Chapter 45
Control Strategies of Hybrid Power Supply System Based on Droop Control

Rongjia He, Ruichang Qiu, Zheming Jin and Weiwei Yu

Abstract Along with the rapid development of Chinese railway, EMU has already become a widely accepted travel tool. But conventional EMU has a high dependency on the overhead contact line (OCL) network as well as a potential risk of injecting harmonics into the OCL network, which may lead to an oscillation in the OCL network. This paper majorly studies the control strategies of hybrid power supply system for the first diesel electric multiple units in China. Due to the natural restriction of permanent magnet synchronous generator (PMSG), the output voltage of the alternator cannot be controlled directly. To solve this problem and achieve a good power allocation, the droop control is applied to build the control system of hybrid power supply system. The result of experimental prototype test shows that the control strategies work well and achieved a good power allocation in its operation.

Keywords Hybrid power supply system · Droop control · PMSG · Bidirectional DC/DC converter

45.1 Introduction

From 1958, when the first electrified railway was started, to the official opening of Harbin-Dalian high-speed railway on December 1, 2012, China has built more than 48,000 km of electrified railway, which holds the world record of the longest electrified railway [1]. Along with the rapid development of electrified railway, higher requirements are emerging, especially in safety, high efficiency, and energy saving.

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In China, electric multiple units (EMU) have many problems to overcome. Firstly, EMU has a serious dependence on the overhead contact line (OCL), but OCL network is not suitable for many areas. Moreover, OCL itself also has short life cycle, low power factor, and other problems, which also increase the cost of construction of electrified railway. Secondly, OCL is the only energy source of EMU, which means that the vehicle can neither accelerate nor brake with renewable braking if the OCL or the main transformer is unavailable. This is a potential problem without temporary solution, and lots of faults are related to this directly or indirectly. Thirdly, the major braking method of EMU is the combination of renewable braking and mechanical braking, but renewable braking may inject a number of harmonics to the OCL network and it may impact on the operation of other EMUs. As for mechanical braking, the kinetic energy will transform into heat and consumed on the braking sheet, which will certainly cause abrasion and increase the maintenance cost greatly [2]. These problems are seriously restricting the further development of EMUs.

To face these demands and problems, a novel hybrid EMU with both traditional OCL system and novel hybrid power supply system is designed as intercity medium-distance transit vehicle by CNR Changchun Railway Vehicles Co., Ltd. and Beijing Jiaotong University. For this vehicle, OCL and hybrid power supply system founded by diesel electric generator set and/or battery banks are both available power sources [3]. This kind of design made the concept of diesel electric multiple units (DEMU) one step forward, and it therefore makes itself more suitable for an intercity rail transit. When OCL is available, the electric drive system will be driven in a traditional way. When operating in a non-electrified area, the hybrid power supply system will supply the electric drive system. By applying high-performance lithium titanate battery, the braking energy can be fully absorbed and stored, and this part of energy would be released during the following acceleration (Fig. 45.1).

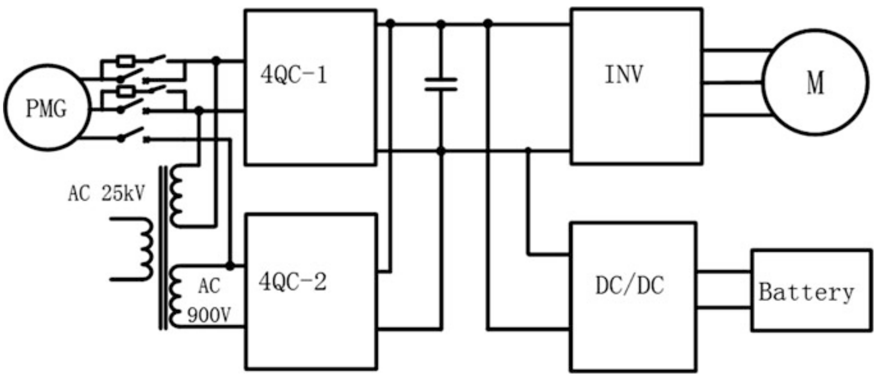

Fig. 45.1 Main circuit of DEMU

This paper is mainly working on the control strategy of hybrid power supply system. Firstly, the behavior and characteristic of diesel electric generator set are studied. After that, the research will focus on the Bi-DC/DC converter, which is the core of the hybrid power supply system. The topology, circuit principle, and control strategy of Bi-DC/DC converter will be introduced. The cooperation control strategy that combines the Bi-DC/DC converter and diesel electric generator set will also be studied and proposed in this part.

45.2 Diesel Electric Generator Set

Diesel electric generator set is the most frequent emergency power supply in many areas. To realize the lightweight high-power generator [4], permanent magnet synchronous generator (PMSG) is used in the diesel electric generator set of the DEMU. The usage of PMSG makes a great contribution to the lightweight design (Fig. 45.2).

Since the rotor is permanent magnet, the exciting winding is saved, which also means that the output voltage of the generator set is no longer fully controllable. Moreover, diode rectifier bridge is used because the frequency of the output varies from 60 to 133 Hz. For these reasons, the natural droop characteristic of PMSG is used to control the output indirectly. By using three-phase dynamic load, a natural droop curve of the system founded by PMSG and diode bridge can be obtained as shown in Fig. 45.3.

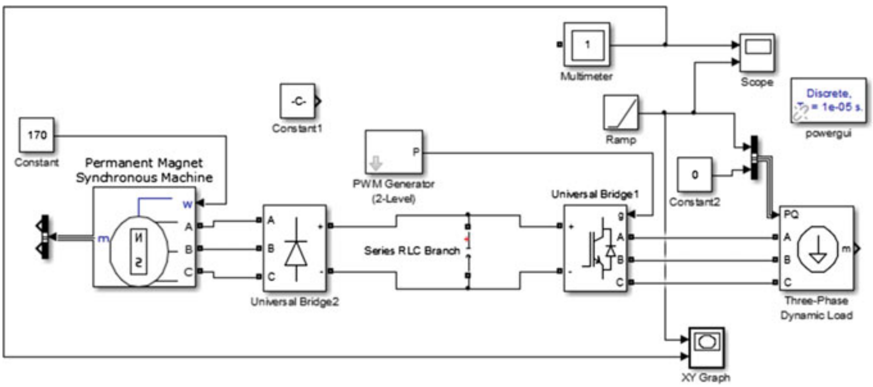

Fig. 45.2 Simulation of PMSG and non-controlled rectifier circuit using MATLAB/Simulink

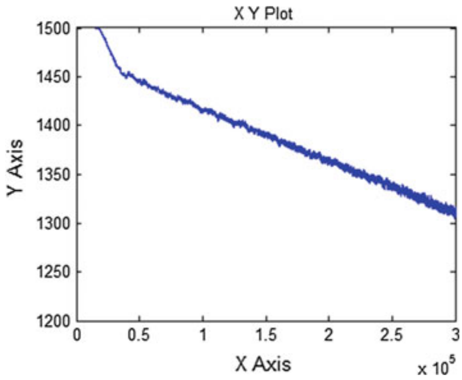

Fig. 45.3 Droop characteristic curve of PMSG

45.3 Bi-DC/DC Converter

Bi-DC/DC converter is two-quadrant-operated DC/DC converter, which can achieve bidirectional energy flow. It is widely used in hybrid electric vehicles, micro-grids, and other areas that may be related to energy storage [5–8]. In the hybrid power supply system of DEMU, Bi-DC/DC converter is the key component which controls the output power of the battery bank directly.

In buck mode, the circuit principle is shown in Fig. 45.4. When the IGBT is switched on, the IGBT Q1, the high-voltage port, the inductor L, and the low-voltage port will form a pathway, and the current through the inductor L will increase as shown in formula (45.1) during this period. When the IGBT is switched off, the parallel-connected diode D2, the inductor L, and the low-voltage port will form a pathway, and the current through the inductor L will decrease as shown in formula (45.2) during this period.

$$L\frac{\mathrm{d}i_{\mathrm{L}}}{\mathrm{d}t}=(U_{\mathrm{dc}}-U_{\mathrm{bat}})-ri_{\mathrm{L}} \tag{45.1}$$

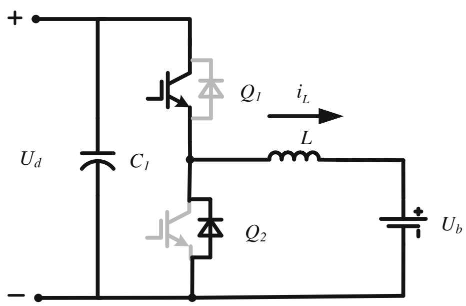

Fig. 45.4 Buck mode of the circuit

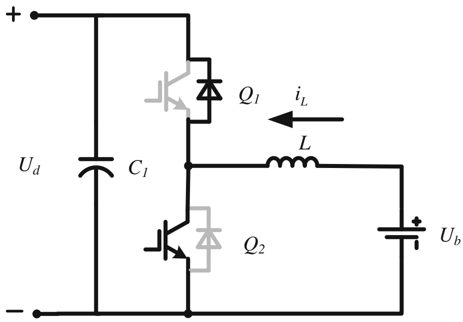

Fig. 45.5 Boost mode of the circuit

$$L\frac{\mathrm{d}i_{\mathrm{L}}}{\mathrm{d}t} = -U_{\mathrm{bat}} - ri_{\mathrm{L}} \tag{45.2}$$

where i_{L} is the current through the inductor L, U_{dc} is the voltage of intermediate DC link which is also the voltage of high-voltage port, U_{bat} is the voltage of battery bank which is also the voltage of low-voltage port, and r stands for the parasitic resistance in the circuit.

In boost mode, the circuit principle is shown in Fig. 45.5. When the IGBT is switched on, the IGBT Q2 and the inductor L will form a pathway, and the current through the inductor L will increase as shown in formula (45.3) during this period. When the IGBT is switched off, the parallel-connected diode D1, the high-voltage port, the inductor L, and the low-voltage port will form a pathway, and the current through the inductor L will decrease as shown in formula (45.4) during this period (Fig. 45.6)

$$L\frac{\mathrm{d}i_{\mathrm{L}}}{\mathrm{d}t} = -U_{\mathrm{bat}} - ri_{\mathrm{L}} \tag{45.3}$$

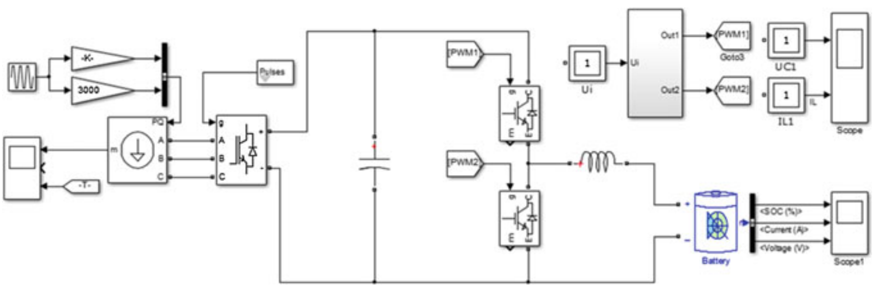

Fig. 45.6 Bi-DC/DC converter simulation model using MATLAB/Simulink

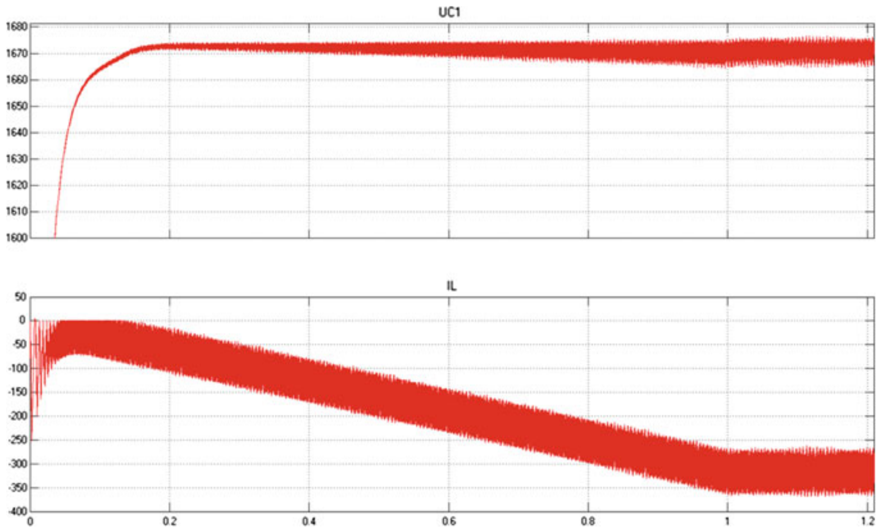

Fig. 45.7 Battery discharge waveform

$$L\frac{\mathrm{d}i_{\mathrm{L}}}{\mathrm{d}t} = (U_{\mathrm{dc}} - U_{\mathrm{bat}}) - ri_{\mathrm{L}} \tag{45.4}$$

By using voltage loop PI control, the waveform of result of simulation for discharging is shown in Fig. 45.7.

45.4 Droop Control Strategy

For a multi-input power supply system, an efficient power conditioning method is to regulate the voltage of DC bus. As for the hybrid power supply system for hybrid EMU, the power conditioning can be realized by using droop characteristic of PMSG and gives a voltage reference by droop curve.

Since the diesel electric generator set is connected to DC link via a diode bridge, a study of three-phase six-pulse diode rectifier is conducted to model it. By applying the droop control theory of power system and P-V droop control method of DC micro-grid and distributed generation to control the Bi-DC/DC converter and the voltage of DC link.

The maximum available power of the diesel electric generator set could be obtained by low-speed communication between two systems, and for each maximum power, there will be a voltage given by droop curve in a certain engine speed.

The voltage reference of DC link is selected according to the droop curve, which limited the output of diesel electric generator set, for this reason, the generator set can be protected from overload (Figs. 45.8 and 45.9).

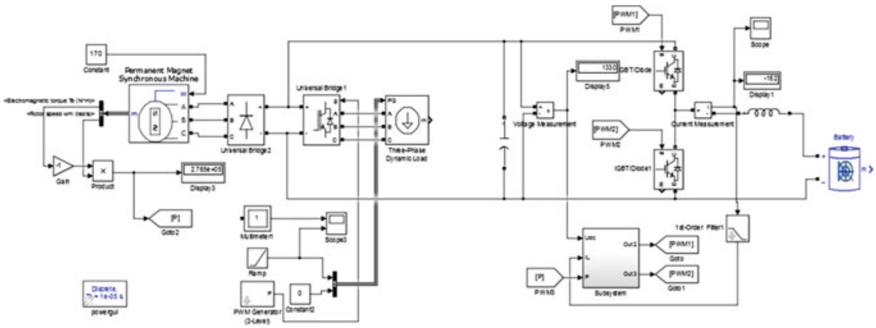

Fig. 45.8 Simulation model of hybrid system using MATLAB/Simulink

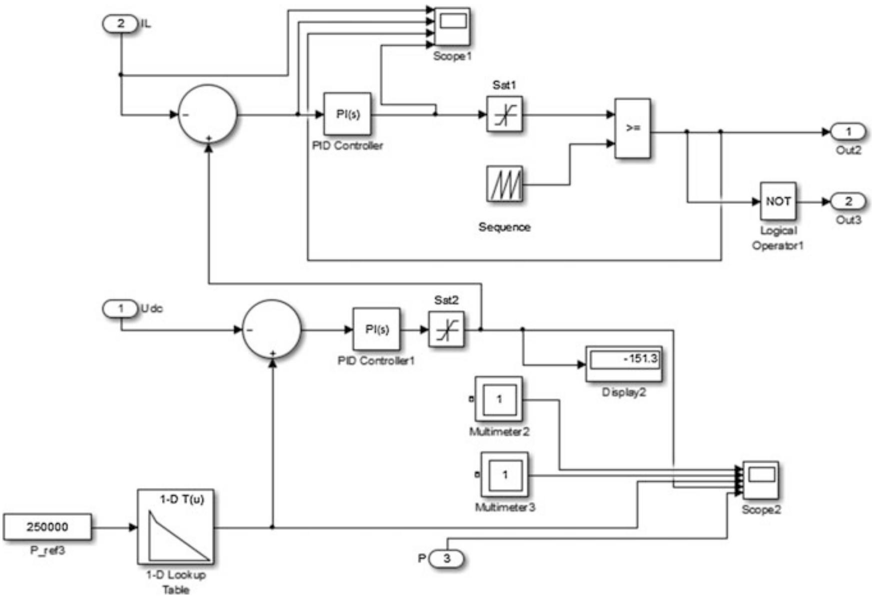

Fig. 45.9 Control system and pulse generation module

A simulation result of power conditioning of the hybrid power supply system is shown in Figs. 45.10, 45.11, and 45.12.

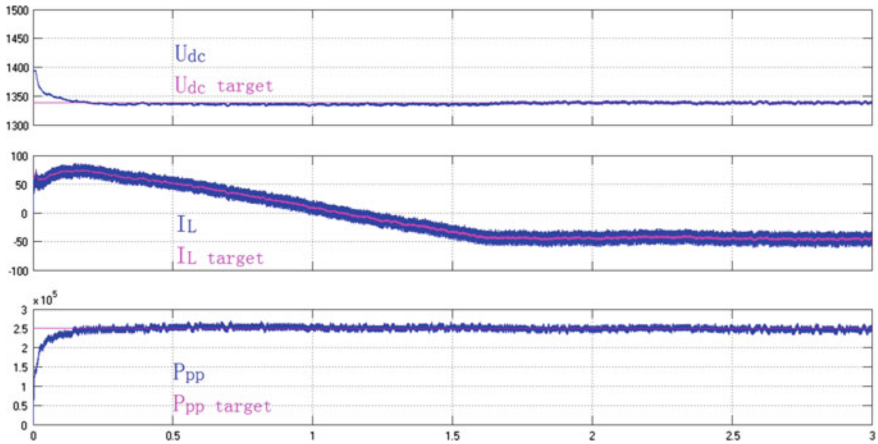

Fig. 45.10 Simulation results of droop control strategy

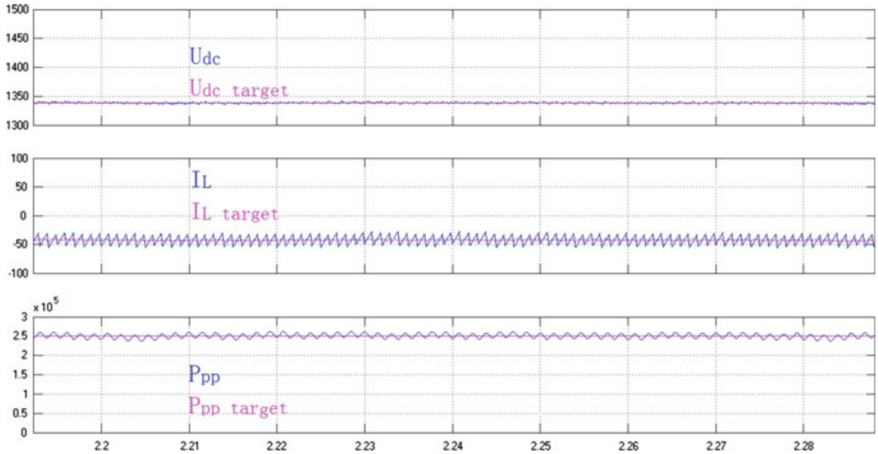

Fig. 45.11 Amplified waveform

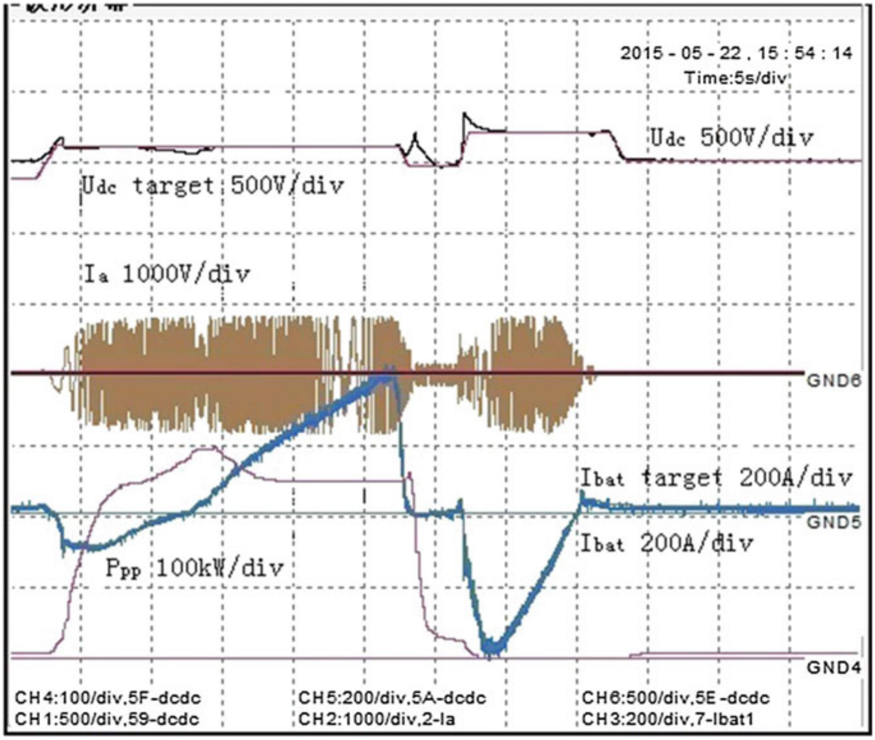

Fig. 45.12 Actual waveform of droop control strategy

45.5 Conclusion

This paper studies the hybrid power supply system with its operating diesel electric generators and power allocation method of traction battery. To reduce the diesel electric generator set, total volume and weight of the permanent magnet synchronous generator are used. Because of the inherent limitations of permanent magnet synchronous generator, the output voltage of the alternator cannot be directly controlled. To solve this problem, to achieve good control of power distribution, the droop control is used to generate a control system of the hybrid power system.

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