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Development of DC Controller for Battery Control for Elevator Car

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Abstract

Among transport vehicles, Special Vehicles (SVs) are seriously exposed to energy and environmental problems. In particular, elevator cars used when moving objects in high-rise buildings increase the engine's rotational speed (radian per second: RPM). At this time, when the vehicle accelerates rapidly while idling, energy consumption increases explosively along with the engine speed, and a lot of soot is generated. The purpose of this paper is to develop a bi-directional DC-DC converter for control of vehicle power and secondary battery used in an elevated ladder vehicle (EC) used in the moving industry.

As a result of this paper, the performance test of the converter was conducted. The charging/discharging state of the converter was simulated using DC power supply and DC electronic load, and a performance experiment was conducted to measure the input/output power of the converter through a power meter. Through this experimental result, it was confirmed that the efficiency was more than 92% in Buck mode and Boost mode at maximum 1.2kW output.

Keywords: *Interleaved converter, Elevator Car, Special Vehicles, Secondary battery, Bidirectional DC-DC converter.*

1. Introduction

The depletion of fossil fuel, one of the main energy sources of industrial activities, has a direct impact on national development and energy security, and air pollution and global warming caused by rapid industrialization cause problems that are directly related to human survival. As a result, global eco-friendly policies are being established. As part of this, there is a strong demand for de-petroleumization and reduction of carbon dioxide emissions for transport systems that consume most of fossil fuels [1]. In particular, among transport vehicles, Special Vehicles (SVs) are seriously exposed to energy and environmental problems [2].

Among special vehicles, the elevator car (EC), which is used in the moving industry, can easily solve the most difficult task, high-rise transportation, even in row houses, villas, business buildings, and low-rise apartments without gondola.

Elevated ladder vehicles that are necessary for moving luggage on high floors are equipped with a rotating plate that is convenient to use at a turning angle of 360°, so you can easily work by rotating the rotating plate

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in a narrow space or in a place where vehicle rotation is impossible. When moving objects, the elevated ladder is operated. At this time, the engine's rotational speed (radian per second: RPM) increases rapidly, resulting in an explosive increase in energy consumption and a lot of smoke. In order to solve this problem, a lot of research is needed to use a secondary battery without using an automobile power unit. This secondary battery method has the advantage of being able to compensate for the shortcomings of the existing internal combustion engine, and it is very helpful to the environment as it can reduce carbon dioxide emissions. As it is in the implementable stage with the current technology level, more attention is being paid to it. Here, the secondary does not directly use the vehicle battery as an input, but uses a voltage stepped down by a separate regulator as an input.

As shown in Figure 1, in this paper, we intend to develop a bidirectional DC-DC converter for EC battery control to control vehicle power and secondary batteries used in the elevator car (EC) used in the moving and transport industry.

As a detailed development of this paper, when the EC is turned on, the converter operates to charge the 12(24)V battery, and when the 12V or 24V battery is fully charged, the converter stops operating. The converter's capacity is designed in a maximum of 2.5kW based on the output (charging) current of 100A, and the converter is equipped with overload, overcurrent, and overheat protection functions to protect the system. It is also designed to enable RS232C, CAN, and Bluetooth communication for high-level controller and wireless monitoring.

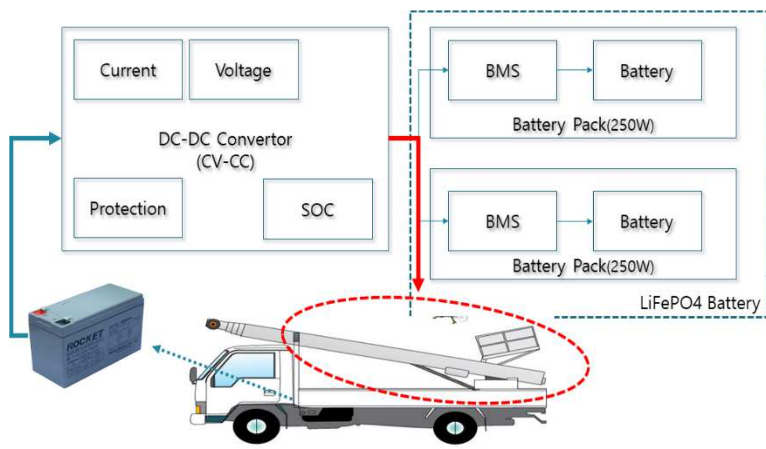

Figure 1. Structure of a bidirectional DC-DC converter for vehicle and secondary battery control

2. Research Method

2.1 Two-way DC/DC Converter Topology

A DC/DC converter is a DC converter that converts an arbitrary DC power source into a DC power source in the form required by the load. It is widely used in industrial application fields such as motor drive devices of vehicles, computer devices, communication systems, and power systems of satellites. DC/DC converters are largely divided into converters that use transformers and converters that do not use transformers, and converters that do not use transformers are divided into Buck, Boost, and Buck-Boost. [3].

In the case of using an expensive battery or in order to utilize high-power energy in a low-voltage battery, a DC-DC converter [4] for battery charging and discharging is required, and an appropriate converter design is required to improve the performance of the system. In order to secure such performance, we intend to apply the interleaved converter [5] among various converter topologies capable of two-way power control. Interleaved converters reduce the ripple of the input/output current of the entire system by connecting several converters in parallel and operating the converters with a phase difference. In addition, it is possible to increase the system efficiency by reducing losses due to current distribution and ripple reduction, which can reduce the capacity of the capacitor, and the inductor and switching elements used due to the distribution of the current are it has the advantage of reducing the volume of the entire system by using it.

Figure 2 is a block diagram of a two-phase interleaved bidirectional DC-DC converter for battery charging and discharging. Each phase of a half-bridge type Buck-Boost converter consisting of L1, S1, S2 and L2, S3, S4 is parallel. It is composed of two phases by connecting, and the switching of each phase is controlled to have a phase difference of 180°.

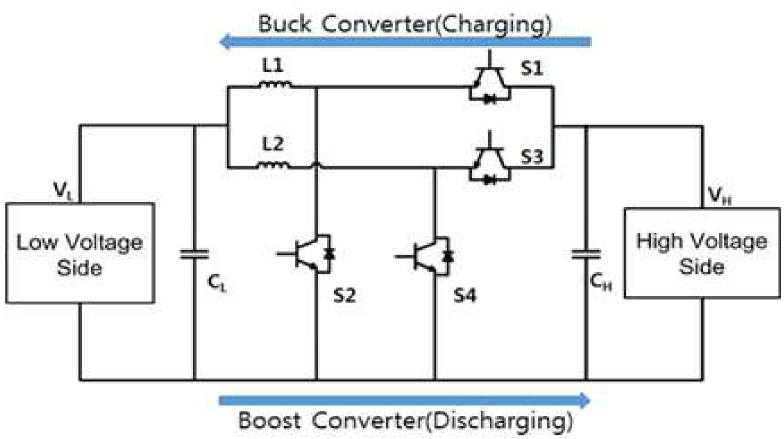

Figure 2. 2-phase interleaved two-way DC-DC converter

Due to this structure, the current is divided by half in the two phases compared to the current ripple generated in the inductor in the topology of consisting of only one phase, and the ripple current generated here is canceled by the phase difference. Is reduced the ripple of the output current. Therefore, the quality and efficiency of the output power are increased. In addition, when designing hardware, the overall system volume can be reduced due to the reduction of capacitors and reduction of the rated current of the device such as inductors.

3. Design of a Two-phase Converter for Charging and Discharging in Both Directions

In this paper, for converter for bidirectional charge/discharge of battery to be used for the power of EC and secondary battery for high ladders that can move moving objects, two-phase converter design is required. For this purpose, the converter operation by mode is designed in the same way as the operation mode of a 1-phase half-bridge type Buck-Boost converter [6].

3.1 Design of Boost Mode

Figure 3 shows the mode according to the ON/OFF operation of the switch when operating with boost. At this time, the case where S_2 is operated as a switch as an active element and S_1 as a diode as a passive element is represented by ② and ③ respectively. The semiconductor device MOSFET[7] is a two-way device and has a smaller loss by Rds(on) resistance than the conduction loss of current flowing through the anti-parallel diode. Therefore, the loss is reduced by turning on S_1 when S_2 is OFF. Can be reduced. When switch S_2 is turned on, energy is accumulated in the inductor as shown in ② in figure 3 below. The main waveform of the inductor current rises as shown in Figure 3, and the voltage across the inductor is the same as the battery voltage. When the switch S_2 is OFF, the energy accumulated in the inductor is discharged through the diode as shown in ③ of Fig. 3. At this time, the inductor current decreases, and the voltage applied to the inductor is equal to the difference between the battery voltage and the output voltage. When the battery is discharged, the condition of the battery must be checked to prevent over-discharge from occurring.

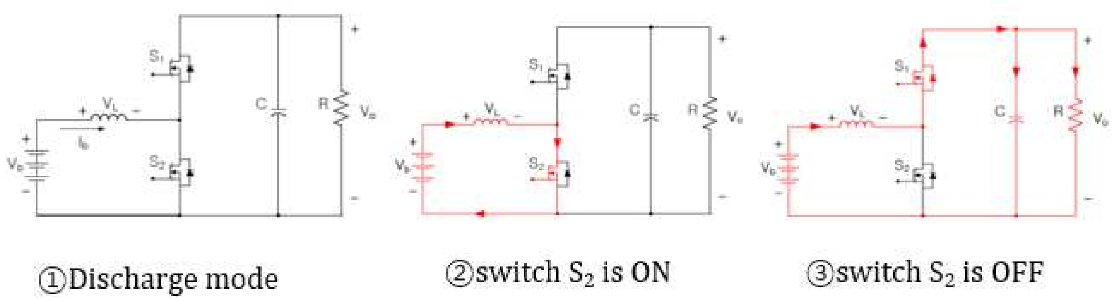

Figure 3. Switch operation in discharge mode and Current flow

3.2 Design of Buck Mode

Figure 4 shows the mode according to the ON/OFF operation of the switch when operating with boost. At this time, S_1 is an active element switch, and S_1 is ON/OFF with period Ts conduction time DTs. When the switch S_1 is ON, there is a difference between the battery voltage and the output terminal voltage in the inductor, as shown in ② in Figure 4, and the inductor current rises and the battery is charged at the same time. On the contrary, when switch S_1 is turned off, battery voltage is reversed to the inductor as shown in ③ in Fig. 4, and the inductor current decreases through reverse parallel diode of switch S_2.

When charging the battery, it is necessary to check the state of the battery to prevent it from becoming overvoltage.

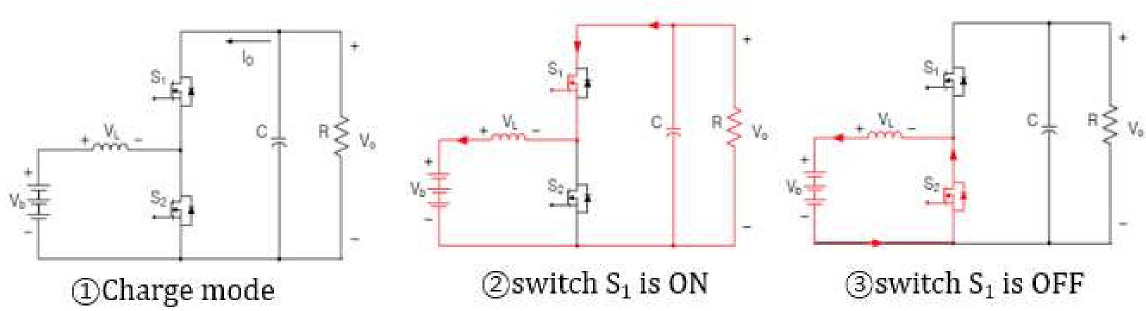

Figure 4. Switch operation in Charge mode and Current flow

3.3 Design of Power Converter

Figure 5 shows the contents of the induction design according to the operation mode. Induction selection is as follows. In the boost mode and buck mode, the current ripple rate is 1%, and the inductor is calculated under conditions such as 12V to 24V battery charging and 24V-12V charging. In the charging mode from 24V to 12V based on 100kHz switching, the inductor was calculated the largest as 44.5uH, and was selected as an inductor of 50uH considering the margin of the inductor.

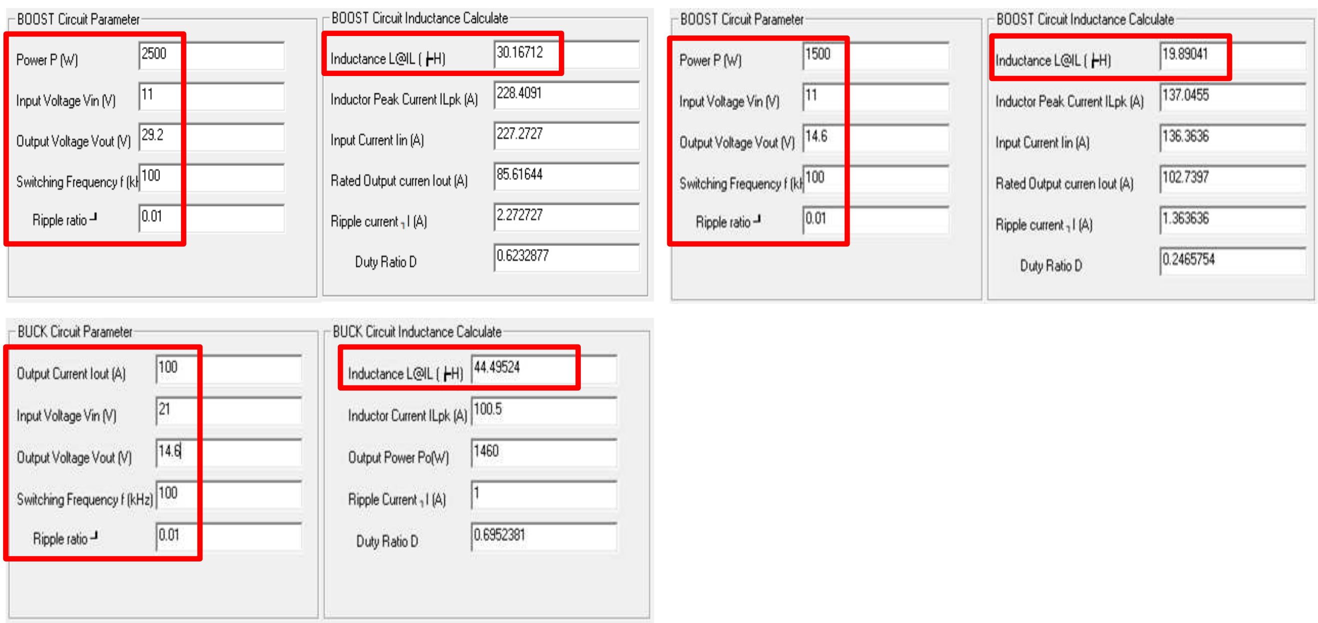

Figure 5. Design of the inductor according to the operation mode

4. Simulation of Two-way DC-DC Converter Topology

Simulation was conducted to verify the designed converter topology, and the simulation conditions were composed of the contents shown in Table 1 below. The parameters in Table 1 are classified as voltage used for general passenger cars is 12V, and 24V for commercial vehicles. In this study, we simulate the topology of a 12V and 24V bidirectional DC-DC converter. High voltage is based on 24V, simulation range is 20~28.8V, and low voltage is based on 12V, range is 11.6~14.8V. In the boost mode and buck mode, select the inductor based on current ripple rate of 1%. Under conditions such as 12V -> 24V battery charging and 24V -> 12V charging, it is based on inductor 100kHz switching and in 24V -> 12V charging mode, the inductor is calculated as 44.5uH as the largest. Therefore, in this study, an inductor of 50uH was selected in consideration of the inductor margin.

Table 1. Main parameters

Parameter	Value	Remark
High voltage battery(Vrec)	20 ~ 28.8V	
Low voltage battery(Vbat)	11.6~14.8V	

Low voltage load(Rbat)	0.146Ω
High voltage load(Rrec)	0.292Ω
L	50 uH
Fsw	100 kHz

Figure 6 shows the simulation's voltage and current control block diagram. The controller was designed by obtaining the transfer function for current and voltage control through the converter system modeling. In order to eliminate mutual interference, the bandwidth of the current and voltage controller was set so that a difference of more than 10 times occurs, and double loop PI controller was used to ensure the stability of the control structure, and integrator saturation anti-wind-up control technique was applied to eliminate the resulting output offset.

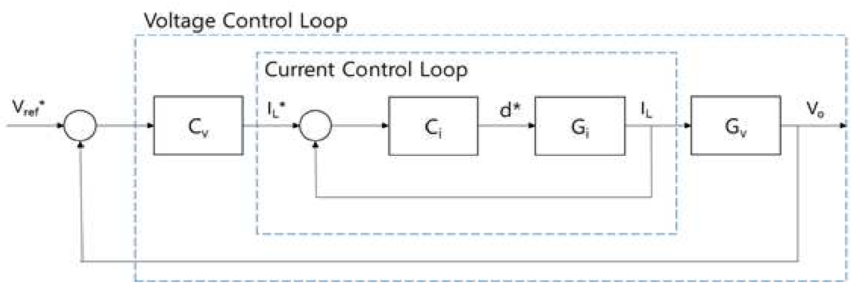

Figure 6. Block diagram of Voltage and Current Controller

The PSIM simulator[8] was used to simulate the power converter in boost mode (12V ~ 24V charging). A two-way converter simulation block was designed applying two-phase interleaved topology, and 29.2V, which is the charging voltage of a 24V battery in a 12V battery, is controlled. In addition, the charging current can be controlled to be supplied at a maximum of 100A, and the converter control logic is programmed in C language by applying C-Block. Power converter simulation in Buck Mode (24V ~ 12V charging) designed a buck mode simulation of charging from 24V battery to 12V battery as opposed to boost mode. Controls to be charged with a 12V battery charging voltage of 14.6V and 100A current.

Based on the simulation, configure a switching topology circuit and select 80V, 150A class FETs for switches, and construct a relay control circuit for ON/OFF control of input and output power. Main MCU selected STM32F730R8Tx and designed peripheral circuit, protection circuit, sensing circuit, etc.

In addition, the power converter's internal power is designed to be received from both input/output (12V, 24V) of the converter, and the communication circuit part is designed to enable RS232C, CAN, and Bluetooth communication. Communication is made possible to mutually insulate the upper level controller and monitoring.

4.1 Result of Simulation

Figure 7 shows the boost mode (12V to 24V charging) simulation results. It can be seen that the output voltage of 29.2V is constantly controlled based on the input voltage of 12V.

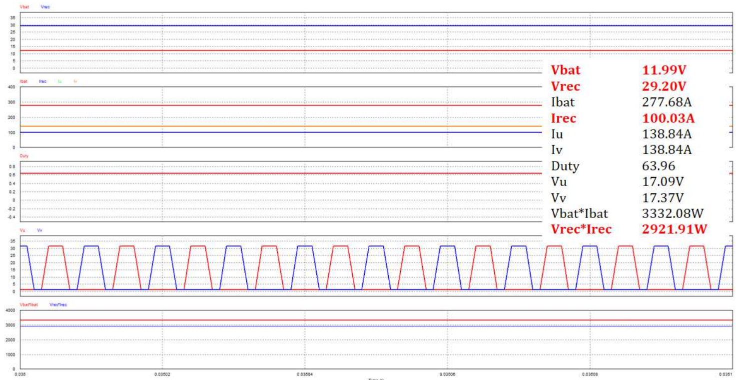

Figure 7. Results of boost mode (12V to 24V charging) simulation

In addition, it can be seen that the output current of 100A and each inductor current flow equally, and the ripple of the current is very low. It can be seen that the output power is constantly controlled at 2.9kW.

Figure 7 shows the simulation result of boost mode and shows the DC-DC converter operating in boost mode, charging from low voltage battery(LVB) to high voltage battery(HVB). This mode becomes a boost converter when the lower switch operates as an active switch among two switches for each phase and the upper switch operates as a diode. Therefore, it operates in a way that energy is transferred from a low voltage battery to a high voltage battery and energy is consumed through a load connected to the high voltage battery. In the case of a high-voltage battery, it can be confirmed that the charging voltage is stably supplied because the charging voltage of the 24V battery is kept constant at 29.2V.

As can be seen from the simulated current waveform performed, it can be seen that the ripple of the current flowing through each inductor through interleaved switching is 180° out of phase", and as these currents cancel each other, the output current is in a state where there is almost no ripple. I was able to confirm that it was controlled.

Figure 8 is the simulation result of Buck mode (24V ~ 12V charging). It can be seen that the output voltage of 14.6V is constantly controlled based on the input voltage of 24V. In addition, it can be seen that the output current of 100A and each inductor current flow equally, and the current ripple is very low. It can be seen that the output power is constantly controlled at 1.46kW.

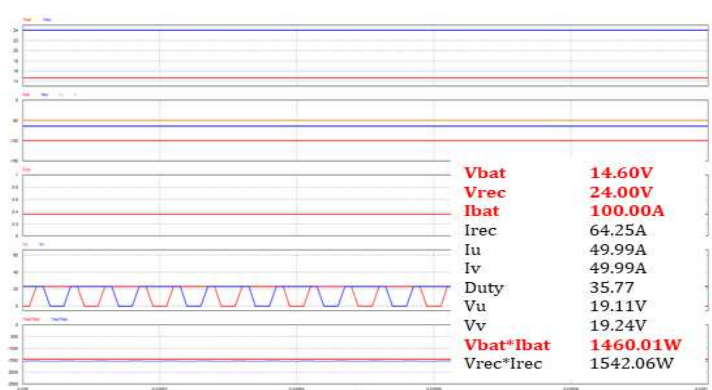

Figure 8. Results of Buck mode (24V to 12V charging) simulation

When charging a low-voltage battery, the DC-DC converter[9] operates in Buck mode. In this case, the upper switch operates as an active switch and the lower switch operates as a diode among two switches for each phase, and the Buck converter it operates in a mode in which energy is transferred from the high-voltage battery side to the low-voltage battery. If the battery is continuously charged at a constant current reference value in the Buck mode, the voltage charged to the battery continues to increase, and voltage control is required to solve this problem.

The control block diagram in Figure 8 shows that the controller in charging mode uses constant voltage control and constant current control to reduce the current reference value when it reaches the reference voltage after charging at a constant current reference value control to keep it at the reference voltage without rising.

In the low voltage charging mode, the charging voltage of the 12V battery is controlled at 14.6V, and through the simulation results, it was confirmed that the operation of the topology proposed in this paper works well in the Buck mode, and the control performance is also excellent.

4.2 Verification and Testing

For the converter performance experiment, the experiment was conducted with the configuration shown in Figure 9. A performance experiment was performed by simulating the charging/discharging state of the converter using a DC power supply and DC electronic load, and measuring the input/output power of the converter through a power meter.

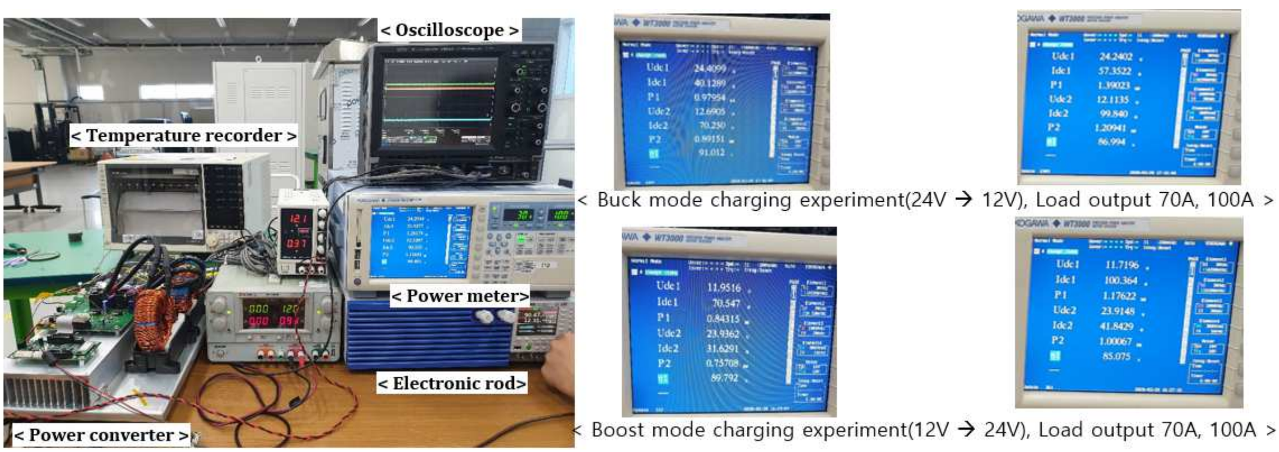

Figure 9. Composition of power converter performance test

Through this experimental result, it was confirmed that the efficiency was more than 92% in Buck mode and Boost mode at maximum 1.2kW output.

5. Conclusion

For the purpose of rice field research, a two-way DC-DC converter was developed to control vehicle power and secondary battery used in elevator cars (EC) used in the moving and transport industry. Simulation was conducted to verify the converter topology designed in this study. The simulation was conducted in two ways: Boost mode and Buck mode. First, as can be seen from the simulated current waveform performed as a result of simulating the Boost mode, it can be seen that the ripple of the current flowing through each inductor through interleaved switching appears 180° phase difference, and the output current ripples as these currents cancel each other. It was confirmed that it was controlled in a state where there was little. Second, as a result of the

Buck mode (24V ~ 12V charging) simulation result, in the low voltage charging mode, the charging voltage of the 12V battery is controlled at 14.6V, and through the simulation result, it can be confirmed that the operation of the topology proposed in this paper works well even in the Buck mode.

In addition, through the experimental results of this study, it was confirmed that the efficiency was more than 92% in Buck mode and Boost mode at maximum 1.2kW output. Therefore, it was confirmed that the control performance was also excellent. Here, by using a lithium secondary battery equipped with a battery management system (BMS), excellent results can be derived eco-friendly or cost-effectively.

Acknowledgement

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