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Development of a Smart DC Micro-Grid for Plug-in Electric Vehicle Charging and Discharging

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Abstract

This paper presents a smart DC micro-grid system for plug-in electric vehicle charging and discharging. This DC micro-grid integrates the plug-in battery electric vehicles (BEVs) & plug-in hybrid electric vehicles (HEVs) together with the AC supply module, storage energy module, and intelligent control module. By connecting with the AC power source and the storage energy module, this grid can offer three types of DC bidirectional interfaces for the plug-in EV charging and discharging. Hence, according to the commands from the intelligent control module, the power in the grid can smartly distribute to the desired plug-in EVs. The system configuration and the testing model are discussed and analyzed.

Keywords: DC micro-grid, smart Grid, smart energy delivery, electric vehicle, plug-in electric vehicle.

1. Introduction

With increasing concert on the renewable energy development, the smart power grid becomes more and more attractable for smart energy delivery [1]-[3]. Also, the DC micro-grid can develop to the smart type of distributing the energy intelligently [4]-[6]. In addition, the emerging electric vehicle (EV) technologies [7]-[13] improve the capability of the plug-in EV to the power grid. In this way, the plug-in battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs) will become more and more important for the power grid due to their huge increasing amount in the near future [14]-[18]. Hence, how to delivery the energy between the plug-in BEVs & HEVs and the modern gird becomes a challenging issue.

In this paper, an intelligent DC micro-grid is proposed for smart energy delivery, which can distribute the energy between the grid and the plug-in BEVs & HEVs. This DC micro-grid system connects with the 230V AC power source and offers three types of DC bidirectional interfaces for plug-in BEVs & HEVs charging and discharging. Hence, according to the practical requirement, the power in the grid can flexibly flow to the targets. Also, this DC micro-grid is suitable used for the parking lot. This paper will present a detail discussion of the DC micro-grid configuration, and the corresponding testing model is also given for illustrating the validity of the grid system.

2. System Configuration

Fig. 1 shows the configuration of the proposed DC micro-grid system. This grid system integrates four major modules together for performing the energy and information transmission, namely the AC supply module, the battery storage module, the special load/energy module, and the intelligent control module. The AC supply module offers the 230V AC power to the 170V DC micro-grid. By using the bidirectional AC/DC converter, the power between the AC supply module and the DC grid can flow to each other. The battery storage module adopts the nickel metal hydride (NiMH) batteries as the energy storage room, which can alleviate the power flow fluctuation and increase the flexibility of the DC micro-grid. The special load/energy module consists of the plug-in BEVs & HEVs. These special loads are different from the tradition loads, which can feed back the energy to the grid. So, the batteries in the plug-in BEVs & HEVs can attract from or feed back energy to the grid. In addition, the intelligent control module takes the responsibility of collection all information of the converters, sensors, power signals by computers. Also, this module accomplishes the corresponding control algorithms in such a way that this DC micro-grid can realize the smart energy delivery.

Hence, the proposed DC micro-grid achieves the following features and characteristics.

- The proposed DC micro-grid offers three types of DC energy output (170V, 100V, and 48V) for the corresponding loads. So, the grid can directly meet three voltage types of plug-in BEVs and HEVs. Furthermore, by using the suitable converters, the grid can offer the different voltages for the EVs.
- The DC grid removes the transformer and has no the harmonic factor, hence inherently achieving the higher reliability and power quality than the traditional AC power supply.
- With the bidirectional AC/DC converter, the power cannot only flow from the AC side to the DC side, but also run from the DC side to the AC side.
- The storage module provides an auxiliary energy distribution room, which can make a power balance for the grid. Also, since the battery module adopts the NiMH type, it can offer/attract a high current to/from the grid in a short time. So, this storage module improves the grid ability of energy delivery.
- The DC micro-grid regards each plug-in BEV or HEV as a load or energy source. So, it means that they can bidirectionally distribute the energy to the grid.

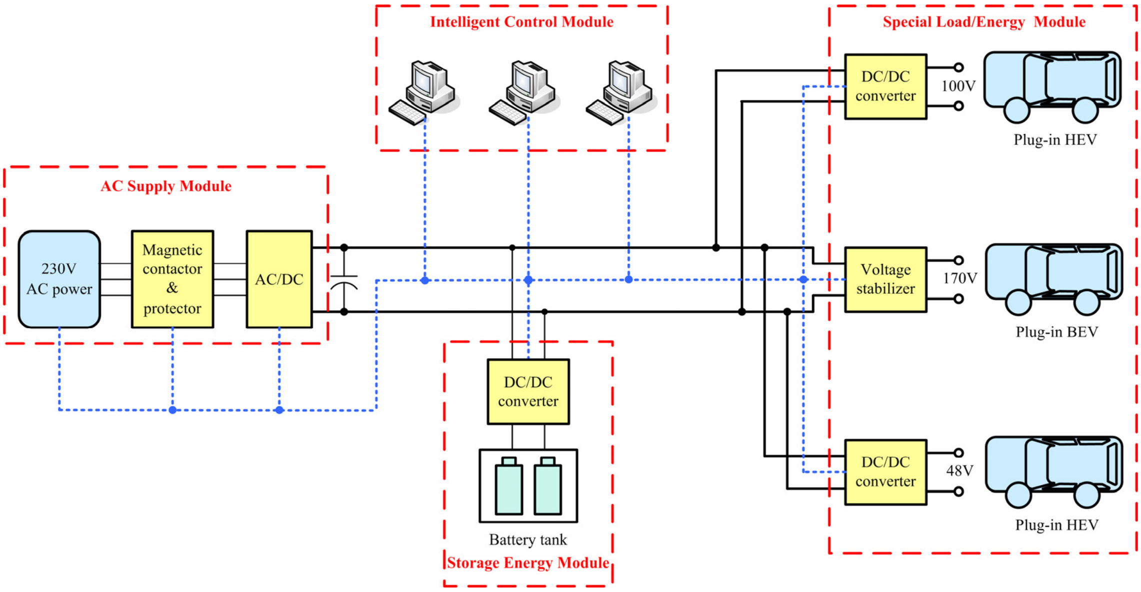

Figure 1: Proposed DC micro-grid system.

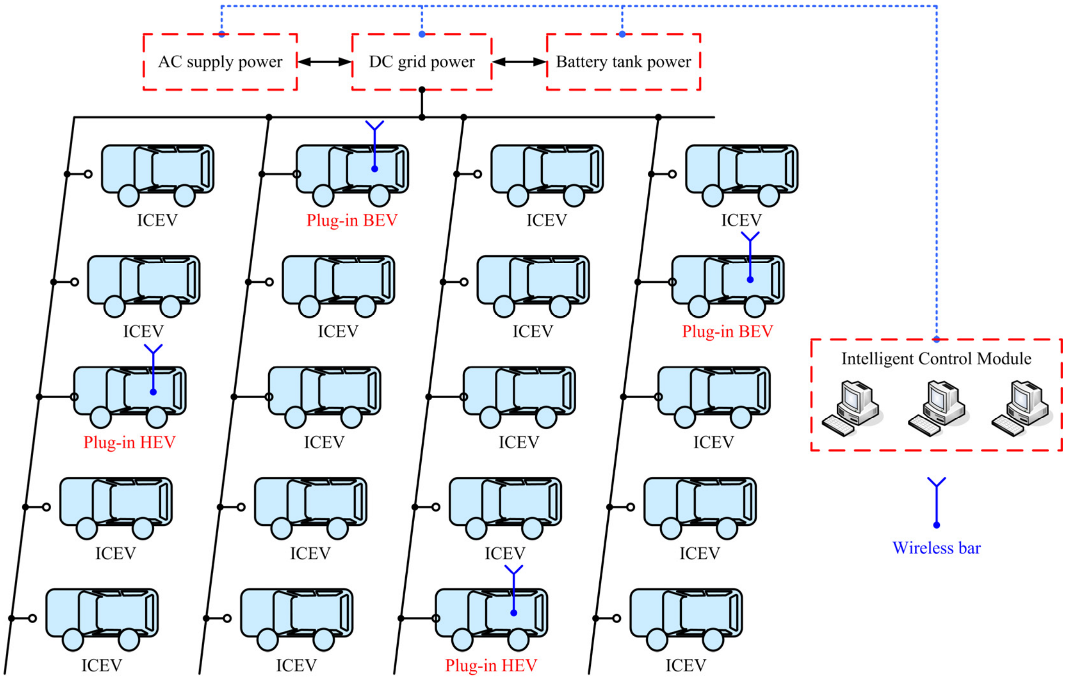

Figure 2: An application instance of the proposed DC micro-grid for a parking lot.

- By incorporating the intelligent control module into the DC grid, the gird has a smart feature of energy delivery. Thus, the grid cannot only deliver the energy from the AC power to the batteries, BEVs and HEVs, but also distribute the power among the batteries, BEVs and HEVs, without intervening the AC side.
- This DC micro-grid system is suitable as the subsystem of the main grid system for DC power requirements, such as for the parking lot.

3. Application Analysis

Fig. 2 shows an application instance using the proposed DC micro-grid for a parking lot, which can be used to demonstrate the power distribution in the grid. The parking lot is assumed to accommodate 300 automobiles, including the traditional internal combustion engine vehicles (ICEVs), plug-in BEVs & HEVs. Since in present and the near future, the ICEVs will still dominate the market, the pug-in BEVs & HEVs are supposed to occupy 10% in the parking lot for demonstration. It can be seen that the DC grid power is supplied with the AC power, and is also connected with the battery tank. Furthermore, all the modules are connected with the intelligent control module by wire connection. And the plug-in BEVs and HEVs can connect with the intelligent control module by wireless connection. Hence, the intelligent control module can perform the corresponding algorithms to distribute the power in the grid.

Fig. 3 shows the energy distribution of the proposed DC micro-grid. The energy distribution in the grid takes the following principles. Firstly, under the setting state of charge (SoC) of the vehicle battery (such as 60%), the power will deliver among the plug-in BEVs and HEVs. It means that the auxiliary energy of some EVs can be directly fed to other energy-required EVs in this micro-grid. Hence, if the EVs energy in the grid is enough for delivery, the DC micro-grid will not attract the power from the AC supply module at first. Then, according to the practical energy requirement for EVs, the DC grid will further provide the power for EVs from the AC side. Thirdly, the battery tank module can also offer the energy to alleviate the grid power fluctuation according to the specific cases. In addition, the EVs energy can be also fed back to the power grid in some period in such a way that the EVs can sell the electricity at high price time and buy the electricity at low price time. By this strategy, the proposed DC grid system can achieve the concept of smart energy delivery.

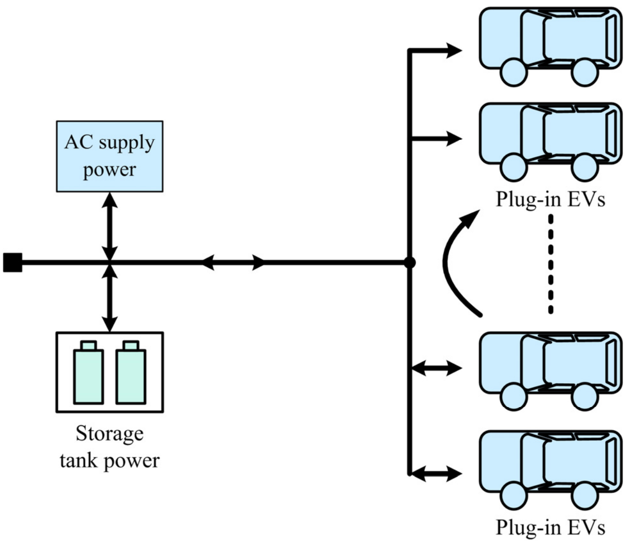

Figure 3: Energy distribution of the proposed DC micro-grid system.

4. Verification Results

The simulation platform is built up and conducted by the SimPowerSystems of MATLAB/Simulink. The basic simulated parameters are summarized as follow. When the EVs are regarded as the loads, they are assumed to three types voltage outputs of 170VDC, 100VDC, and 48VDC. And each of them is 10kW. Nowadays, there are different types of batteries and the corresponding technologies, which can be used in EVs, including the Lead-acid types, nickel metal hydride (NiMH) types, and Lithium-ion types, as well as the emerging technologies [19]-[25]. When the EVs are treated as the storages, they are assumed to the same type of the NiMH batteries due to their most common usages. The storage energy mdodule also adopts this kind of batteries. And this kind of battery can be fast charged and discharged in a very short time, which can be referred the model of 10/GP100EVH [26]. The storage energy module and each type of EV battery module use 20 units of 12V 10/GP100EVH, hence offering the energy of 240V and 100Ah. For shortening the simulated time, the capacity of the storage energy module and each type of EV battery module are rescaled to 1/300. It should be noted that this rescaling method will not influence the simulation performance of the grid system.

Firstly, the proposed DC micro-grid system delivering three types of DC power to the loads is simulated as showed in Fig. 4, which can demonstrate the situation for the grid power distribution. It can be seen that the current fluctuation is below 3.0%, and all the voltage fluctuation is less than 0.5%. Thus, it illustrates that this grid can successfully distribute the power to the targets.

Secondly, the charging and discharging performances of the battery tank are simulated as given in Fig. 5 and Fig. 6, which can demonstrate the simulation for the plug-in EVs & HEVs charging and discharging. It can be seen that the proposed DC micro-grid can effectively take or intake the energy from or to the battery tank with the fluctuation less than 2.5%. Also, the battery tank can readily attract/provide the energy from/to the grid with the satisfied condition. Thus, it can prove that the proposed grid system can transfer the energy within the grid system while maintaining the high power quality.

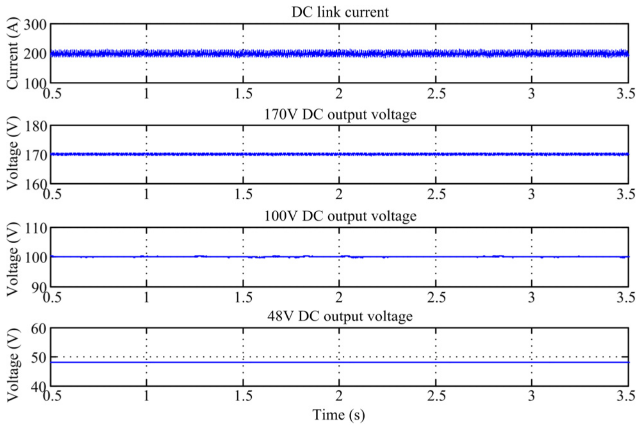

Figure 4. Power delivering performance of the proposed DC micro-grid system.

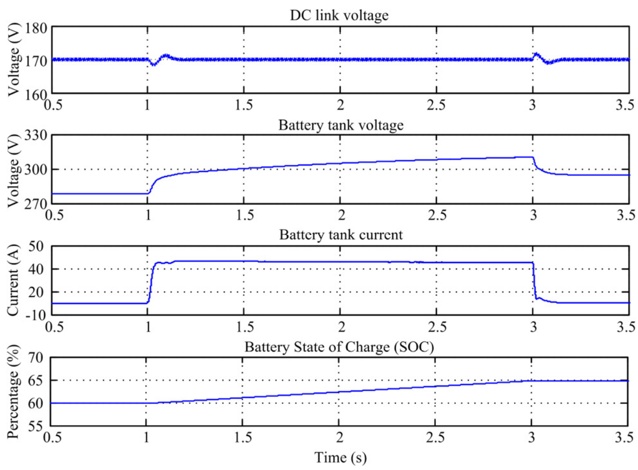

Figure 5. Charging performance of the grid system.

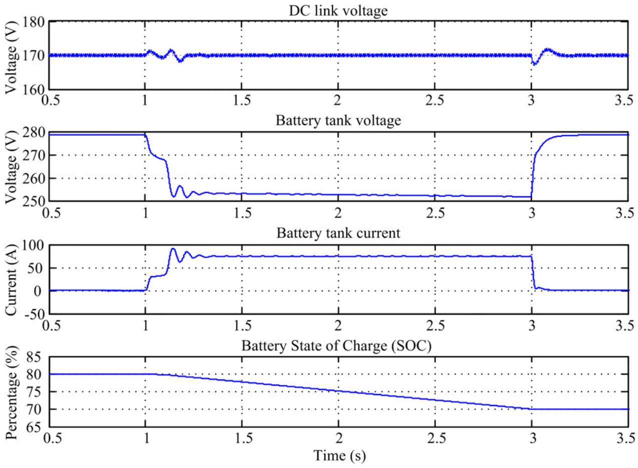

Figure 6. Discharging performance of the grid system.

5. Conclusion

In this paper, a smart DC micro-grid is proposed for the charging and discharging of the plug-in BEVs and HEVs. The proposed grid system consists of four major modules for distributing the energy and information, namely the AC supply module, the battery storage module, the special load/energy module, and the intelligent control module. Hence, the proposed DC micro-grid can distribute the energy smartly. The system configuration and an application testing model are demonstrated and analyzed.

6. Acknowledgement

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