Development of high efficiency bi-directional DC/DC Converter for 48V-12V Dual voltage system in vehicle

Hoonsung, Sung
Electric Power & Materials Research Team, Kyungshin Corp.

Abstract
To meet environmental regulations in Europe, recent automobile industry has focused on the development of vehicle systems for fuel-efficient. In addition, the electrical equipment of various high output increases, the need for 48V-12V dual voltage system (below 48V system) is on the rise. The main role of the DC / DC converter that can be counted as one of the important components of the 48V system is one in which to apply a 48V power supply to 12V load. It can be seen that is the same to minimize the power loss in this process, and for increasing the fuel efficiency of the vehicle. This paper proposes to minimize power loss in 48V-12V DC/DC Converter. Firstly, to divide the parallel structure of the FET(main switching element of each phase in converter). Secondly, by applying the incision type cross pin with the heat dissipation performance of the best in the turbulent state. So we have achieved the minimization of power loss due to heat. Through this study, I have got more smaller and high efficiency bi-directional DC/DC Converter in vehicle.

Keywords: Dual voltage system, 48V system, DC/DC Converter

1 Introduction
The biggest issues in the car market of late are environment-friendliness and convenience. The supply of fossil fuels is decreasing, and many weather anomalies are taking place due to the increasing carbon dioxide emissions and environmental pollution. Playing a part in this environmental pollution, the automobile industry started to regulate CO2 emissions by adopting the Kyoto Protocol in 1997, and car makers are scrambling to release environment-friendly vehicles such as HEVs (hybrid electric vehicles), EVs (electric vehicles), and FCEVs (fuel cell electric vehicles). At the same time, automobiles are being fully integrated with electronics. The convenience of motor vehicles is improving with the electronization and automation of various components that used to operate mechanically.

Figure 1: Main drivers of 48V development
Consumers are grateful for these developments, but the automobile industry cannot be completely
happy about them because they require a large amount of electric energy, which cannot be supplied by the conventional 12V internal combustion engine. The solution to these two issues, environment-friendliness and convenience, is the 48-12V dual voltage system (hereinafter, “48V system”). Increasing the main power supply from 12 V to 48 V cannot only achieve environment-friendliness by miniaturizing and reducing the weight of the components and reducing the diameter of the wiring harness, but also satisfy consumer needs by acquiring four to six times higher available electric energy than the conventional system. The 48V system is not a wholly new automobile application. A recent technical advancement has revived the 42V system, which had disappeared due to technical and theoretical limitations. Some people think the 48V system is only a pipe dream, as was the 42V system, but the recent movements of German OEMs and parts manufacturers suggest that the 48V system will be actualized soon. [1] Therefore, this paper addresses the development of a converter that is one of the core components of the 48V system.

2 48V-12V DC/DC Converter

The 48V system largely consists of a 48V battery, a BSG (belt-driven start-generator), a 48-12V DC/DC converter, a 12V battery, and electronic components for 12 V. Among these, the 48-12V converter converts the power supply from 48 V to 12 V to supply power to 12V components. Since the converter plays a central role in power supply, the selection of efficient and high-capacity converter is critical. This paper discusses the specifications, circuit design, assessment method, and assessment results of the converter developed by Kyungshin.

2.1 Selection of Specifications

The most important element of the decision on the converter specifications was the existence of electronic components for 48 V. During the development of this converter, electronic components for 48 V were included in the 48V system application, as shown in Figure 2, and the converter specifications were determined under the assumption that the three components--MDPS, the cooling fan, and the screen heater--will be designed for 48 V, as shown in Figure 3.

Furthermore, a bidirectional converter was deemed needed because in addition to the conversion from 48 V to 12 V for the power supply to the electronic components, a voltage boost is also needed for charging (jumpstarting) through the 12V battery in the event that the 48V battery is discharged. [2]

2.2 Action Sequence

Following the determination of the specifications, the action sequence of the converter was defined. This had to be completed in advance because the converter circuit configuration varies according to the action conditions.

2.2.1 Basic Action

As shown in Figure 4, the converter action starts with the IGN signal after the ignition. The basic
action is Buck (48 V \rightarrow 12 V), which is called the “Normal Mode,” whereas Boost is the Emergency Mode for the jump start when the 48V battery is discharged. The change to Boost occurs in the MCU (micro control unit) of the converter, which changes from the Normal Mode to the Emergency Mode upon receiving the SOC (state of charge) signal of the 48V battery. This signal is given as CAN (controller area network) or SOC by the BMS (battery management system). All these judgments are made at the moment when the converter turns on (at the ignition). While driving (ignition on), the mode is not changed immediately to Boost, but a warning is sent to the driver through a LED lamp, etc.

2.2.2 Input Criteria for the Electronic Component Operation Voltage
The converter reduces the voltage received through the 48V battery or the BSG so that it can be used by general loads at the 12V battery side. However, the load switched on from the ACC (accessory) state before the ignition is applied to the 12V domain and temporarily driven by the 12V battery. This can discharge the 12V battery. After the ignition, all the loads in the 12V domain, including the ACC connection load, are operated by reducing the voltage of the power supply from the 48V domain.

2.2.3 Criteria for Action Judgment
The converter receives the sensing value of the 48V battery during the ignition and driving, and memorizes the last sensing value of the 48V battery at the time of stopping (ignition off). By comparing the memorized value and the value inputted during the ignition, the converter checks the discharge state of the battery. There are two criteria for action judgment at this time: when the newly inputted 48V battery SOC is above a certain level or when the difference between the newly inputted value and the memorized value is positive. (The battery SOC value for judging the discharge state can be changed when applying it to a vehicle.)

2.3 Development Concept
Kyungshin’s DC/DC converter was developed with three goals: high efficiency, scalability, and low heat. High efficiency, circuit stability and scalability were ensured by applying the interleaved method and the half-bridge structure, which are essential and commonly applied, and low heat was achieved by applying the 2x2 parallel structure of the FET (field effect transistor).

2.3.1 Circuit Configuration
As mentioned, the interleaved structure was applied to the converter hardware. Figure 5 shows that the circuit was composed of three modules with two phases each. One phase covered about 400W electric energy. Furthermore, shunts were added to both ends of each module to achieve stability through a short-circuit protection circuit, and overvoltage/overcurrent protection circuits were implemented through the current balancing of each phase.
Figure 6 shows the overall circuit operation. When the MCU sends a signal (ModeSel signal) for voltage boost/reduction mode control, the MUX (multiplexer) receives it and changes the mode. Then the MUX sends a signal (DREN K/T signal) to the PWM (pulse width modulation) IC, through which the PWM IC commands the activation of the Gate Driver IC. After that, the Gate Driver activates the FET to actually carry out the voltage boost/reduction. At this moment, the PWM IC receives the current value sensed at the phase to detect a circuit abnormality, and sends an abnormal signal to the MCU when there is a circuit abnormality. Then the MCU carries out a blocking action according to the received signal, and the corresponding action upon receiving the OVP and OTP abnormal signals, as well as the overcurrent (OCP) signal.

Figure 7 shows the power conversion circuit applied to the converter, to which a transformation circuit of the conventional half-bridge structure was applied. The FET quantity applied to the half-bridge structure was doubled from the general number for the 2x2 parallel configuration, which decreased the heat generation per FET and secured the device stability. The increased FET quantity also ensured scalability, which can increase the transformation capacity from the PCB structure with the same size as the current size, as needed.

2.4 Configuration of the Heat Sink

Cooling is a major issue of a converter. High heat is generated from the process of transforming and storing electric energy; and if this heat is not discharged, the product life can be shortened and the product may fail.

Kyungshin’s converter maximized the cooling effect by applying the offset strip interlaced cooling fins shown in Figure 8.

In general, as a separate fan is not required inside the 48V system, unlike in high-voltage vehicles, cooling fins that can show the best performance in a natural air cooling type were used. [3]

Furthermore, as the wind inside the vehicle was turbulent, strip fins were applied that showed higher cooling performance than the general linear plate cooling fin.

2.5 Evaluation Method and Results

For the efficiency evaluation, a 48V Li-ion battery, 12V Pb battery, and charger/discharger were used, as shown in Figure 8.

For the connection wires, an exclusive cable for batteries was used. Although an electric loader could be used instead of a charger/discharger, the charger/discharger was used to get results similar to those in the environment of a vehicle.

As shown in Figure 9, the proposed system showed about 96% efficiency when a 700W load was applied, which was about 35% of the total load; and about 95% efficiency when 1,600 W was applied, which was 80% of the total load.

The aforementioned 80% section was selected for the prediction of the most frequently used load when the converter is actually used in the vehicle, and evaluates the actual converter efficiency.

One issue of the evaluation was the aging time. As shown in Figure 10, when the aging time was not above a certain level when the applied load was changed during the evaluation in the same environment, the efficiency decreased by about 0.1%.
Therefore, this must be considered when the converter is used in a vehicle condition.

3 Conclusion

This paper discussed the converter that is one of the essential techniques of the 48V system. Kyungshin is researching the development of a bidirectional DC/DC converter, which is believed to be a critical element of the settlement of the 48V system in the market. In particular, the power transformation feature of the converter and a next-generation converter block, which is an integrated item of the junction block (J/B), are being developed for weight reduction and miniaturization. When the development of exclusive electronic components for 48 V is accelerated, this converter is expected to become more efficient than the conventional converter packaging item of general batteries.

References


Authors

Hoonsung Sung was born in 1985. He received the BS degree in electronic engineering from the University of Soongsil, Korea. He was member of KAA until 2013. And 2013, he joined the Advanced Development Team of Kyungshin Corp.