Auxiliary Inverter Charger (AIC) *

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Electric Vehicle (EV) and Plug-in Hybrid Electric Vehicle (PHEV) have been globally developed to realize sustainable world. An on board charger is required for charging at home, but it is not necessary to bring the charger while driving. The on-board-charger becomes only `weight' while driving vehicles. A newly developed Auxiliary Inverter Charger (AIC) eliminates a stand-alone on-board charger. AIC integrates an on board charger with an existing on board auxiliary inverter. AIC works as a charger while parking and exclusively AIC works as an inverter while driving the vehicles. This means that AIC offers time-sharing function of charger and auxiliary inverter.
AIC offers three benefits. 1) 30% smaller in volume and 35% lighter in weight compared with separated conventional charger and auxiliary inverter, 2) No additional cooling parts in vehicle is required for charger, 3) Bidirectional 3.3kW charging for smart grid can be easily realized by AIC. Method and experimental results are shown in this paper.

Key words :
On board charger, Auxiliary inverter, High Efficiency, Integration, Bidirection

電動化

1. Introduction

In these days PHEV/EV are becoming popular, and this tendency will continue[1) 2)]. An important feature of these vehicles is an ability to charge battery in anywhere, and therefore an on board charger is settled in each PHEV/EV. However the on board charger does not work while driving the vehicle, and it becomes only weight and waste of space while driving. Other problem for installing on board charger[3)] is cooling system for the charger. Water cooling system with pump motor, radiator, pipe and fan, or forced-air-cooling system with air duct is required in PHEV/EV. However, cost and space for these systems cannot be negligible.

On the other hand, a demand of new function such as bi-directional charging has arisen beside a development of smart grid. An optimal energy management for not only vehicle side, but also Home and Grid side such as Home Energy Management System (HEMS) and Building Energy Management System (BEMS) requires bidirectional charging[4) 5)]. Bidirectional charging system also supplies electricity from vehicle to electrical equipments in case of commercial power failures. General chargers require a lot of changes to realize bidirectional charging such as changing all diodes to IGBTs and adding drive circuits for the IGBTs. These changes cause a significant increase in cost and volume of the charger.

The purpose of this paper is restructuring on board

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electric components for popularization of PHEV/EV. Smaller in volume and lighter in weight for charger is achieved with a modification of existing auxiliary inverter. No additional cooling unit such as cooling liquid pipe, air duct, fan etc. is required for charger function. And important bidirectional charging function can be easily realized easily with software control.

2. Concept of AIC (Auxiliary Inverter Charger)

A charger works at parking period and the on board auxiliary inverter works at driving period As charger and inverter are composed with similar power devices, concept of AIC is settled as combined and time sharing of the charger and the auxiliary inverter. With existing on board auxiliary inverter and some additional parts, AIC works charger and inverter as time sharing manner (Fig. 1). This combined and time sharing concept eliminates volume and weight compared with stand alone charger and on board auxiliary inverter.

Besides AIC itself, as the on board auxiliary inverter is already equipped with its own cooling system, there is no need for additional cooling system in vehicle. This feature eliminates cooling liquid pipe, cooling pump, air cooling duct & fan for charger and saves lots of space, costs and installing man-hour.

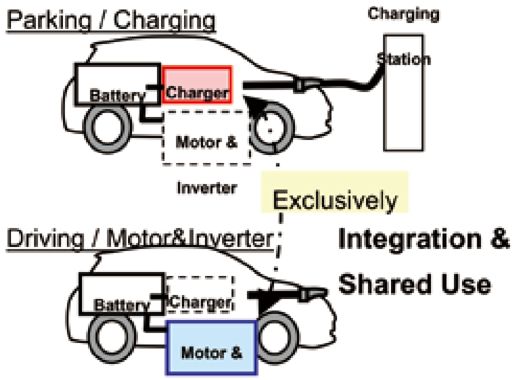

Fig. 1 AIC Concept

As the AIC is originated from inverter, bidirectional charging can be achieved with switching control of power devices.

Table 1 Comparison of inverter as a charger (3kW)

	Stand alone	Inverter modified	
	On board Charger	Auxiliary Inverter	Traction Inverter
Output	3kW	3-5kW	50-100kW
Safety / Durability	Independent from driving, braking, steering		Related with driving and braking
Loss@3kW	100W		300W
Additional Parts for Charger	Input Filter 4leg Inductor Relays Control ECU	Input Filter 1leg Inductor Relays	Input Filter 1leg Inductor Relays (large capacity)
14V board net at charging	Only charger wakes	Only Auxiliary Part wakes	All traction parts wake and cause large loss

3. Design of AIC

3.1 On board Auxiliary Inverter

There are a lot of inverters on vehicle. Auxiliary inverter nearly 3kW range is good candidate as a charger. To select an inverter for charging purpose, three items are considered as Table 1. Firstly, as a charger works longer time rather than conventional on board power equipments, lifetime of an inverter as a charger should be concerned. Compared with a traction-motor inverter, an auxiliary inverter, which is independent from driving, braking and steering, is a good candidate as a charger.

Secondary, power ratio between charger (3kW) and inverter should be in the same range. If traction motor inverter is applied as a charger for 3kW, a large power capacity (50-100kW) of power semiconductors in the traction inverter causes large recovery current loss for 3kW electric power conversion.

Third point is basic load of 14V board net. Duration of PHVE/EV charging is usually more than one hour, and woken-up equipments while charging consume basic power for electric control unit (ECU) and so on. Therefore, it is preferable to wake up limited equipments. When traction inverter is woken up for charging, a lot of equipments are also woken up, and causes large power. On the other hand, AIC can be woken up with limited area.

For a fast charging more than 20kW, traction inverter is required for large power conversion[6], but for a conventional power charging (3kW), because of the above three reasons, auxiliary inverter is preferable.

3.2 AIC Circuit Diagram

Based on auxiliary inverter (Blue dotted area in Fig. 2), Input filer, reactor, one leg power devices and relays (Red dotted area) are added for charger function. Circuit and function in each mode are explained as follows.

In a motor drive mode, utility power/alternative current (AC) input parts are separated and two relays between the motor and the inverter are connected. The third relay between the conventional inverter and the additional power devices is also connected. The inverter drives motor in the blue dotted area and there is no drive for additional power devices.

In a charging mode, AC input parts are connected and the motor is separated from the inverter with two relays. The third relay is also disconnected. The input EMC filter is same one used in a conventional charger. The left two legs (S1-S4 in Fig. 2) in inverter act as diode bridge rectifier, and right two legs (S5–S8 in Fig. 2) and reactor act as step up / step down DCDC converter to control charging power for the battery. With this structure, input voltage 100V/200V (AC) and output voltage 100-400V (DC) is available.

In a discharging mode for bidirectional charging, wiring connection is just same as charging mode. The right two legs (S5–S8 in Fig. 2) and reactor act as step up / step down DCDC converter as charging mode, and change battery voltage to variable DC voltage. Then the left two legs (S1-S4 in Fig. 2) in inverter controls polar so as to produce AC voltage. With this structure, input voltage 100-400V (DC), and output voltage 100V/200V (AC) is available.

Circuit diagram of a unidirectional charger that does not share auxiliary inverter is shown in Fig. 3. To realize bidirectional charging, it's necessary to change six diodes into IGBTs. Additionally six drive circuits are also required to drive the IGBTs. These changes cause a significant increase in cost and volume of the charger.

As the AIC is originated from inverter, IGBTs are used as switching device. Therefore AIC realizes bidirectional charging easily.

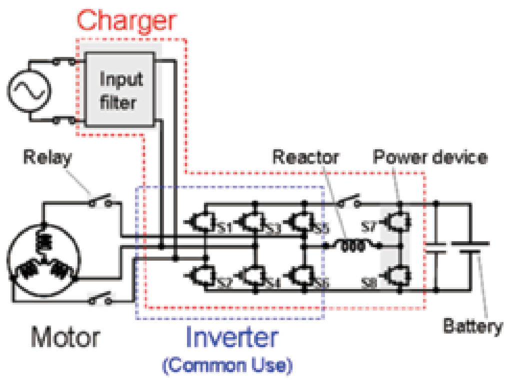

Fig. 2 AIC circuit diagram

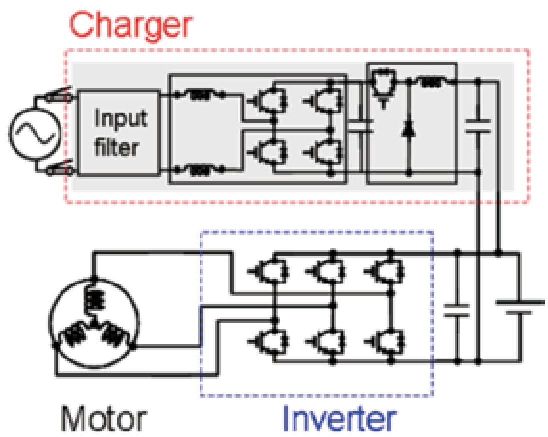

Fig. 3 Conventional circuit diagram

3.3 Switching control of step up / step down DCDC converter

Proposal switching control diagram of step up / step down DCDC converter (S5-S8 in Fig. 2) in charging mode is shown in Fig. 4. In the step up mode, only S8 (shown in Fig. 2) is driven unlike conventional switching control which is shown in Fig. 5. And in the step down mode, both S5 and S8 (shown in Fig. 2) are driven in the same manner as conventional switching control. As a result, proposal switching control can realize higher efficiency as compared with conventional one, because sometimes S5 switching is stopped. And harmonic current is low as well as conventional one, because S8 is consecutively driven.

Proposal switching control diagram of step up / step down DCDC converter in discharging mode is shown in Fig. 6. In the step down mode, only S7 (shown in Fig. 2) is driven unlike conventional switching control which is shown in Fig. 7. And in the step up mode, both S6 and S7 (shown in Fig. 2) are driven. As a result, proposal switching control can realize higher efficiency as compared with conventional switching control and harmonic distortion at the same level as conventional one in discharging mode.

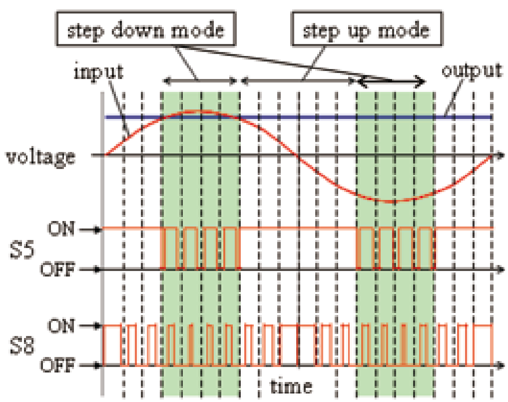

Fig. 4 Proposal switching control diagram in charging mode

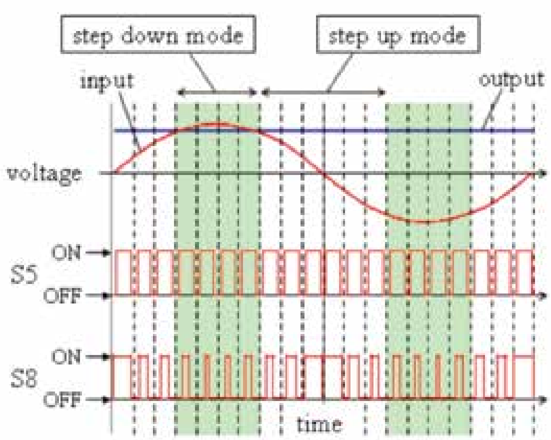

Fig. 5 Conventioinal Switching control diagram in charging mode

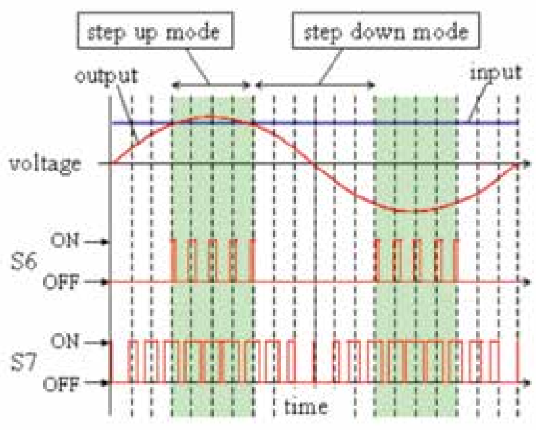

Fig. 6 Proposal swtiching control diagram in discharging mode

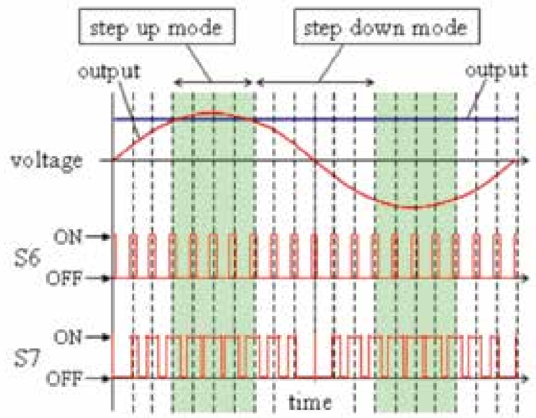

Fig. 7 Conventional switching control diagram in discharging mode

3.4 Wiring of power line in vehicle

Wiring of power line from Grid & Home to the traction battery through AIC is shown in Fig. 8. A plug, an inlet and a Charging Circuit Interrupt Device (CCID) parts are used same as conventional charger.

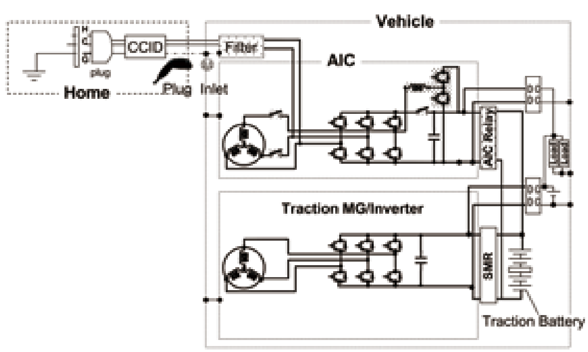

Fig. 8 Wiring of power line in vehicle

AIC is connected to the traction battery through AIC relay, which is separated from system main relay (SMR). This diagram limits live parts area while charging, and reduces electric power loss in the traction motor-generator (MG) area.

3.5 Heat Dissipation

Heat dissipation of AIC can be realized with cooling system, which is originally equipped with inverter. In this paper, a new approach to reduce power consumption for cooling is applied.

AIC is designed to install in an engine compartment in PHEV. Original inverter drives auxiliary motor while driving. Therefore, the inverter has fluid cooling equipment so as to cool the inverter even when the engine produces maximum power and heat. AIC uses this cooling system in the motor drive mode. Energy for this cooling system is off-course required.

On the other hand, in the charger mode, heat source is only loss in power conversion in AIC. Therefore, heat dissipation through AIC-chassis can be applied to cool AIC while charging. With calculation by a simple thermal model (Fig. 9), AIC can be estimated to be cooled with some radiator fan (ca. 30W) even though initial temperature of engine is high (90 degrees Celsius) while charging.

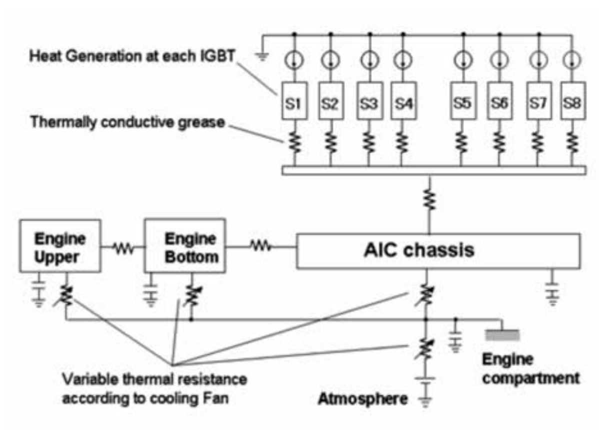

Fig. 9 Thermal flow model

4. Experimental Results

To evaluate AIC concept, an inverter in air conditioning system is selected as an on board auxiliary inverter. Installation of AIC in vehicle engine compartment is shown in Fig. 10. This AIC prototype is 35% lighter in weight compared with conventional separated ones. Experimental tests show the following results.

Fig. 10 AIC installed in engine comartment

4.1 Charger Efficiency and EMC

Experimental conditions are as follows, AC power supply, Electrical load are applied. Efficiency and harmonic current are measured with PZ4000 by Yokogawa Electric Corporation. Efficiency of charger is over 96% (Fig. 11), because the number of switching times is less with proposal switching control and AIC has no transformer-loss. Harmonic current is below the limit of IEC 61000-3-2 (Fig. 12).

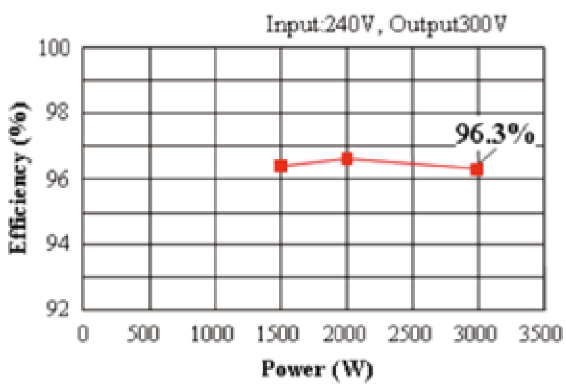

Fig. 11 Efficiency of AIC / charging mode

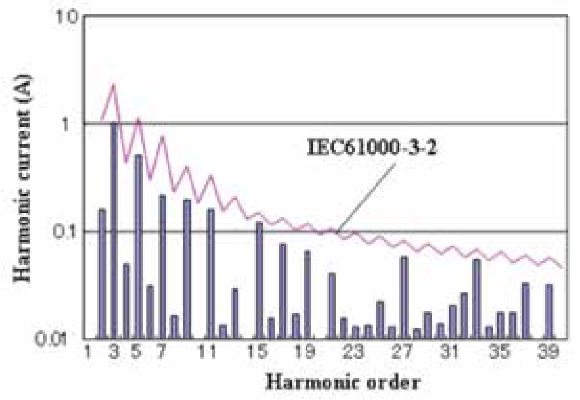

Fig. 12 Harmonic current

4.2 Cooling Performance

Temperature of AIC parts while charging is measured and plotted in Fig. 13. AIC is installed in engine compartment of PHEV. After engine driving mode of PHEV, when engine temperature is high (75 deg C) and charging starts, each part in AIC remains under 125 deg C without special cooling.

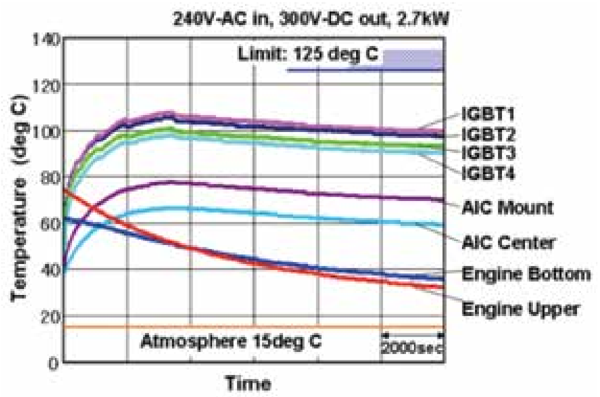

Fig. 13 Temperature of AIC parts

4.3 Bidirectional charging

To evaluate the discharging characteristics of AIC, DC power supply is connected to input of AIC, electronics resistor (16 ohm) and AC power supply is connected to output of AIC. Fig. 14 shows an efficiency of discharging mode when electricity flows from vehicle battery to AC power out. The efficiency is almost 96% in range of 1500 to 3000W, and the efficiency is high as well as charging mode which is shown in Fig. 11.

AC output voltage waveform and output current waveform are shown in Fig. 15. Power factor is over 0.99, and total harmonic current distortion is 2.1% (Fig. 16). These results show that AIC has sufficient performance for grid connection and operating electrical equipment.

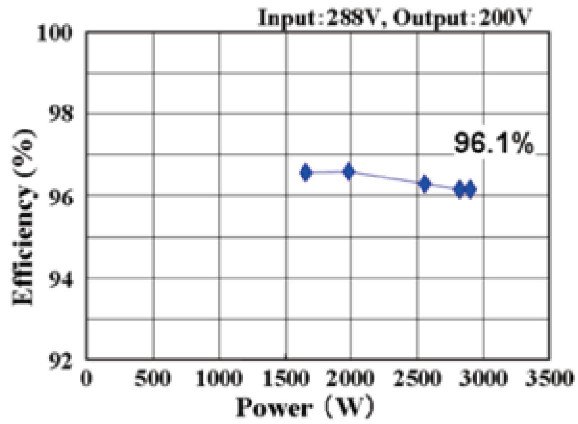

Fig. 14 Efficiency of AIC / discharging mode

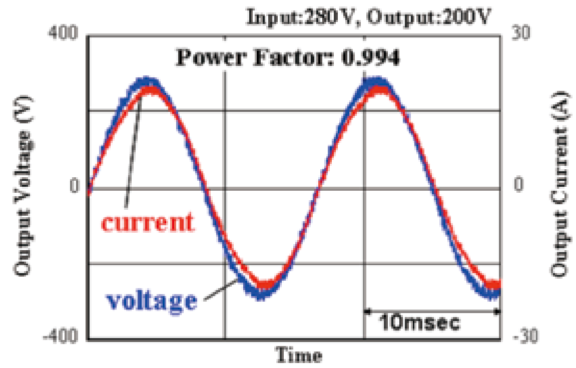

Fig. 15 Output waveform

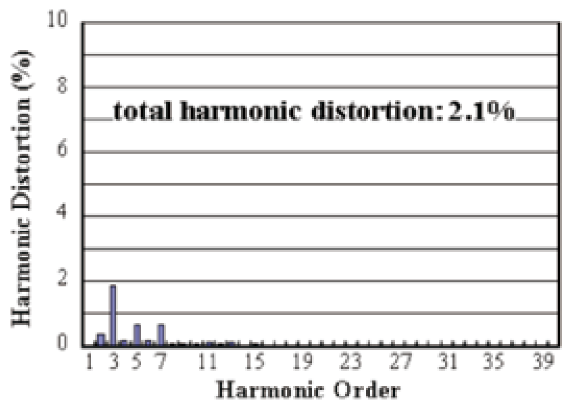

Fig. 16 Harmonic distortion

5. Conclusions

The AIC concept is presented and evaluated with experimental results. 1) AIC eliminates 35% in weight compared with separated ones. 2) No additional cooling system is required in vehicle. 3) Bidirectional charging can be realized with high efficiency, high power factor and low harmonic distortion. This key technology accelerates popularization of PHEV/EVs.

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