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Chargers for electric cars with V2G (vehicle to grid) technology - connection principles for the distribution network

Streszczenie. *Pojazdy elektryczne są jednym z elementów, które w przyszłości będą stanowiły integralną część smart grid. Dzięki ładowarkom z usługą V2G możliwe jest pobieranie i oddawanie energii elektrycznej do sieci zasilającej. Oprócz zalet, jakie niesie ze sobą ta funkcjonalność, w artykule przedstawiono wątpliwości dotyczące bezpieczeństwa osób zajmujących się eksploatacją i utrzymaniem urządzeń elektroenergetycznych oraz zwrócono uwagę na konieczność opracowania wymagań dla zabezpieczeń i warunków przyłączenia do sieci dystrybucyjnej ww. ładowarek.* ***Układ ładowania do samochodów elektrycznych w technologii V2G***

Abstract*. Electric vehicles will be an integral part of the smart grid in the future. The chargers that come with the V2G (vehicle to grid) service provide bidirectional electrical energy flow between the cars and the grid. Although this functionality has many advantages, the current paper presents doubts about the safety of the people involved in the operation and maintenance of electrical power equipment. It also signals the necessity to develop security requirements and connection conditions for the electrical distribution grid.*

Słowa kluczowe: e-mobility, V2G, rozproszone źródła energii elektrycznej, ochrona przed podaniem napięcia do sieci zasilającej.
Keywords: e-mobility, V2G, distributed electrical energy sources, protection against voltage back to the supply network.

Introduction

In recent years, there has been an escalation in the development of the electromobility (e-mobility) market. This escalation directly results in the increased requirement of charging stations supplied from the public distribution network. According to various forecasts, it is estimated that by 2040, about 500 million electric vehicles will travel on the roads around the world [1, 2]. This will undoubtedly be one of the biggest challenges that distribution system operators, regional and country governments and all the road users have to face in the coming years. It should be expected that e-mobility will be an important factor for global economies and ecological trends. In fact, electric vehicles will act as a catalyst for the development and expansion of the smart grid infrastructure, being one of its elements at the same time (see Figure 1).

The Polish Parliament Act on Electromobility and Alternative Fuels that came into effect on January 11, 2018 can be considered as the first step to popularize e-mobility in Poland. Apart from the incentives that will be granted to electric vehicle drivers, the Act defines the rules for the development and operation of charging point infrastructure. The Act gives a green light to the car sharing service as well as research on autonomous vehicles on public roads [3].

Fig. 1. Electric vehicle as an element of a smart grid [4].

Literature presents quite a few more or less futuristic visions that show the possibilities of using electric vehicles as dispersed energy sources [5, 6, 7, 8]. The vehicles would be used for among others things, shaping the 24-hour load curve, reactive power compensation, storing electric energy produced by RES (renewable energy sources) [6, 9]. All these assumptions, even if their implementation is still far in the future, are built on a common basis, namely the V2G (vehicle to grid) concept.

Chargers for electric vehicles

The simplest method to classify electric cars is by their charging methods (Figure 2) or in terms of the energy source used for their drive, for example, BEVs (battery electric vehicles), FCEV (fuel cell vehicles). Producers of electric vehicles and charging stations are racing to develop the most convenient solution for users which will ensure that the time taken to charge batteries is similar to the time taken to refuel a traditional car. However, due to the lack of a uniform international standard, manufacturers launch solutions for chargers dedicated to specific car brands (CHAdeMO, CCS, Supercharger). This means that all users cannot use all charging points, or they must purchase special adapters to use chargers not specific to their vehicles.

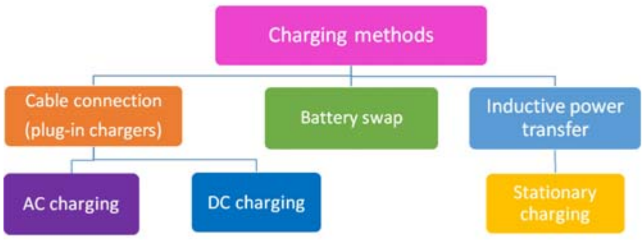

Fig. 2. Charging methods of electric vehicles.

Perhaps even greater encapsulation of the market would be achieved by the Tesla rapid battery swap system launched in 2013. However, reports show that this approach did not meet with a positive response from customers who were more interested in the fast Supercharger. Numerous works and research projects [5, 7, 8, 10] predict that in the near future, the most popular solution will be stationary wireless charging of electric vehicles called inductive power transfer.

Inductive power transfer, in simple words, is a charging system that consists of a primary winding coil placed in a parking spot and a secondary winding coil that is part of the vehicle. The primary winding coil is supplied by a high frequency converter from the mains and the coils are magnetically coupled to form a transformer with an air gap.

Much research has gone into improving these charging systems that are based on the principle of electromagnetic resonance (Nicola Tesla's invention). The main goal is to find a cheaper and safer way of charging vehicles than inductive power transfer [11].

Inductive power transfer systems are used, among others, in Turin, Genoa, Gumi and Mannheim [12]. Extensive research has been carried out to develop systems that will allow vehicles to be charged while driving (dynamic wireless charging).

Currently, the most popular (apart from micro, mild and fully hybrid cars) are cars that can be charged using a special cable – plug-in electric vehicles (PEVs) (Figure 3).

At present, there are four charging modes of PEV [12]. The first and second charging mode applies to cars in which the charger is located inside the vehicle, and charging takes place directly from the electrical outlet. In the first mode, the three-phase charger can take a maximum current of 16 A; in the second mode, the three-phase charger can take a maximum current of 32 A.

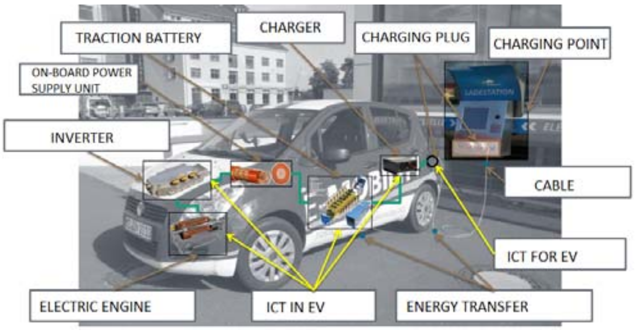

Fig. 3. A car with an electric drive (PEV) [13].

In the third mode, the charger is not part of the vehicle. The charger is equipped with an EVSE (electric vehicle supply equipment) control module permanently connected to the grid. The control module is responsible for relaying communication between the charging station and the car; it also provides protection against electric shock.

DC chargers (the fourth mode) provide currents up to 400 A. They are called quick chargers. The purpose of these chargers is to rectify and decrease the voltage to a level that ensures safe charging of the batteries inside the vehicle. Each charger of this type consists of two basic parts – a rectifier and a DC/DC converter.

There are chargers with unidirectional electric energy flow, i.e., G2V (grid to vehicle) and V2G systems with bidirectional electric energy flow, in which two-wire rectification is realized by a transistor–diode assembly. The assembly is shown in Figure 4.

Chargers with bidirectional electricity flow – The V2G system

V2G technology allows the use of electric vehicles for transport purposes and as well as distributed sources of electricity (Figure 5). Such a dual functionality will be important in creating future solutions of smart grids. It can be concluded that the V2G system will be one of the main elements of an intelligent power grid, for example, the National Power System, where electric vehicles will act as energy storages, energy which at a given moment can be returned to the grid. With appropriate legal regulations, technical solutions and high awareness of the owners of electric cars, this will have a direct impact on the curve of the daily demand for electric power.

An innovative project is being carried out by the manufacturer of Nissan cars and by the energy company Enel in the UK. The main goal of the project is to enable users of electric vehicles to sell energy accumulated in their batteries to the distribution grid. Enel and Nissan have realized the potential of V2G services to ensure network stability with increasing electricity demand. They predict that V2G services will also contribute to the integration of energy produced by renewable energy sources from the National Power System [15].

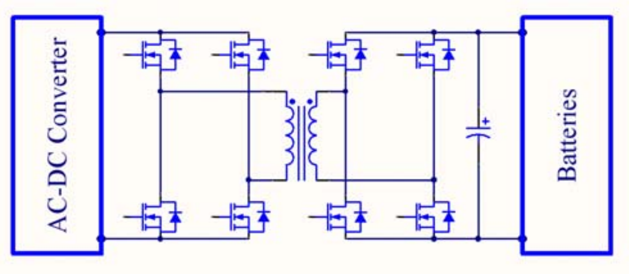

Fig. 4. The scheme of a bidirectional e-charger.

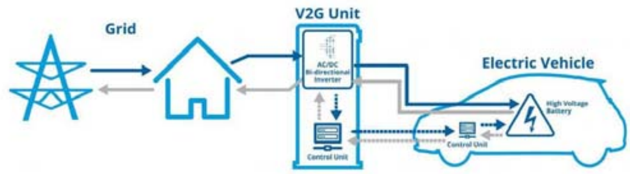

Fig. 5. The idea of V2G system [14].

Similar studies were realised by the California Independent System Operator (CAISO) and the Southern California Edison. A system was developed by which CAISO and the users of electric cars could communicate with each other. If CAISO reported a power deficit, the cars would respond by providing energy to the grid; whereas, for example, at night-time, the batteries were recharged from the grid. It has been pointed out that it would be necessary to develop a universal interface that will ensure the exchange of information on electricity demand between the distribution system operator and the vehicle.

In addition to the aforementioned applications, V2G technology can be used to adjust the power factor by transferring capacitive or inductive reactive energy to the grid depending on the actual demand [11, 16].

This functionality is ensured by the use of two fully controlled transistor–diode assemblies. With this function, it is possible to take energy (switching input transistors) as well as transfer energy stored in the battery to the mains (switching transistors on the battery side).

To adjust the power factor, the transistor keys in the charger system are switched on in such a way that the angle of the phase shift between the supply voltage and the current delivered to the grid is of a predicted value. Thus, it is possible to change the nature of the load from capacitive to inductive loads, which is the charger.

V2G chargers – Cooperation with the distribution grid

As mentioned earlier, electric vehicles can be used as electricity storages. One should consider how to treat such units when we connect them to a charging station supplied by the distribution network and that enable two-way flow of electricity. Should these chargers be treated only as a burden or should distribution system operators also treat them as generating units?

According to the definition given by the Polish Parliament Act 2015 [17] and Kałek [18], the electric energy storage must be physical and permanently connected to the electrical installation; it can only store the energy generated in it. According to the Polish Parliament Act 2015 [17], the energy storage facility can be used only for one purpose – the temporary storage of energy. Of course, electric vehicle batteries also accumulate energy for a limited time, but it is mainly used as a drive.

In view of the aforementioned interpretation, EVs together with V2G chargers should not be treated as electric energy storages [18, 19]. However, generally, if a charger operating in the V2G system is connected to the distribution network, electric vehicles should be treated as dispersed sources of electric energy [19, 20]. Of course, there are a number of questions about legal regulations, economic aspects and advantages of using such solutions [21, 22, 23], but it should be remembered that even the market development of photovoltaic panels had a similar start.

Currently, charging stations connected to distribution networks do enable the use of V2G technology. Therefore, the question should be asked whether the connection conditions for such facilities should be the same as, for example, residential buildings, or analogous to mini photovoltaic plants installed on the roofs of detached houses.

As an electric vehicle that transfers energy via a charger with the V2G service to the mains cannot be strictly classified as an energy storage or generation unit, there are currently no special regulations that can impose cooperation of such devices with the distribution network. In the majority of charging stations with bidirectional energy flow, the V2G function is not used. However, they do not constitute an autonomous island, and therefore all potential threats originating from the systems should be identified.

Imagine a situation in which due to, for example, human error, failure or incorrect use of the device, the V2G service is activated and electricity flows back to the network. This results in not only the risk of an electric shock, but also, for example, if the unit malfunctions, a fire risk.

The main similarity between systems with V2G service and photovoltaic installations is of course the ability to return energy to the mains. For this reason, analogous security requirements should be set in stations with V2G service with the cooperation of the distribution network, as in the case of photovoltaic panel connection.

The basic protection against electric shock, which every charger with V2G service should be equipped with, is protection against the possibility of voltage flowing back to the supply network in the event of voltage decay in this network. Similarly, as in the case of photovoltaic installations, electricians should be protected against electric shock during the repair or operation of the electrical power equipment, in which, as a result of, for example, incorrect operation of the charger, there may be high voltage.

Sanchez-Sutil et al. [24] proposed the introduction of standardized rules for connecting electric vehicle chargers that had V2G function to the distribution network. By adapting these standards [25], the requirements of distribution network operators in the field of photovoltaic installations [26, 27] and the proposals presented in the IEEE 1547-2018 [25], it can be concluded that the scope of applied protections will be extended to include detection of abnormal situations in the distribution network (e.g., short circuits). These protections should include the following:

- overvoltage protection with function of short time delay
- undervoltage protection with function of short time delay
- overfrequency protection with function of short time delay
- underfrequency protection with function of short time delay.

In order to ensure proper cooperation of the charger with bidirectional electricity flow with the power grid, an automatic reclosing system may be considered. This will also be helpful in case of transient faults.

More and more dispersed energy sources are being connected to the distribution network. This state brings new and potentially dangerous situations. Let us consider the case when a part of the network is disconnected from the distribution network in order to carry out maintenance or repair a failure. Protection provided against the possibility of supplying voltage to the distribution network of one of the distributed sources can incorrectly interpret the voltage coming from another distributed source as the voltage coming from the distribution grid. As a result, it will not be possible to disable this part of the network from undervoltage. Therefore, the cooperation of the collateral used in installations of individual dispersed sources is very important. It is also recommended to use active methods of detecting disconnection from the distribution grid (loss of mains, LOM) instead of passive methods [28].

Many energy storages have the possibility of islanding. The main purpose of these storages is to stabilize the input of local renewable sources. They can also be used as a backup power source. Due to the fact that a charger with the V2G function is not always connected to energy storage, it cannot perform functions such as energy storage. Therefore, protection against islanding should be considered for systems with bidirectional electricity flows which are connected to the electricity grid.

Dolata [29] recommends supplying the protection automation from a guaranteed voltage source (UPS, buffer power supply), which is a source of electricity in case of a power failure in the mains. Analogous requirements should be specified for chargers with V2G service, as there is not always any energy storage in the form of an electric vehicle connected to them.

It is also necessary to take into consideration the potential negative impact on the grid of not only chargers with V2G service but all type of chargers for EVs.

The authors of this paper investigated the electrical energy quality of a charger installed in a circuit. After simulations (Figure 8) and careful measurements, they deemed the charger not dangerous [33].

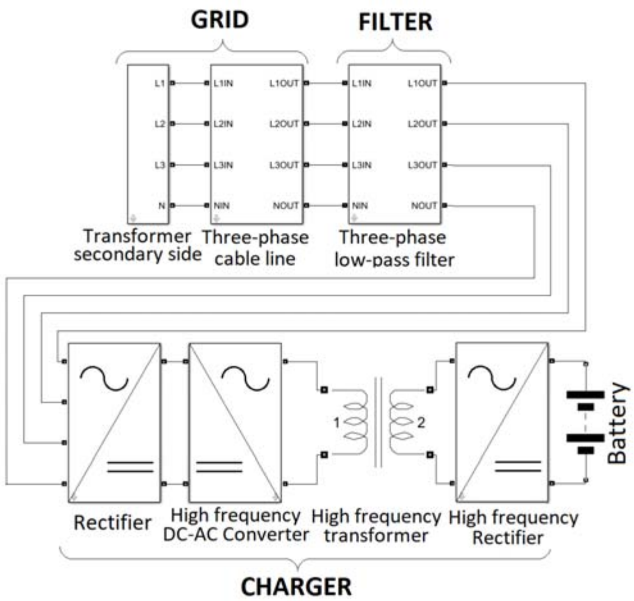

Fig. 6. Block diagram of the simulation model [33].

The modelled DC charger was supplied from a three-phase grid with a nominal voltage of 400 V. The real distribution grid was mapped in the simulation model (transformer and cable line parameters). The modelled block diagram is presented in Figure 6 and described in detail [33]. The network was loaded by only one device which was the DC charger.

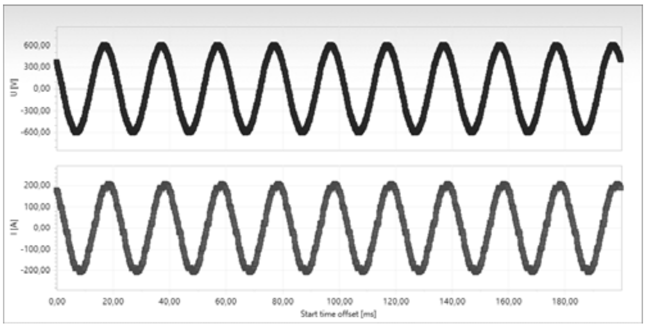

Fig. 7. Registered main current for the real charger during measurements.

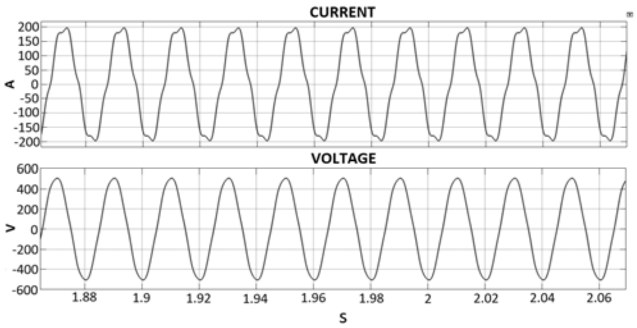

Fig. 8. Simulated mains current and mains voltage for a charger equipped with LCL filter and connected to the real grid [33]

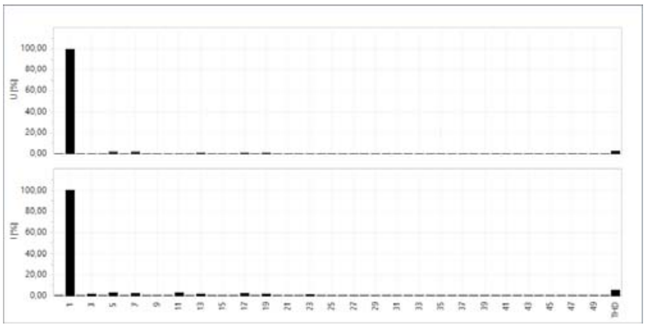

Fig. 9. Registered THD_I and THD_U.

During charging, the total harmonic distortion (current), THD_I was about 7.8%, which even with a significant current drawn from the network had little effect on the total harmonic distortion (voltage), THD_U, which did not exceed 2.2%.

Attention should be paid to the problem of simultaneous operation of many chargers in the common circuit, which will often take place, especially in urban areas. In such a situation, the disturbances caused by these chargers will overlap, which with the significant current values taken in total by such chargers, may have a noticeable effect on voltage deformation.

Conclusions

The development of electromobility will implicate changes and result in the emergence of new industries related to transport and the maintenance of charging infrastructure. The electricity market model and the electricity system that we know now will also change. Raising questions about the possibility of this ever happening is pointless, because we are already witnessing these changes [1, 3, 16, 20]. Therefore, we should focused on recognizing opportunities and risks that will appear in the coming years.

Undoubtedly, the number of electric cars, which, according to forecasts, will in the near future travel on the roads, will build a challenge for the National Power System. The issue of the impact of e-mobility on the quality of electricity has been often and very broadly discussed in literature around the world [28, 29, 30].

The purpose of this paper is to draw attention to the potential risks that may arise by the unintentional flow of voltage back to the network from the V2G charger. A deeper analysis of the problem raised should be made while the principles of connecting chargers with V2G service to the distribution network are developed.

Future studies will take into account the parallel work of various DC chargers (slow, fast, ultra-fast chargers with a capacity of around 20−200 kW) connected to the same circuit with other loads like houses, apartment and office buildings. The main purpose of these researches will be to investigate the real impact of DC chargers on the distribution grid and on the electric power quality (THD_I, THD_U, power losses, voltage drops, overloads). Based on the results, the next steps for research can be laid.

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