Development of New AC/DC Converter for PHEVs and EVs

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As a global warming countermeasure, reduction of carbon dioxide and improvement of fuel efficiency have become increasingly important. Recently, automotive manufacturers have been developing not only hybrid electric vehicles (HEV), but plug-in hybrid electric vehicles (PHEV) and electric vehicles (EV), which are more effective on carbon dioxide reduction. The vehicles, such as PHEV and EV, have an AC/DC converter which supplies electric power from a commercial power system to an onboard high-voltage battery, in addition to a DC/DC converter which generates electric power for the accessory. Because of the shortened charging time and restricted space, AC/DC converters require efficiency improvement and downsizing.
We have been developing reactors, which are the key parts for high-efficiency and downsized AC/DC converters. This paper reviews the high-efficiency and downsized AC/DC converter that we have developed by applying our unique transformer-less insulation circuit.

Keywords: AC/DC converter, transformer-less, reactor

1. Introduction

As a global warming countermeasure, reduction of carbon dioxide emitted from vehicles and the improvement of fuel efficiency have become increasingly important for the automobile industry. In such circumstances, many automakers have concentrated their efforts on the development of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs), from which greater carbon dioxide reduction effects are expected. PHEVs and EVs are equipped not only with a DC/DC converter which generates electricity for the accessories but also with an AC/DC converter which supplies electric power from a commercial power system to an onboard high-voltage battery. The AC/DC converter is required to work more efficiently to shorten the charging time and also to be downsized so as to be fitted in a restricted space. The problems lie in large and heavy coil parts and large power loss accompanied with high frequency switching.

We have been engaged in the development of reactors, which are the key parts for high-efficiency and downsized AC/DC converters. This paper reviews a new AC/DC converter that we have developed by applying our unique transformer-less insulation circuit.

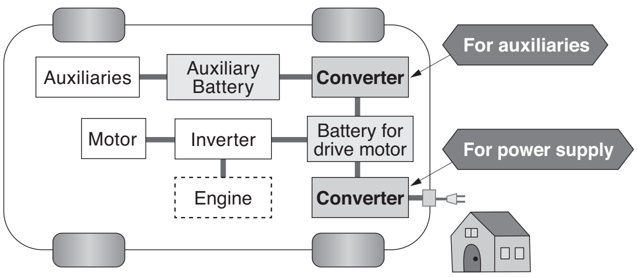


Fig. 1. PHEV/EV Systems

2. Concept of the New AC/DC Converter

2-1 Conventional circuit diagram and its problems

An example of the circuit configuration of an AC/DC converter is shown in **Fig. 2**. The AC/DC converter consists of a power factor correction (PFC) which converts input AC voltage into DC voltage, an H-bridge circuit which converts the DC voltage into high-frequency AC voltage, a high-frequency transformer which regulates transformation and insulation, and a circuit which rectifies and smooths high-frequency AC voltage.

This circuit diagram has two problems. One is that the coil parts, such as the transformer and the choke coil, contribute to an increase in the volume and weight of the AC/DC converter. Generally, an AC/DC converter has higher output power than that of a DC/DC converter for driving auxiliaries, and accordingly AC/DC converter's coil parts occupy a larger space. As the AC/DC converter is also equipped with a reactor for the PFC, the coil parts alone weigh as much as 20-30% of the total weight of the AC/DC converter.

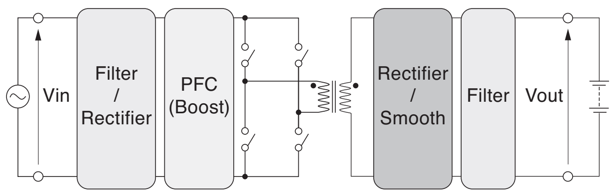


Fig. 2. Example of circuit diagram of AC/DC converter

Another problem is that the AC/DC converter involves large power loss in high-frequency switching. While the increase of switching frequency can reduce the volume of coil parts, power loss by the power device increases.

Therefore, for a downsized high-efficiency AC/DC converter, we need to review the circuit diagram to reduce the volume of coil parts and the power loss in switching frequency.

2-2 Concept of Sumitomo Electric's AC/DC converter

As a result of studying various circuit diagrams, we have selected the unique transformer-less insulation circuit as shown in **Fig. 3** to reduce the volume of coil parts and power loss. This circuit diagram transfers electric power by the flying-capacitor method which requires neither a transformer nor a choke coil. This circuit also ensures an insulating capability when used with high withstanding voltage power devices. Although this circuit needs high-frequency switching to transfer electric charge from a capacitor to the output side, the potential difference is so small that the power loss in switching can be negligible.

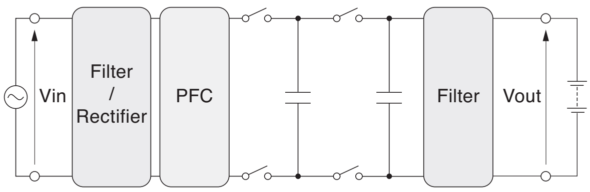


Fig. 3. Transformer-less insulation circuit we have developed

3. Development of On-board AC/DC Converter

3-1 Specifications

Table 1 shows the major specifications of the prototype AC/DC converter we have developed. We have set the development targets of achieving an efficiency of more than 90% and reducing the weight to 6 kg or less.

Table 1. Specifications of prototype

Item	Value
Input Volatage	AC80V~132V/AC180V~264Vrms
Output Volatage	300Vdc
Rated Output Power	1.5kW/3kW

3-2 Insulation circuit design

Generally, on-board AC/DC converters are connected to the ground in order to prevent electric shock. To ensure the insulation between input and output ports, power devices with 1 kV or higher withstanding voltage are applied to the insulation circuit. This transformer-less insulation circuit has an advantage in reducing the power loss in switching because the voltage supply to the two ends of the switching device is regulated. This means that most power loss is associated with conduction. To solve this problem, metal-oxide-semiconductor field-effect transistors (MOSFETs) or insulated gate bipolar transistors (IGBTs) are used as the switching devices. While MOSFETs with high withstanding voltage have high on-resistance, IGBTs have low on-resistance regardless of the withstanding voltage applied to the power device in the insulation circuit. As IGBTs do not have the reverse withstanding voltage, the reverse blocking diodes are inserted in the series with IGBTs to acquire a bidirectional insulation capability (**Fig. 4**).

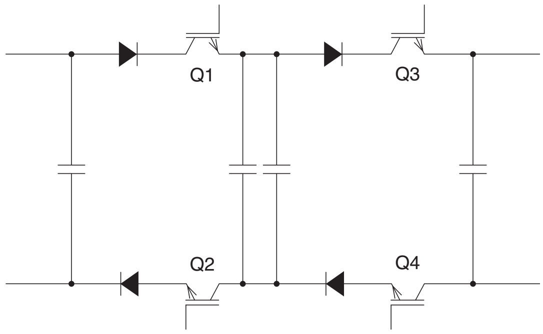
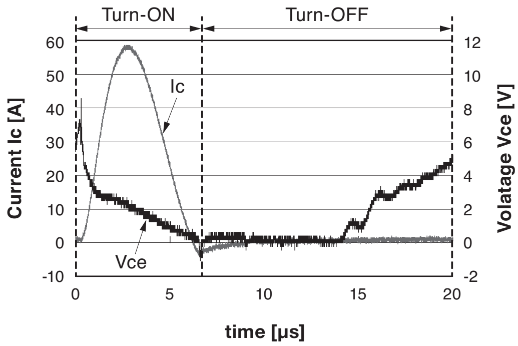


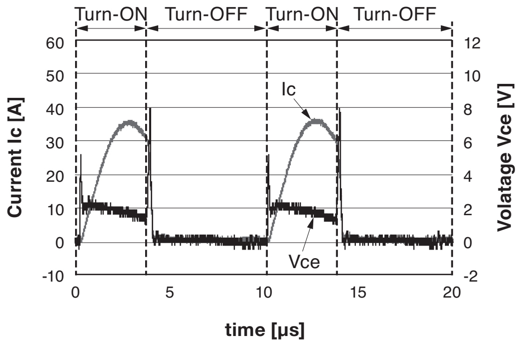
Fig. 4. Diagram of insulation circuit

This circuit transfers electric power to the output side by operating the former switching devices (Q1, Q2) and the latter switching devices (Q3, Q4) alternately. **Fig. 5** shows the driving wave of the insulation circuit. When the switching frequency is low (**Fig. 5 (a)**), the switching loss in this circuit is also low, allowing ZCS (Zero-Current Switching) operation. When the device is turned on, however, the conduction loss of the device increases because the effective value of the current increases. In contrast, when the switching frequency is high (**Fig. 5 (b)**), no ZCS operation is realized, leading to a switching loss of the device. However, when the device is turned on, the conduction loss of the device remains low because the effective value of the current decreases.

We set the switching frequency higher so as to make the volume of the capacitor smaller. We also set a dead time for all the switching devices to be off in order to ensure the insulation between the input and output ports. Thus, we choose the frequency to satisfy the targeted size and efficiency. As IGBTs, used as switching devices, have long turn-off time, we set the switching frequency to 100 kHz. The insulation circuit has a protection circuit to detect a short-circuit fault for IGBTs (Q1～Q4), therefore, we designed the IGBTs not to be turned off when the IGBTs are at fault.

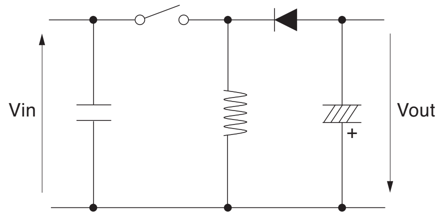


(a) Switching frequency: 50 kHz

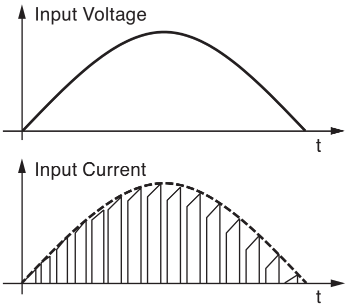


(b) Switching frequency: 100 kHz

Fig. 5. Motion of insulation circuit

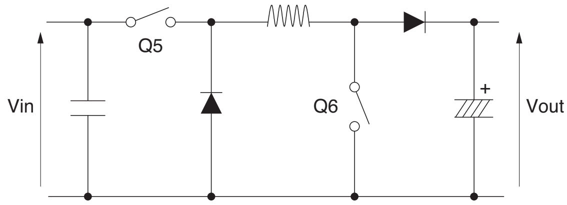


(a) General buck-boost converter

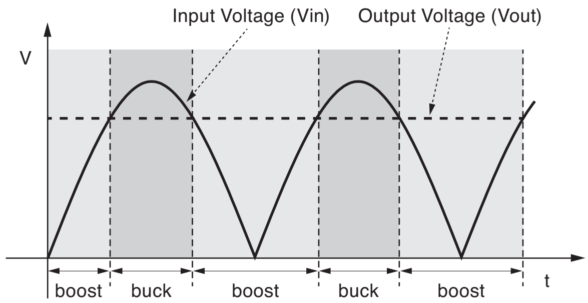


(b) Input current wave for circuit (a)

Fig. 6. Primary design of buck-boost PFC



(a) Applied buck-boost circuit



(b) Control motion of Improved design of buck-boost PFC

Fig. 7. Improved design of buck-boost PFC

3-3 Power factor correction (PFC) design

The AC/DC converter, which supplies power from a commercial system to an on-board high voltage battery, has a power factor correction (PFC) to meet the harmonic-current regulations. As shown in **Fig. 2**, a general circuit is equipped with a boost-type PFC, which converts electric voltage for an H-bridge circuit and transformer. In contrast, the insulation circuit shown in 3-2 has no voltage conversion function, and therefore a buck-boost type PFC is employed to deal with a wide range of input/output voltage specifications.

A general buck-boost circuit is shown in **Fig. 6 (a)**. This circuit has only a reactor to accumulate and release energy, leading to an increase in the footprint of the circuit and in the transmission loss compared with a boost type. Furthermore, as this circuit has the switching devices on its input line, the input current becomes intermittent as shown in **Fig. 6 (b)**, reducing its power factor.

Therefore, we applied the circuit diagram as shown in **Fig. 7**. This circuit combines a buck circuit and boost circuit, enabling buck-boost functionality by switching two devices independently (**Fig. 7 (b)**). In the boost operation, the circuit takes the continual current mode, where device Q1 is always turned on. Thus this circuit obtains an improved power factor compared with that of the circuit shown in **Fig. 6 (a)**. With this circuit diagram, we have acquired high efficiency and power factor comparable to those of conventional circuits.

3-4 Cooling mechanism

Considering on-board applications of the AC/DC converter, we have chosen the air-cooling method. We have installed a dedicated blower fan to cool the power devices, reactors and other major thermal sources. **Figure 8** shows the result of thermo-fluid analysis. We confirmed that every component part is within the permissible temperature range.

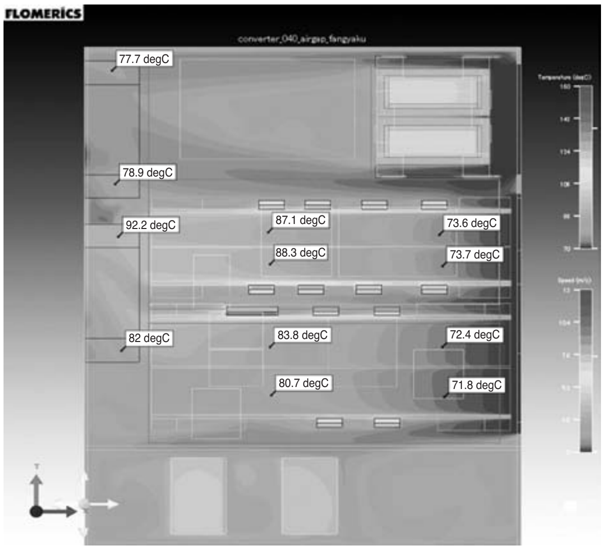
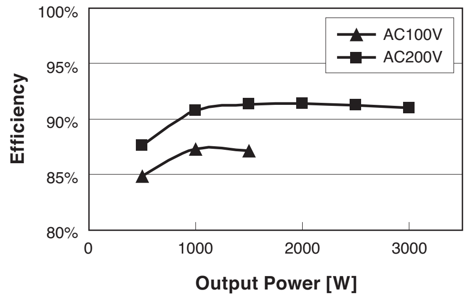
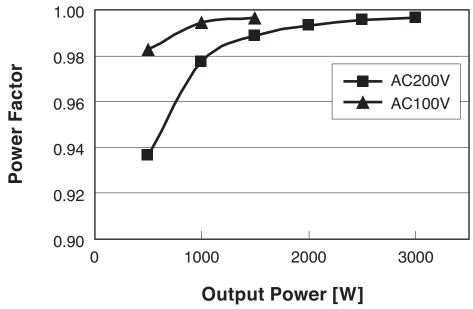


Fig. 8. Result of thermo-fluid analysis



(a) Efficiency-output characteristics



(b) Power factor-output characteristics

Fig. 9. Evaluation results for the developed AC/DC converter

4. Evaluation Results

Photo 1 shows the prototype of the AC/DC converter we have developed. It weighs 5.6 kg and the volume is 6.4 L.

Photo 1. Power supply converter prototype

Figure 9 shows the evaluation results for the prototype AC/DC converter. At the rated output of 3 kW, the converter demonstrated an efficiency of about 91% and power factor of 0.99 or more, achieving our original development goal.

5. Conclusion

We have developed an on-board AC/DC converter for PHEVs and EVs. A prototype of this AC/ DC converter weighs less than 6 kg and demonstrates an efficiency of over 90% at an evaluation test. Thus we have proved that the newly developed AC/DC converter achieves high efficiency with a small body as compared with the conventional products in principle.

Going forward, we will continue to examine requirements for PHEV/EV on-board applications and noise control measures. Sumitomo Electric remains committed to the development of smaller and more efficient AC/DC converters.

References

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