A 15kW Grid-Connected Battery Charging and Discharging System with AC Regeneration Function

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ABSTRACT

In this paper, a 15kW grid-connected battery charging and discharging system was proposed. AC regenerative device which consisted of an inverter using IGBTs and LCL filter transferred surplus power to grid. Phase locked loop(PLL) was used to resolve three-phase unbalance. AC regeneration function is able to improve the rate of energy use and the cost savings of energy is expected.

1. Introduction

The demand of secondary batteries has increased, and its researches have performed actively in lots of countries. Power Electronics techniques are being developed to utilize battery energy. As a part of smart grid, grid-connected eco-friendly distributed generation is also in spotlight.[1]

Due to the power that is regenerated to a grid, positive economical effects are expected. Particularly, through using the regenerated power, systems are able to not only reduce power consumption but also increase the energy usage ratio. The conventional DC regeneration system supplies power from a grid to battery by a diode rectifier in charging mode. Because the surplus power is exhausted to heat at the electric load in discharging mode, the percentage of power usage is lower. This system is utilized at a battery test device.

In this paper, proposed AC regeneration system supplies energy to batteries by a PWM converter in charging mode and regenerates the energy to a grid by a 3-phase inverter that is activated in discharging mode.

2. Conventional DC Regeneration System

The block diagram of the conventional DC regeneration system is shown in the Fig. 1. Energy is supplied to batteries by a diode rectifier and bidirectional converters in charging mode. Batteries that are charged and discharged differently regenerate the energy through a DC Bus Line. When the discharging and charging ratio is over 8:2, regeneration is unavailable. Because of the surplus power, the voltage at the bidirectional converters is exceeded certain limit. Therefore electric load consumes the energy as heat. For this reason, additional devices are required in order to eliminate the heat, and the power usage rate is decreased.

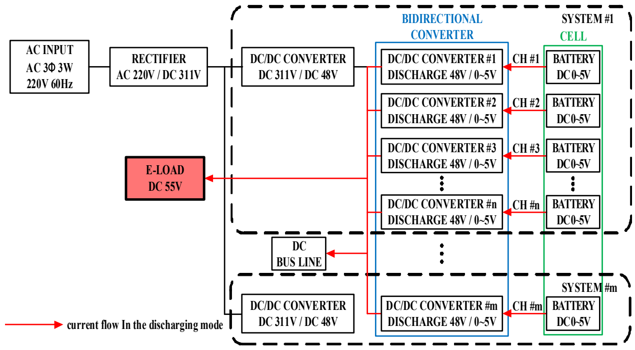

Fig. 1 Block diagram of conventional DC charging and discharging System.

3. Proposed AC Regeneration System

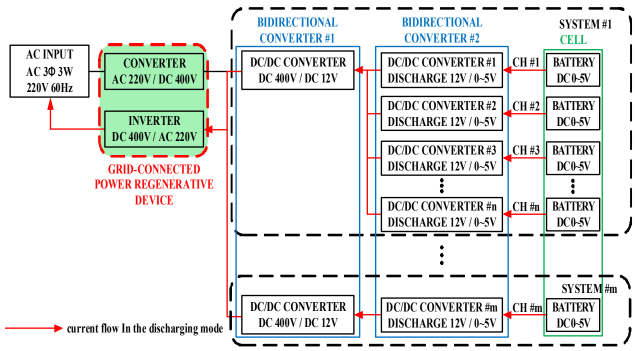

Fig. 2 Block diagram of proposed AC charging and discharging System.

A block diagram of the proposed grid-connected AC regeneration system is shown in Fig. 2. The voltage boosted by the bidirectional converters upto 400[V_{dc}] is transformed to AC voltage, and the AC voltage is regenerated to the grid by the PWM inverter in discharging mode. The diodes of the DC regeneration system are changed to switches in order to operate bidirectional converters. The higher step-up/step-down ratio by controlling the switch is gotten. As diodes of the 3-phase rectifier are replaced to IGBTs that are able to control regenerative voltage, the rectifier is able to operate as a 3-phase inverter utilized in discharging mode. Therefore reduction of unnecessary hardwares and stable operation are possible. Unlike the DC regeneration system, the usage of energy is increased by regenerating the surplus energy to the grid without exhausting the energy at the electric load. The device is decreased because the electric loads and a cooling system do not exist.

3.1 Bidirectional DC/DC Converter

The first bidirectional converters are isolated full-bridge converters, and the converters boost the output voltage of the second converters to 400[V_{dc}]. The second bidirectional converters are non-isolated buck-boost converters that boost the output voltage of the battery from 5[V_{dc}] to 12[V_{dc}]. The output voltage of the first converters is able to be regenerated since the switches are employed instead of diodes. The converters of battery charging and discharging system consist of modules. Each module is able to control the voltage of a battery. As the number of modules, the total capacity of the batteries is increased. The broken modules are able to be replaced conveniently. The modules of the converters are shown in Fig. 3.[2]

Fig. 3 Modules of Bidirectional DC/DC Converters.

3.2 Grid-connected DC/AC Inverter

Fig. 4 shows a grid-connected DC/AC inverter used for an AC regenerative device. It operates as a PWM converter rectifying 3-phase AC voltage in charging mode. It changes the boosted 400[V_{dc}] at the charging and discharging device to 3-phase AC 220[V_{rms}] and connects to the grid in discharging mode. The device for controlling the gate drive circuits of the IGBTs is TMS320F28335 and the control method of switches is Space Vector PWM(SVPWM). The size of filter is reduced through using the delta connected LCL filter, and the filter eliminates the noise comes from 3-phase power.[3],[4]

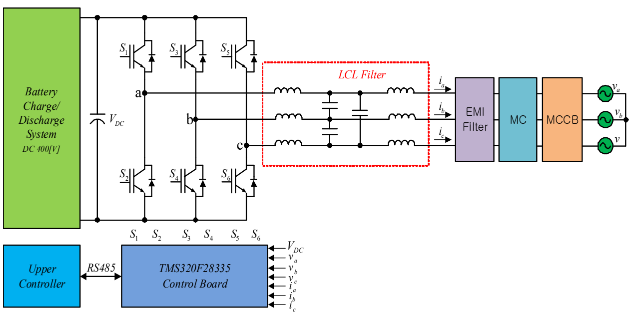

Fig. 4 Block diagram of a grid-connected DC/AC inverter.

Table 1 Parameters of AC regenerative device.

Parameters		Values	Units	Parameters		Values	Units
Input	DC Max Power	16500	[W]	Output	AC Rated voltage	220±13	[Vrms]
					AC Rated current	23.75	[Arms]
	DC Max Voltage	500	[V]		Rated freq	60	[Hz]
	DC Min Voltage	311	[V]		THD	3	[%]
					PF	>0.98	
	DC Max current	57.88	[A]		Efficiency	>0.95	

3.3 Control Algorithm of DC/AC Inverter

A block diagram of an AC regenerative device controller is shown in Fig. 5. The voltage and phase are detected to consider unbalance component of a grid and controlled by d-axis and q-axis. In order to operate an inverter, the 3-phase switching signals are produced by SVPWM.[5],[6]

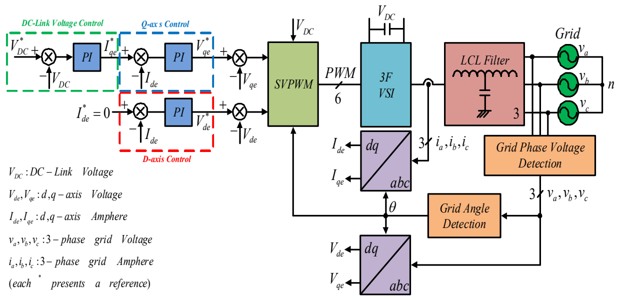

Fig. 5 Block diagram of an inverter controller.

4. Simulation and Experimental Results

The scheme of the Psim model is shown in Fig. 6. The changing voltage source is used for presenting the charging and discharging states of batteries.

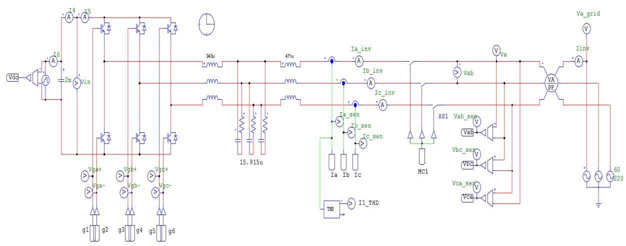

Fig. 6 Scheme of the Psim model.

The waveforms of the simulation are shown in Fig. 7. Fig. 7(a) shows the voltage of the batteries and the ouput power waveforms. Regeneration through the inverter is shown in Fig. 7(b). When the charged voltage of the battery is over 400[V_{dc}], the voltage is regenerated to the grid. The current flowing to the grid is increased and the positive sequence voltage and current have the same phase. The charging mode by the PWM converter is shown Fig. 7(c). When the charged voltage of the battery is below 400[V_{dc}], batteries are charged by the PWM converter. The current flowing to the grid is decreased and the phases of positive sequence voltage and current become inverted.

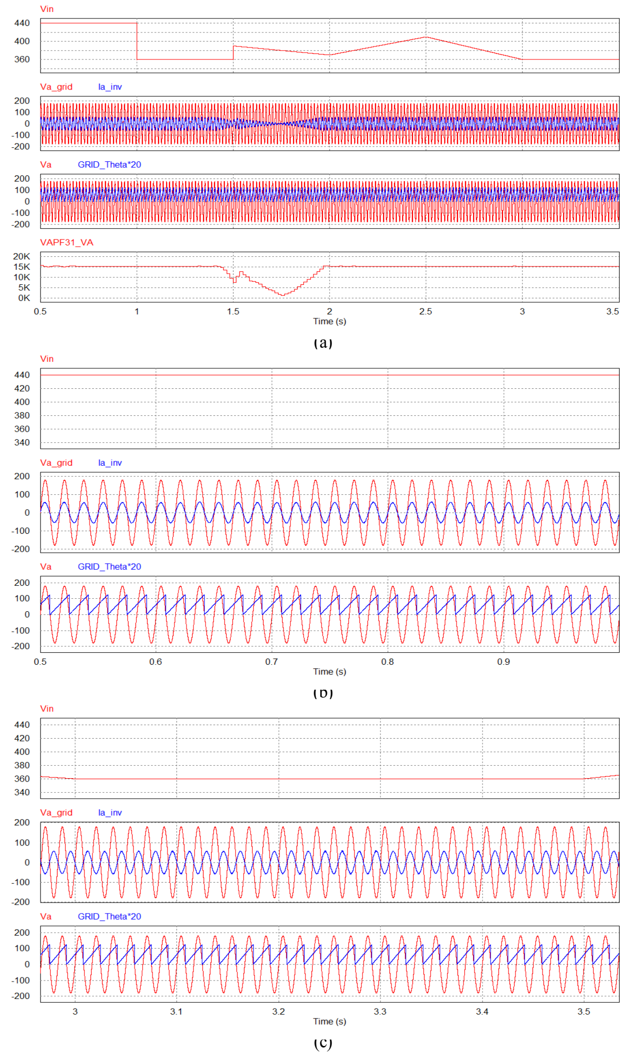

Fig. 7 waveforms of the Psim simulation.

Fig. 8 shows an experimental setup of AC regenerative device and the waveforms of an experiment are shown in Fig. 9. The positive sequence voltage is detected by sensing the line-to-line voltage of a grid. The positive sequence current getting into a grid is measured. PLL considering load unbalance is used and the delay component by a low pass filter(LPF) is compensated.

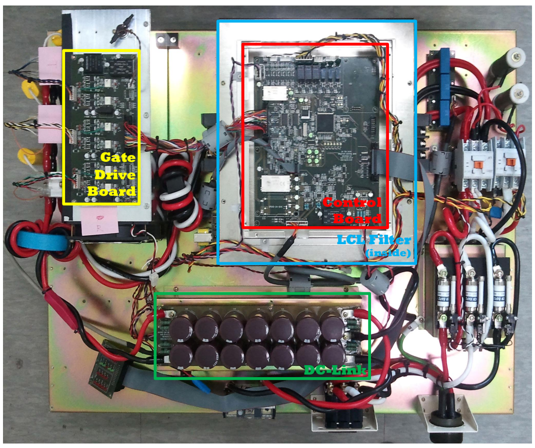

Fig. 8 Experimental setup of AC regenerative device.

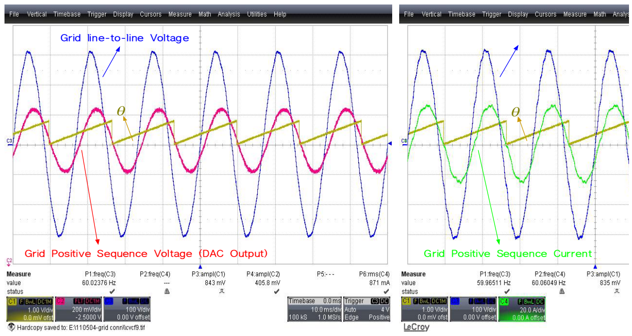

Fig. 9 Waveforms of the positive sequence voltage and current.

5. Conclusions

In this paper, the AC regeneration system that regenerates the surplus power to a grid in the discharging mode was proposed. Regeneration to the grid and the batteries charging was confirmed by the Psim simulation. The regenerated AC positive sequence voltage and current were confirmed by the 15kW experimental setup in the discharging mode. The additional experiment for battery state transition will be performed.

Acknowledgements

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