Modelling of Electric Vehicle Charging Station for DC Fast Charging

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ABSTRACT

Electric vehicles (EVs) require fast-charging station networks to allow owners to rapidly charge the battery on long-distance drives. Fast-charging electric vehicles requires a sufficiently powerful connection to the electric power grid. Modeling and control of the process for charging the electric vehicles (EVs) are reviewed. The modeling approach and the models describing the system components are detailed. A model of a charging system for EVs and plug-in electric vehicles (PHEVs) is developed.

INTRODUCTION

In the recent years the developments in the field of electric vehicles (EVs) has been propelled by the obligations for reduction of carbon emission due to EVs advantages over the vehicles with internal combustion engines. EVs derive their power from large rechargeable batteries, which require charging stations. Hence, the deployment of a complete charging station infrastructure with special equipment becomes quite important. Plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) are two quickly emerging technologies that use powerful electric motors for propulsion source. A suitable understanding of electric vehicle battery helps to analyze and investigate EVs and how they interact with electric vehicle's charger and charging stations. EV batteries are very different from consumer electronic devices for example computers and mobile phones, etc. Equivalent circuit models are mainly used in the field of lithium-ion batteries for electric vehicles. They simulate the dynamic characteristics of the batteries. EV batteries need to deliver high power (up to a hundred kW) and highenergy capacity of tens of kWh within a limited space and weight. As most battery electric vehicles, hybrid vehicles also use regenerative braking to recharge the battery, which makes better the efficiency, and brake wear. The other type plug-in hybrid electric vehicles work similarly to hybrid vehicles.

PHEV also has an electric system and a combustion motor that can charge the vehicle's battery. These two types have larger batteries than conventional hybrid vehicles and can also be charged from the mains [1]. EVs have large battery packs that have a finite energy storage. Typically, they must be recharged by connecting to the power grid at home or in public areas. Usually, the charging systems for electric vehicles consist of an AC-DC converter used to rectify the AC voltage to a DC voltage, followed by a DC-DC converter used to adapt the rectified voltage required by the battery and to control the batteries charging process. Additionally, the charging systems can communicate with the power grid using power line communication devices to adjust the charging based on power grid conditions. Nevertheless, the battery pack should be monitored by a battery management system during operation in order to maximize energy usage and prolong battery life as well as to prevent charging and discharging processes. There are three types of charging station types called levels: Level I, Level II, and Level III (DC Fast charging. The battery charging system has an important role in the development of electric vehicles and plug-in hybrid electric vehicles (PHEV). In this paper a review of battery charging stations in section 2 will be reviewed, modeled of a charger in section 3 will be analyzed and simulated and a conclusion in Section IV .

2. A REVIEW OF CHARGING STATIONS

The Society of Automotive Engineers (SAE) has been working on the SAE J1772 standard for electric connectors for electric and hybrid vehicles, which classifies the electric vehicle stations into three levels:

2.1. Level I Charging Station

Level I charging station is used for smaller battery sizes. It is designed to allow a vehicle to be plugged into a household socket. This charging station can charge the vehicle's battery in approximately 8 to 10 hours depending on the energy capacity of the battery. Level I is an AC charging station only. The charger device is located inside the electric vehicle itself, known as an on-board charger. In European countries a single phase 230 VAC with fuses at 12 or 16 A are used while in the USA a single 120 VAC is used at maximum current of 16 A. The Level I charging is too slow to be beneficial as it can be plugged in for a limited period. The SAE J1772 standard covers the following charging power level: Level I up to 1.92 kW power .

2.2. Level II Charging Station

Level II charging station uses 240 VAC or 480 VAC 3-phase power supply and it is typically used in commercial applications to enable faster regeneration of electric vehicles battery system. It can be installed in home, public facilities or workplace. This type of charging requires service equipment unit in the electrical vehicle as well as electrical wiring, capable of delivering higher voltage depending on the BEVs and PHEVs requirements. Level II charging station delivers mains electricity to the electric vehicle like Level I charging station. The charging time on Level II is less than half the time than Level I charging. According to a SAE J1772 standard Level II charging supports charging at 208 VAC and 48 A (9.98 kW) and at 240 VAC and 80 A (19.2 kW). Most Level II charging station nowadays include a human-machine interface to make better the user experience with the charging station. The block diagram of the on-board charger is shown in Fig. 1.

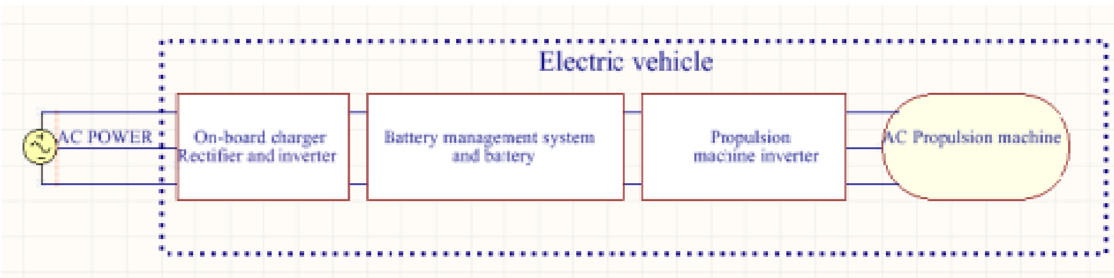


Fig. 1. Block diagram of on-board charger used in Level II charging station In the presented block diagram shown in Fig.1. the charging device is built into the vehicle. The main disadvantage of this topology is that the on-board charger needs an additional DC-AC inverter circuit.

2.3. Level III Charging Station (DC Fast Charging Station)

Level III fast charging stations uses an external charger (off-board) to supply high voltage up to 500 VDC at up to 400 A directly to the vehicle's battery. Generally, Level III charging station bypass the on-board charger on the electric vehicle. These DC charging stations are different from AC charging station because of the existence of the power factor correction (PFC) circuit and DC/DC converter [15]. Level III charging stations are also known as DC-fast charging stations and can operate very differently converting the mains voltage to the boosted DC voltage level able to deliver high current (up to 400 A). It is capable to charge the electric vehicle as little as 20 to 30 minutes while a Level I or Level II charging stations can charge the vehicle in four to eight hours. DC fast charging is managed by SAE J1772 Combo standard and Japanese CHAdeMO standard. The maximum charging power defined by the CHAdeMO standard is 62 kW (125 A at 500 VDC), while the J1772 Combo standard supports the maximum power at 100 kW (200 A at 500 VDC). Practically very few batteries support 500 V and charging stations are commonly equipped with both standard connectors and limit the rated power. Fast charging stations require very high power and complex electrical circuits. In order to support electric vehicles adoption in the market place, consumer will request faster charge rates for all electric vehicles. The block diagram of off-board charger is shown in Fig. 3. In this topology the charger can make use of higher power circuits than the on-board chargers .

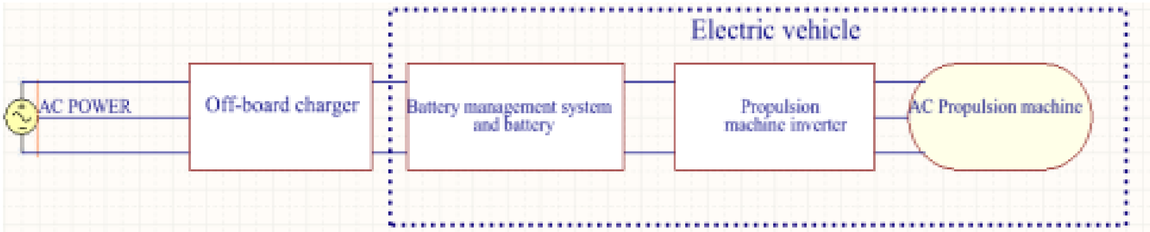


Fig. 2. Block diagram of off-board charger used in Level III charging station.

3. EV BATTERY CHARGER SCHEMATIC MODEL

There are several converter topologies, which can be used for power battery charger applications. The battery charger system for the EVs consists of an AC/DC rectifier, followed by DC/DC converter, which has to generate a DC voltage required by the battery pack. Primarily, in the AC/DC converters there are a variety of options to choose ranging from single phase to three phases. On the other hand, the three phase converters can also be soft switched or hard switched. A schematic model of the EV charging process is developed incl. grid–electronic power converter(s)–battery. The power converters are described by their transfer function: input voltage – converting function – output DC voltage. Block diagram and topology of batter\y charging system are shown in Fig.3 and Fig.4

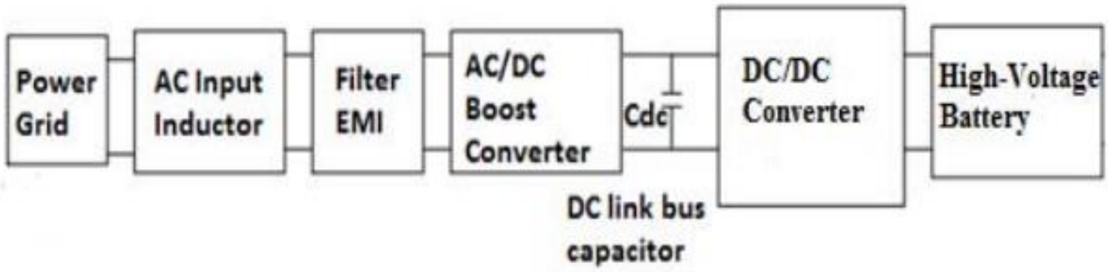


Fig. 3. A block diagram of EV charging system

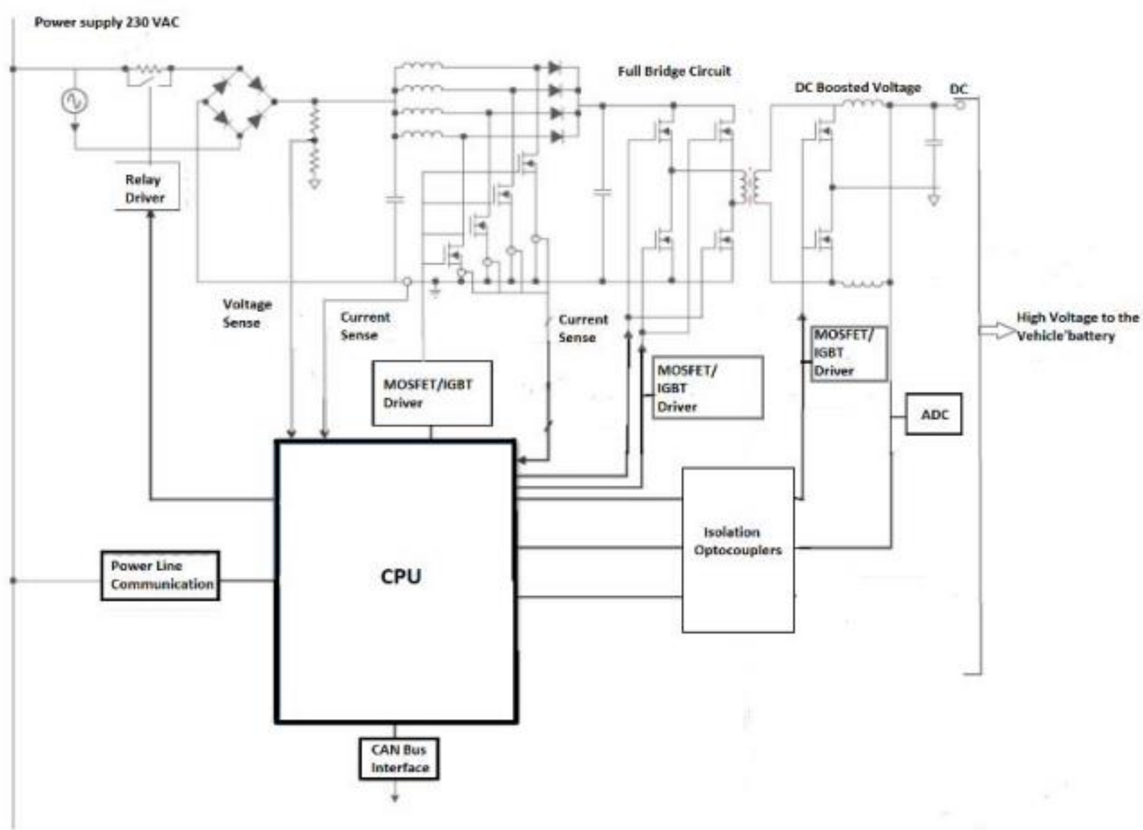


Fig. 4. Topology of EV battery charging station

3.1. BATTERY CHARGER MODEL

In Fig. 5, we show the model of a charging system implemented in Matlab/Simulik. The model of the charging system consists of three main blocks – battery, power converter and controller. The power converter model uses averaged parameter values and the presence of filter elements is accounted for by placing time-delay segments. This method of realization allows doing numerical experiments with limited computational power and long duration of over seven hours. This simplified model describes the main dependencies and includes a controller realized as aproportional P-regulator with coefficient of 25 and 400 V limitation for the battery in order to prevent over charging. The battery charger model is simulated and realized via Matlab/Simulink.

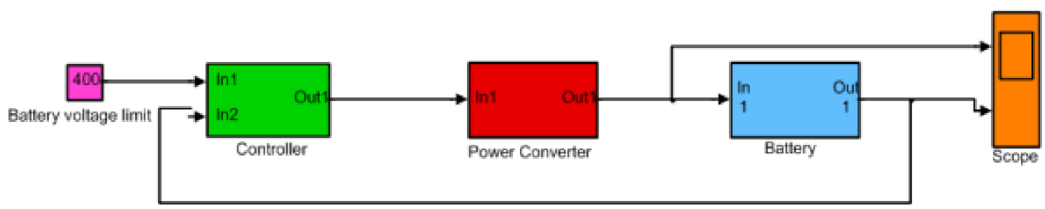


Fig. 5. Model of simulated battery charger system in Matlab/Simulink.

3.2. Battery Equivalent Circuit Model and Parameter Identification

Selection of a suitable battery circuit model is required for an accurate model-based estimation method. In order to simulate the battery characteristics, various battery models have been proposed, such as the thermal model, the equivalent circuit model and the electrochemical model. Generally, the equivalent circuit models are used to simulate the dynamic behavior of the battery. For EV batteries, it is important to be able to deliver random charging due to regenerative braking. The charging time and the lifetime of the battery depend on the battery charger characteristics. Safety limitation should be applied to guarantee the safe operation of batteries. The equivalent circuit model of the battery presented in this paper is frequently used to describe the influence of electrochemical processes as mass transport effects and layer effects, which have influence on the performance of the battery in EVs and HEVs. For example, Li-ion batteries are charged using constant current/constant voltage, but the charge rate and the voltage limit differ for different batteries from different manufacturer.

Li-ion batteries are most widely used in EVs and PHEVs. Fig. 6 shows the typical charging profile of a Li-ion battery cell . The common charging methods used for EVs and PHEVs battery are constant current (CC) and constant voltage (CV) charging. During the CC charging the current is regulated at a constant value until the battery cell voltage reaches a certain voltage level. Afterwards the charging is switched to CV charging and the battery is charged with a current applied by a constant voltage output of the charger .

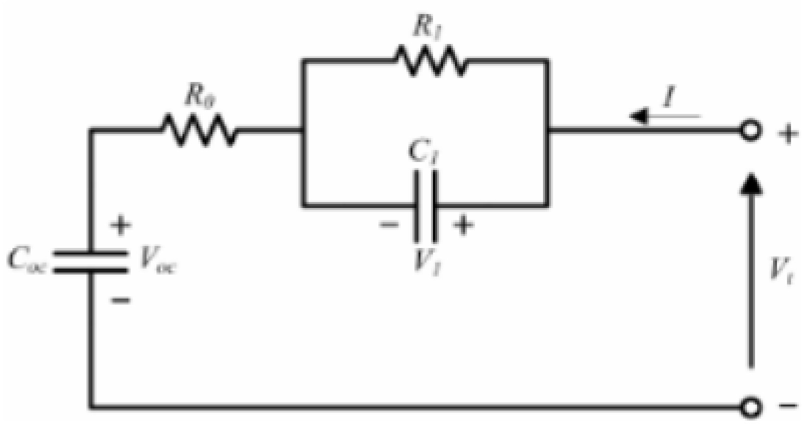


Fig. 6. Equivalent battery circuit model

3.3. Equivalent Battery Circuit Models This simplified equivalent battery circuit model is widely used. It is composed of three parts including an open circuit voltage (Voc) that is a terminal voltage of a battery, a parallel RC branch, which is responsible for the transient response during charging and discharging in the battery. The ohmic resistance R0 is connected in series in the battery model and it is the battery input voltage responsible for characterize the charge and discharge losses of the battery. Considering a low voltage that R1 has a low resistance, the capacitor C1 is in kilo-farad range. These resistance R1 and capacitance C1 compose a branch which modelling the electric dynamics. The voltage over Coc can be considered as the open circuit voltage of the battery. The capacitance Coc drops with the increase of the cycle number of discharge current. The voltage over Coc that determines the state of charge (SoC) of the battery depends on state of charge; it varies between 0 and 1. This capacitor has a very large capacitance and it presents the battery capability to store charge power. V1 is the terminal voltage drop across the capacitor C1. The model parameters are functions of SoC. The battery parameters to be determined are: the battery open circuit voltage, the ohmic resistance R0, and the parallel RC branch at different SoC. The SoC is used to indicate the remaining capacity of the battery and it is influenced by its own operation conditions such as temperature and load current. It is a critical parameter for battery management. The battery output voltage can be calculated from the battery open circuit voltage, the voltage drops from the battery equivalent impedance and the temperature correction of the battery potential. It is can be expressed by the following equation:

$$U(t)=V_{oc}-IR_1 e^{-t/\tau}$$

where τ =RC presents the time constant.

The electric behaviour of the equivalent battery model can be expressed by:

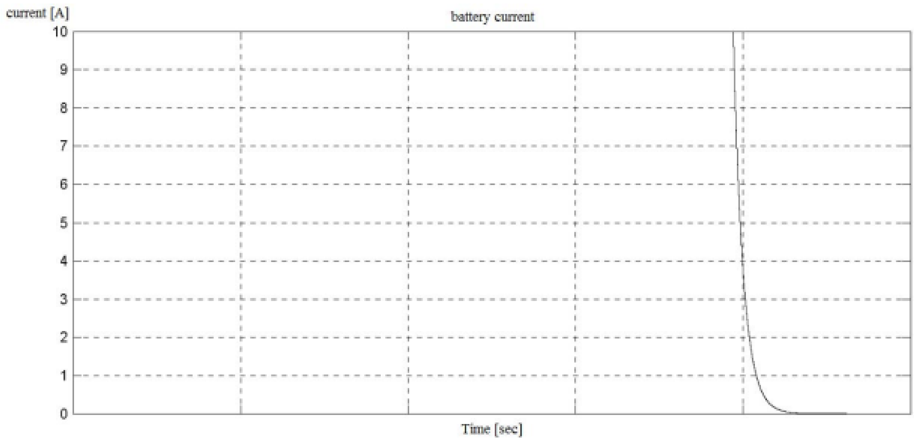
$$V=-V_1/R_1 C_1 + I_L/C_1$$

$$V_L = V_{OC} - V_1 - I_1 R_0$$

4. SIMULATION RESULTS AND ANALYSIS

The graphical results in Fig. 7 to Fig. 10 represent the simulation results for the charging station at normal charge with charging current of 10 A and accelerated charging with charging current of 100 A. The voltages of energy storage element are given as follows: for the case of normal charge (Fig.8) and for the case of accelerated charge (Fig.9).

Fig. 7.



Constant current at 10 A normal charging of the battery.

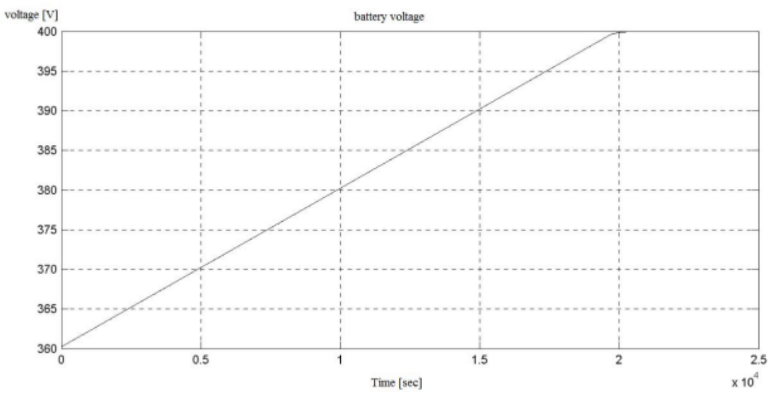


Fig. 8. Constant voltage charging of the battery.

From the simulation results, it can be seen that the charging system successfully processes the assignment and it is operational both in accelerated charging process and during normal charging

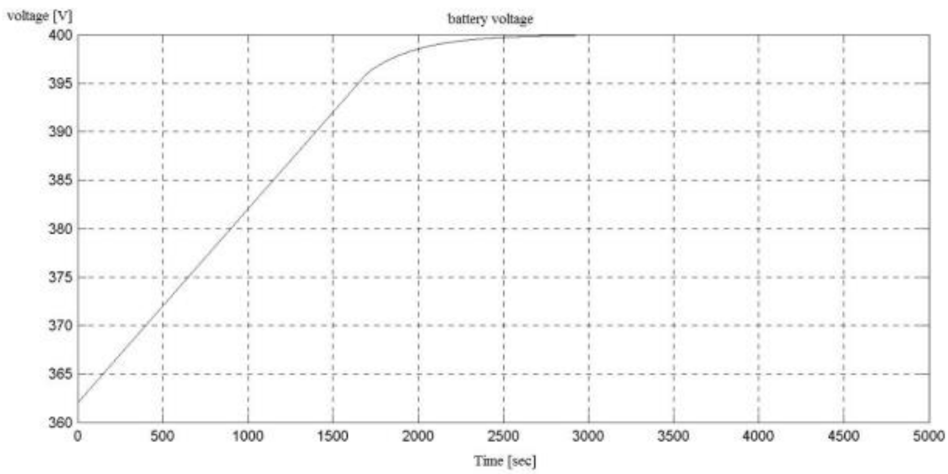


Fig. 9. Constant voltage charging of the battery.

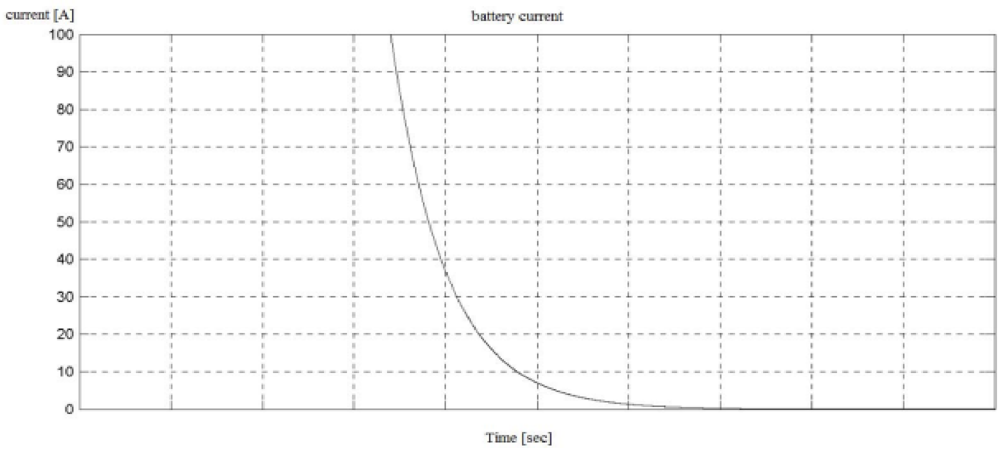


Fig. 10. Constant current at 100 A accelerated charging of the battery.

process. In addition. The use of a simple proportional regulator enables easy hardware realization and tuning.

4. CONCLUSION

This paper presents a simplified model of charging system simulated in normal and accelerated charging modes. We identified and determined the parameters of charging system and its equivalent battery model in order to obtain good battery management functions. Using a simplified model of power electronic system allows realization of numerical experiments with large duration. In result, we avoid the use of a battery size scaling to perform the model experiments. The proposed approach is useful in engineering design (design considerations) carrying out of the system and its validation and prototyping.