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Auxiliary Inverter Charger (AIC) – Concept & Experimental Results –

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Abstract

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 a stand alone conventional charger and an auxiliary inverter. 2) No additional cooling parts in vehicle is required for charger function, with more than 96% efficiency of power conversion from commercial AC line to battery DC line. 3) Bidirectional 3.3kW charging for smart grid, home energy management system (HEMS) and building energy management (BEMS) is easily realized.

Concept, Design and Experimental results of AIC are shown in this paper.

Keywords: Charger, Inverter, AIC, Bidirectional, integration, high efficiency

1 Introduction

In these days PHEV/EVs 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 works only while parking and charging battery, and does not work while driving the vehicle. Therefore, the on board charger becomes only weight and waste of space while driving vehicles.

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.

The other demand such as bidirectional charging function has been focused on because of a worldwide development of smart grid. An optimal energy management between vehicle side and Home and Grid side such as HEMS (Home Energy Management System) and BEMS (Building Energy Management System) requires bidirectional charging function. [4][5]

The purpose of this paper is restructuring on board 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 liquid cooling pipe, air duct, fan etc. is required for charger function. In addition, bidirectional charging function becomes available with this structure.

2 Concept of AIC (Auxiliary Inverter Charger)

A charger works at parking period and an on board auxiliary inverter works at driving period. As the charger and the 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 as charger and inverter in time-sharing manner (Figure 1).

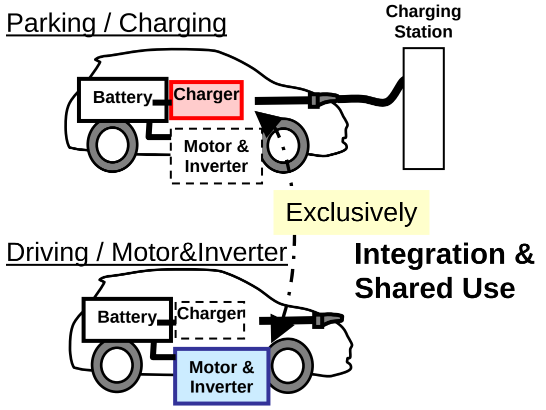

Figure1: AIC Concept

This combined and time-sharing concept eliminates volume and weight compared with a stand-alone charger and an 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.

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

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 loss for 3kW electric power conversion.

Table1: Comparison of chargers (Stand-alone, Auxiliary Inverter, Traction Inverter)

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

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][7], 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 Figure 2), input filer, reactor, one leg power devices and relays (Red dotted area) are added for charger function. Circuit and function in a motor drive mode and a charger mode are explained as follows.

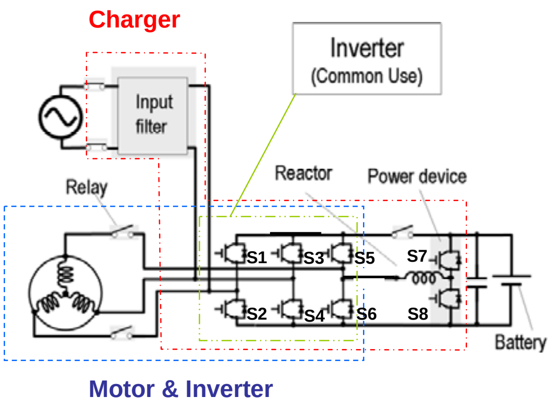

Figure2: AIC Circuit Diagram

In the 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 the charger 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 in inverter act as diode bridge rectifier, and right two legs 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.

3.3 Wiring of power line in vehicle

Wiring of power line from Grid & Home to the vehicle main battery through AIC is shown in Figure3. A plug, an inlet and a CCID (Charging Circuit Interrupt Device) parts are used just same as conventional charger.

AIC is connected to the main battery through AIC relay, which is different from system main relay (SMR). This diagram limits woken up parts area while charging, and reduces electric power loss in the traction motor inverter area.

3.4 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.

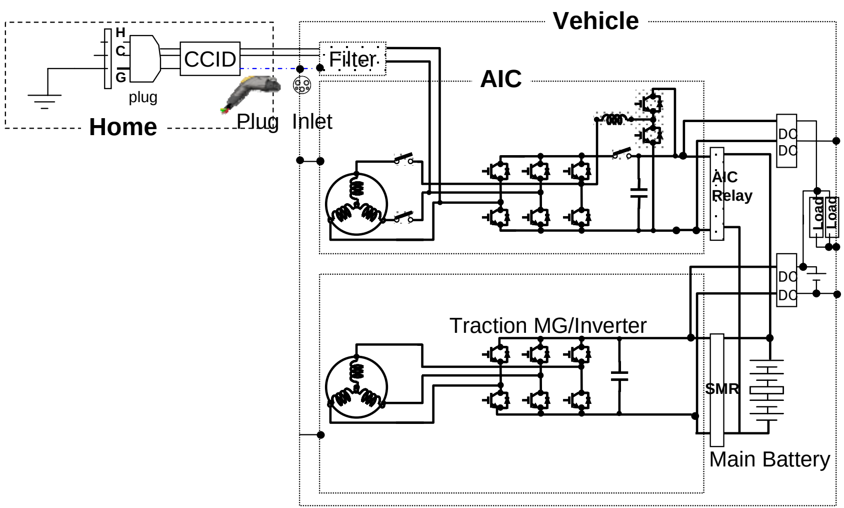

Figure3: Wiring of power line in vehicle

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 (Figure 4), 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.

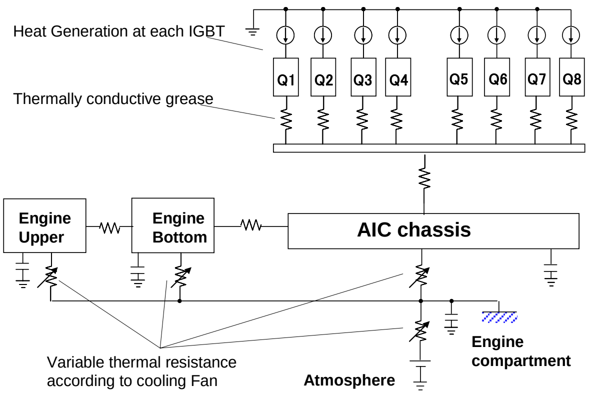

Figure4: Thermal flow model

4 Experimental Results

To evaluate AIC concept, an inverter in HVAC system is selected as an on board auxiliary inverter. Installation of AIC in vehicle engine compartment is shown in Figure 5. Experimental test shows the following results.

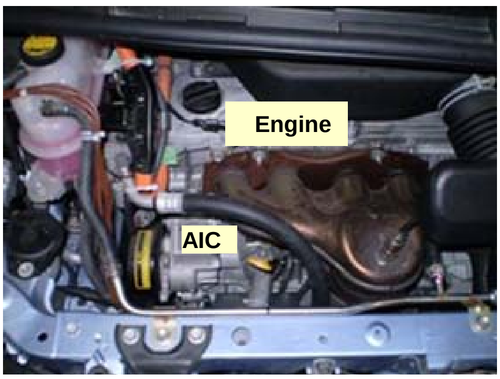

Figure5: AIC installed in engine compartment

4.1 Charger Efficiency and EMC

Efficiency of charger is almost 96% high (Figure 6), because AIC has no transformer-loss.

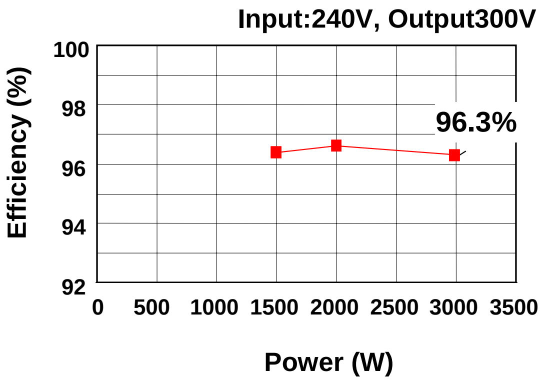

Figure6: Efficiency of AIC as Charger

Harmonic current while charging is below the limit value in IEC 61000-3-2 (Figure 7).

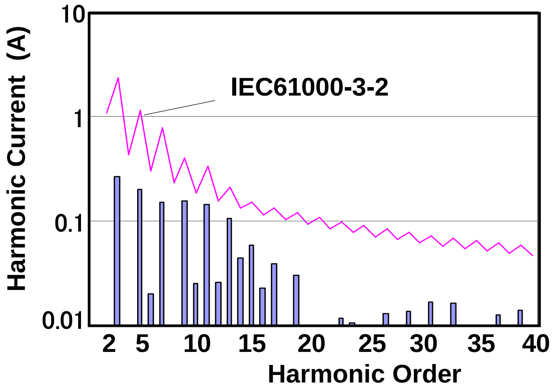

Figure7: Harmonic current

4.2 Cooling Performance

Temperature of AIC parts while charging is measured and plotted. When engine temperature is same as room temperature (both 35 deg C) and charging starts, each parts in AIC remains under 125 deg C, and there is no need to use cooling fan (Figure 8).

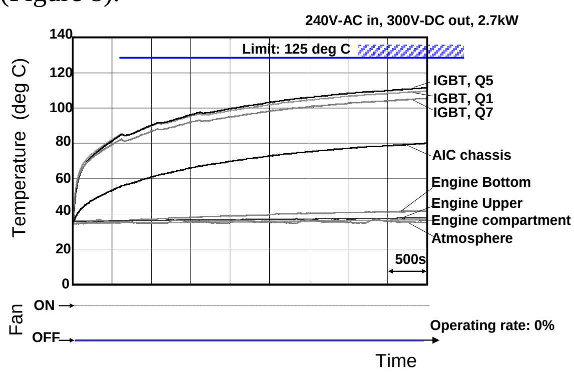

Figure8: Temperature of AIC parts
(T_engine = 35 deg C)

After engine driving mode of PHEV, when engine temperature is high (90 deg C) and charging starts, the radiator fan works as time-sharing manner according to the AIC temperature (Figure 9). Without additional cooling units, each parts in AIC remains under 125 deg C.

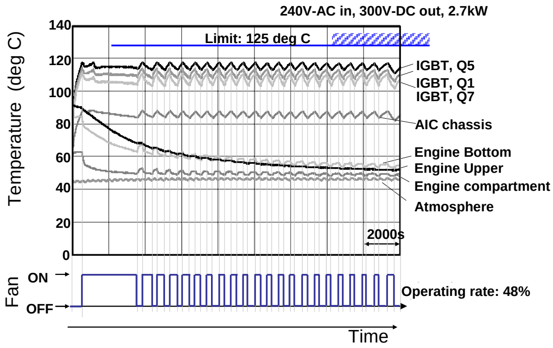

Figure9: Temperature of AIC parts (T_engine = 90 deg C)

4.3 Bidirectional charging

Bidirectional charge can be realized with AIC as follows. Wiring connection is just same as charging mode. AC output parts are connected and the motor is separated from the inverter with two relays. The third relay is also disconnected. The right two legs and reactor act as step up / step down DCDC converter, and change battery voltage to variable DC voltage. Then the left two legs 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.
This function is experimentally evaluated. The conversion efficiency from DC (battery voltage) to AC output is 95-96%, and the power factor is over 0.99.

5 Conclusions

Concept of AIC is presented and evaluated with experimental results. 1) AIC eliminates 30% in volume and 35% in weight compared with separated ones. 2) No additional cooling system is required in vehicle. 3) Bidirectional charge is available with high efficiency. This key technology accelerates popularization of PHEV/EVs.

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