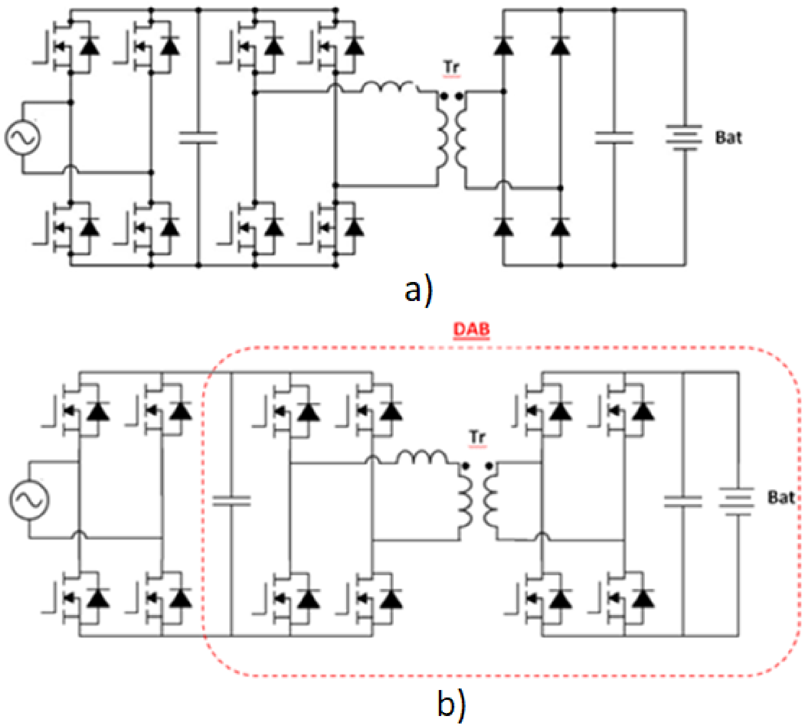

Fig. 4. Integrated EV charger: a) uni-directional, b) bi-directional.

The Dual Active Bridge (DAB) block in Fig. 4 b) consisting of two active bridges separated by a medium frequency transformer Tr with matching and isolation function is one of the simplest bi-directional inverter modules [8].

The DAB can also be built for bi-directional wireless power transmission. The only difference from the scheme in Fig.4 b) is that the transformer Tr is replaced by resonant inductive coupler [9].

4. Public EV charging station with integrated bi-directional inverter

The energy efficiency of the V2G system is increased for public stations with many charging sockets in which one or more bi-directional inverters are integrated. Currently these stations allow both battery charging up to 22 kW AC voltage and high power DC fast charging (>50 kW). The charging system is either CCS [10] with two outputs: AC and DC voltage, or ChadeMO [11] for DC voltage only, the last as the only system currently capable of bi-directional V2G charging. With the widespread transition to DC charging, the EV-integrated bi-directional charger will no longer be used and will become an integral part of the charging station according to its power level.

5. Standardization of the technical solutions for the smart grid integration of EVs

One of the most important requirements for electric transport is unlimited interoperability between the charging solutions of all suppliers. This is the role of the international standards ISO/IEC 15118 and IEC 63110 which form the basis of the integration systems.
ISO/IEC 15118-1 [12] specifies all the links of communication between the EV and the charging station, whether conductive charging (Plug-In) or contactless charging (WPT). The second version of the standard (Ed 2) is currently available as ISO/IEC 15118-20 [13].
IEC 63110 deals with the communication between the charging station and the power supply network and consists of three parts: IEC 63110-1:2022 basic definitions and application cases [14], IEC 63110-2 technical specifications and IEC 63110-3 requirements for compliance testing (the last two parts will be issued in 2023).

6. Conclusions

Reliable communication networks are a prerequisite for all the functionalities and technologies mentioned above. Without standardized data exchange between EVs and charging systems on the one hand, and between stationary charging equipment and the service provider or smart grid on the other hand, it would be impossible to implement bi-directional smart charging, authenticate, bill, accurate positioning and provide interoperability of EVs in contactless charging system, provision of auxiliary services and much more;

The VGI technology ensures the charging of batteries when the condition of the power system is not affected and can return battery power to the grid for system services;
The VGI system has the potential to contribute to the profound transformation of both the power and transmission systems by promoting the implementation of alternative EV technologies, reducing inefficient investment in conventional power generation and supporting the installation of renewable electricity sources;
The VGI system uses the stored, unused energy of an EV fleet for system services without any additional investment;
There are, of course, many obstacles to such an unconventional transition, some of which are shown in Table 1, and which the standardization process that is partly underway will address;
The promotion of the VGI technology in Romania, even if there is now a relatively small number of EVs compared to other EU countries, has a significant growth potential and the development of an applicative research project "V2G Romania" can be justified.

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