The System of Fast Charging Station for Electric Vehicles with Minimal Impact on the Electrical Grid

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Abstract. *The searching and utilization of new energy sources and technologies is a current trend. The effort to increase the share of electricity production from renewable energy sources is characteristic for economically developed countries. The use of accumulation of electrical energy with a large number of decentralized storage units is most preferred, as well as the focus on the production of energy at the point of its consumption. Modern cogeneration units are a good example. This paper describes the accumulation of electrical energy for equalizing the power balance of electric charging stations with high instantaneous power. The possibility of re-utilization of electrical energy from the charged vehicle in the case of lack of electricity in the power grid is solved at the same time. This paper also deals with the selection of appropriate concept of accumulation system and its cooperation with both renewable and distribution networks. Details of the main power components including the results obtained from the system implementation are also described in this paper.*

Keywords

Accumulation, electric vehicle, electrical grid, fast charging station, renewable energy sources.

1. Introduction

The growing share of electric vehicles in passenger traffic brings demands for expansion of infrastructure of fast charging stations. The average annual electricity consumption of the personal electric vehicle is reported to be around 3300 kWh/year. This value is very close to the average annual household consumption, which is reported to be in the range of 3700–5400 kWh/year for flats and smaller family houses. The disadvantage in covering the consumption of electric vehicles unlike households is that vehicles can take their charging energy at different places and at different times depending on their actual position. Electrical distribution network for households and other immobile points of consumption is sufficiently dimensioned and there is always a firmly defined maximum of consumed power given in the contractual relationship with the customer. The consumption facilities for charging electric vehicles have their position defined, but their operation is dependent on the number of charged vehicles. This creates an inappropriate load for the grid, especially during a short consumption period associated with fast-charging [1], [2].

1.1. State of the Art

Contemporary fast charging stations require high power connection with electrical energy, and their usage causes large consumption peaks in the grid. With a growing number of electric vehicles and proportionally expanding infrastructure of charging stations there are two possible ways to solve this problem. The first solution is very economically challenging and requires strengthening of the distribution system, the other one is to build charging stations with minimal impact on the electrical system. A brief overview of similar existing solutions in the area of fast charging stations for electric vehicles is presented below.

One of the known solutions is called the high-speed charging station for EV's battery charging which has a high power output converter, whose input and output terminals are connected to respective electrical energy storage device and electrical load. The disadvantage of this solution is that it does not allow bidirectional power flow between the electric vehicle and the distribution network [3].

Another similar patented solution is called the fast charging system of electric vehicle. The accumulation system is composed of at least two accumulators connected in parallel or in series which can be repeatedly charged or discharged. Again, this solution does not support the bidirectional flow of electric power [4].

Last patented solution, which will be mentioned in this paper, is called the electric automobile fast charging station. It contains the charging system with multi-source power supply. Again, this solution does not allow to supply the energy back to the grid from connected electrical vehicles or from its own storage system [5].

One of the basic general requirements on the charging station is to work with minimal impacts on the power grid. It is possible to meet this requirement through sufficient amount of energy stored in the storage station. Charging stations with accumulation will then work within the framework of the daily consumption diagram, in the balanced energy budget if possible [6], [7].

Another option is to connect different types of renewable energy sources, especially solar and wind power plants. Active behavior of the system with respect to the distribution network allows supplying the electricity from solar and wind power plants during peak demands of the daily chart according to the needs of the power grid. When the charging station is not used, it is possible to supply power to the grid from connected renewable energy sources (if they are active) and to consume power from the storage station at the same time. Under critical operating conditions of the power grid, the system is also able to consume power (while meeting defined requirements) from the battery of electric vehicle which is connected to the charging station. However, this mode is considerably limited by the properties of the charging station and even by the structure and by defined modes in the connection point. Figure 1 shows the structure which represents the requirements for a conceptual solution of the system for electric vehicle charging.

1.2. The Main Elements of Active Charging Station

The basic elements of the power system of an active charging station are DC/DC converters used for fast charging and the storage system of the station. Linking the battery with the AC power grid is provided by a three-phase pulse rectifier which enables bidirectional flow of electric power. The fast charging process is provided by a two-quadrant DC/DC converter with current reversion. This converter allows bidirectional flow of energy throughout the whole power range. Its disadvantage is that it does not provide galvanic isolation of the charging station from the vehicle's battery, but this can be solved in other ways. The storage system of the station is composed of $LiFePO_4$ batteries containing about 80 kWh of electrical energy. The energy stored in the station's storage system may be sufficient to charge two to four common personal electric vehicles without the use of other connected sources. If the energy is supplied to the system from renewable energy sources, or if it is consumed from the power grid, then it is possible to charge the electric vehicles continuously. The designed conceptual solution fully satisfies the above defined requirements and allows many variations of energy flow according to actual conditions and requirements [8], [9].

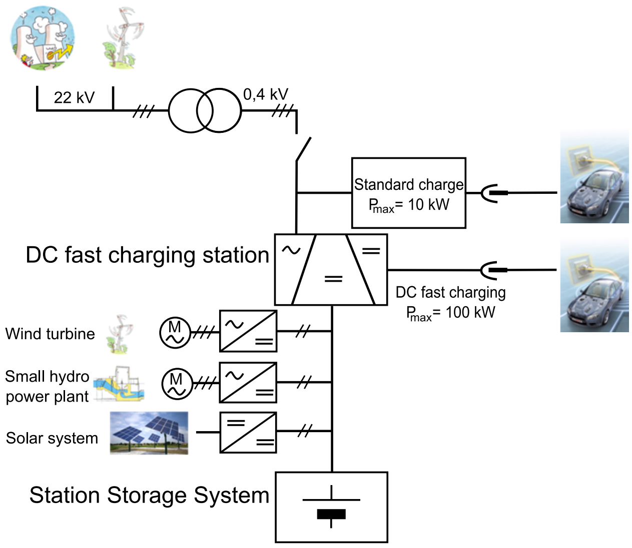

Fig. 1: Active charging station with renewable sources.

2. Description of the System

This paper follows up on implementation of storage systems in the framework of the Technology Center of Ostrava (TCO) built with the support of the project ENET - Energy Units for Utilization of non Traditional Energy Sources. The pilot production facilities were built in the TCO for research and development of energy accumulation systems. One of those systems utilizes lead-acid and $LiFePO_4$ batteries in a large accumulation station, the other one is a mobile accumulation unit [10].

The system of mobile accumulation is designed as a battery container unit equipped with $LiFePO_4$ batteries, which allows the connection of renewable energy sources, energy networks and fast charging stations for road and also rail electric vehicles. The system is designed with respect to development possibilities of various energetic solutions like Smart grids with ability to test these solutions and to put them into practice.

Figure 2 shows a block diagram of the mobile accumulation station. The block called ACB is the basic accumulation element of the station which is in this particular case composed of $LiFePO_4$ batteries. The block called RE represents the renewable energy source, such as a solar power plant or wind power plant, which can be connected to the accumulation system usually via a suitable coupling converter. Another unit, directly connected to the DC link of the accumulator system, is the device for fast charging of electric vehicles with the power up to 100 kW, which allows the vehicle to charge in 20 to 30 minutes, depending on the type and quality of its battery system. That block is marked by EVC – DC. The next part of the mobile accumulation system is a standard network connection using its own charger for vehicles with power up to 10 kW. With the support of energy accumulation it is possible to charge several vehicles at the same time from this terminal for a time period of 2-8 hours (according to the number of installed devices) without undesirable effects on the power grid. That block is marked by EVC – AC. The accumulation unit is connected to the network via a reversible voltage inverter for the possibilities of transmission of electricity produced from renewable energy sources and also for accumulation of energy surplus in the grid.

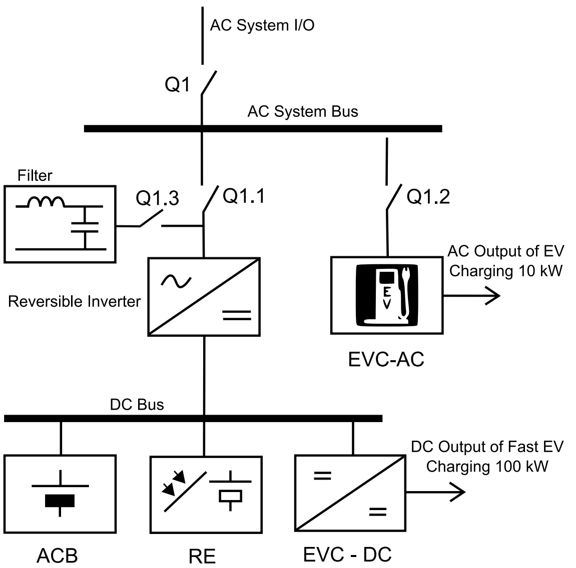

Fig. 2: Topology of mobile accumulation.

3. Modelling of the Charging System and Analysis of Simulation Results

Modelling of the charging system is implemented in two separate parts. The first part consists of a model of the pulse rectifier which creates a link between the grid and the battery station. The second part consists of a pulse converter which creates a link between the battery station and the charged electric vehicle. The function of the entire system in required operation modes was verified by the simulation results which are presented below.

The simulation of the pulse rectifier model verifies its function in the rectifier mode, in the inverter mode and the transition between these two modes. The results of the simulation are shown in Fig. 3 and Fig. 4. The waveforms of voltage and current are simulated on the input and output of the pulse rectifier. The first period of both pictures shows the start of the rectifier with charging current 1 A. After stabilization of circuit parameters the value of the charging current is set to 5 A (second period). The last period presents the transition to the inverter mode with a current value 3 A supplied from the battery station to the grid.

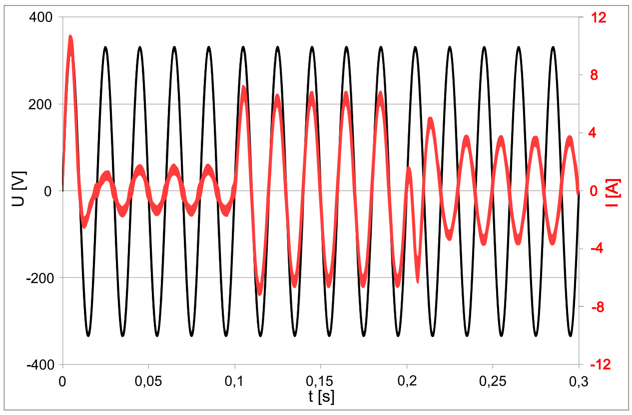

Fig. 3: The AC voltage and current on the input of a pulse rectifier.

The simulations of the standard and fast charging processes were performed in the simulation software Matlab Simulink. In this software, the entire structure of the charging system was designed to resemble the real model as much as possible. The results depicted on the following pictures are demonstrating the functionality of the system in both required modes [8], [9].

Figure 5 shows the waveforms of basic variables during a step-change of charging current supplied to the battery. The black waveform represents the change of the battery's state of charge. This value increases linearly while charging with constant current. Due to the

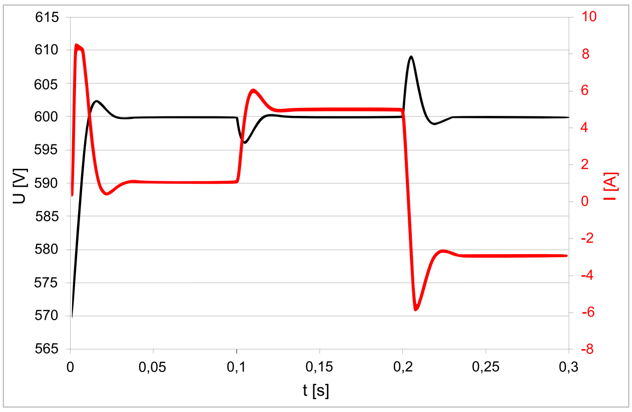

Fig. 4: The voltage and current at the battery station.

transparency, the red curve in the chart was inverted and represents the current supplied to the battery. In the case of negative current value, the battery is charging, and the product of negative current and positive voltage on the battery means that the negative power is "consumed".

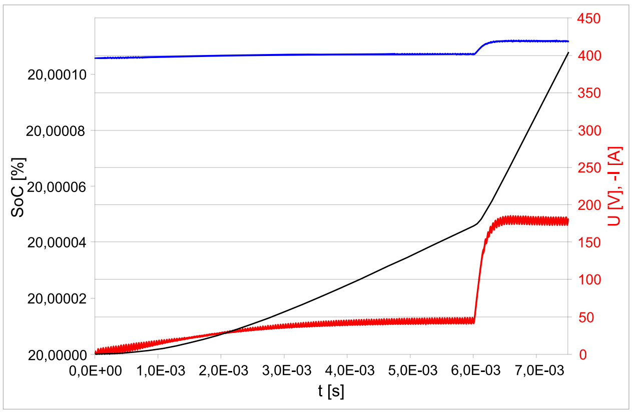

Fig. 5: Waveforms of variables in the battery of charged EV with charging current 45 A in time interval (0–6) ms and 180 A after 6 ms.

Tab. 1: Detailed description of waveforms in Fig. 5.

Color	Variable	Description of the waveform
Black	SoC	The state of charge of the EV battery unit
Red	I_{ACU}	The current supplied to the battery
Blue	U_{ACU}	The battery voltage during charging

The following Fig. 6 shows the waveforms of basic variables informing about the status of electrical energy consumed from the battery of electric vehicle.

In the first time period, the current is set to 45 A and after 6 ms of simulation, the value is increased to 180 A. The battery voltage and current are both positive and their product represents the consumed power – so the battery is discharged. The state of charge curve (SoC) decreases during discharging of the battery. If the consumed current value is constant, the curve is linear.

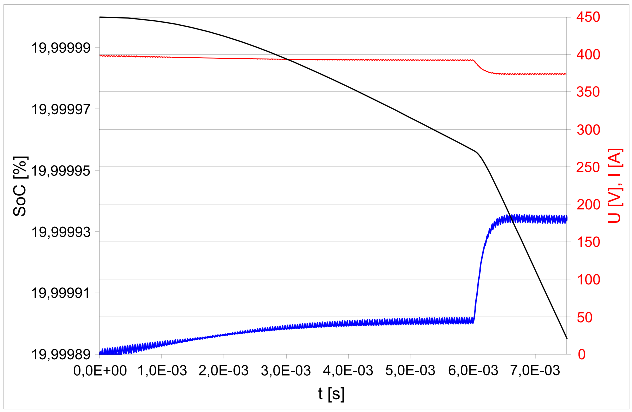

Fig. 6: Waveforms of variables in the battery of discharged EV with discharging current 45 A in time interval (0–6) ms and 180 A after 6 ms.

Tab. 2: Detailed description of waveforms in Fig. 6.

Color	Variable	Description of the waveform
Black	SoC	The state of charge of the EV battery unit
Red	I_{ACU}	The current consumed from the battery
Blue	U_{ACU}	The battery voltage during discharging

4. Experimental Results in Different Modes of Operation

The main purpose of this paper was to verify the functionality of the proposed system in the view of energy flow between various sources or energy storing elements such as electrical grid, battery stations and batteries of electric vehicles. The electrical energy in a form of power flow which is in time supplied or consumed by various sources is shown in Fig. 7. A negative power value of the particular component indicates that this component constitutes a power source and supplies its power to the system. On the other hand, a positive power value indicates the opposite action when this component acts as an electrical appliance and the energy of the system is consumed or supplied to the grid.

Three different sections A, B and C are highlighted in the Fig. 7, where the section A shows the mode of energy consumption from the distribution network, section B represents the off-grid mode when the system operates independently on the distribution network, and the section C displays the mode of energy supply to the distribution network.

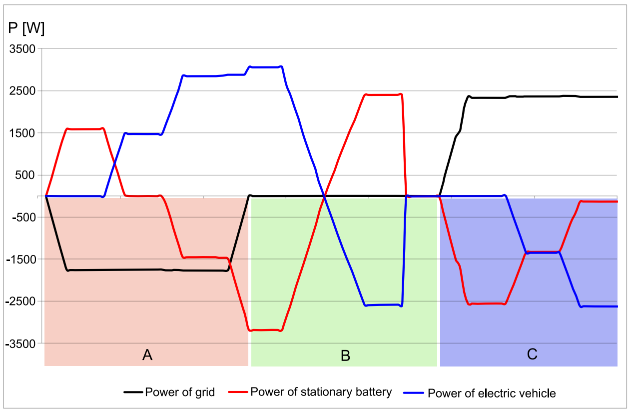

Fig. 7: Waveforms of the power flow in particular system sources in different operation modes.

Tab. 3: Detailed description of waveforms in Fig. 7.

Color	Variable	Description of the waveform
Black	P_{GRID}	The power of the grid
Red	P_{ACU}	The power of stationery battery
Blue	P_{EV}	The power of electric vehicle

5. Conclusion

This paper deals with the energetic structure for accumulation of electrical energy which is utilized as a storage unit in intelligent energy networks, commonly referred to as Smart grids. A section of the fast charging station for electric vehicles is contained within this structure. The entire structure creates a link between the grid and fast charging, which requires large amount of electric power. The energetic structure enables the charging station to consume high power and does not create a demand for high power consumption from the grid at the same time, because the peak power is provided by the storage unit.

The experimental part of the paper demonstrates the functionality of the system in all modes of operation. The efficiency of the entire system in a limited operating range reaches 89 %. It is a product of partial efficiencies of two separated power converters connected in series. The efficiency of individual converters reaches acceptable values: 92.5 % for the pulse rectifier and 96 % for the DC/DC converter.

Acknowledgment

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