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A Novel Bidirectional DC-DC Converter With Flyback Snubber For Hybrid Electric Vehicles

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Abstract: Hybrid electric Vehicles combine the benefits of engine, electric motor and batteries to provide improved fuel economy. A converter is needed in hybrid Electric Vehicle for charging and discharging of the batteries. So a charging and discharging can be combined in one circuit topology known as bidirectional DC-DC converter. Here the output is completely isolated from input, so an isolated bidirectional Dc-DC converter is used. In the bidirectional DC-DC converter, there occurs overvoltage and overcurrent stress, which can be reduced by snubber circuits. Various technologies such as RCD, active clamp and flyback snubber for bidirectional DC-DC converter are compared. The bidirectional DC-DC converter with flyback snubber is explained in detail. The simulations are carried out using Simulink/MATLAB 7.6.0 (R2009b) package. The hardware is done using PIC16F877A, a microcontroller to generate the PWM pulses for the MOSFET switches so that harmonics in the circuit can be reduced.

Keywords:Hybrid Electric Vehicles, Bidirectional DC-DC converter, Flyback Snubber, RCD Snubber, Active Clamp Snubber

I. INTRODUCTION

Electric vehicles, Hybrid Electric Vehicles have been typically proposed to replace conventional vehicles in the near future. The inherent flexibility of Hybrid Electric Vehicles makes them suited for personal transportation and military applications. The major components are battery, engine, electric motor which also can work as generator and power electronic equipment. Hybrid Electric Vehicle combines the benefits of engine and electric motor to provide improved fuel economy. Engine provides most of the vehicle's power and the additional power is provided by the motor when needed such as for accelerating and passing. The electric power for the motor is generated from regenerative braking and from the engine, so Hybrid Electric vehicle don't have to be "plugged" into an electric outlet to recharge [4]. Batteries in a Hybrid Electric Vehicle are usually required to backup power for power. Their voltage levels are typically much lower than dc bus voltage. Some converters are only suitable for stepping up or stepping down the voltage. Bidirectional converter is used for both stepping up and stepping down the voltage. Bidirectional converters for charging/discharging the batteries are therefore required.

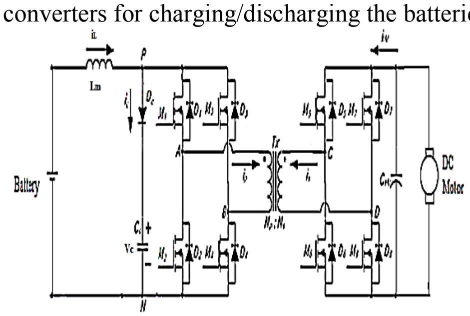

Fig.1 Bidirectional DC-DC Converter

In Fig.1, the left hand side is a low voltage side and right hand side is a high voltage side. Low voltage side consists of battery and current fed full bridge and high voltage side consist of voltage fed full bridge. Low voltage side and high voltage side is separated by an isolation transformer with turns ratio, 1:n. Inductor, L_m acts as boost inductor when power flows from the low voltage side to high voltage side, which is described by boost mode of operation. On the other hand, inductor, $L_m$performs output filtering, when power flows from high voltage to low voltage side, which is described by buck operation. But in the main circuit there occurs over voltage and over current stress which can be reduced by the snubber circuits [1].

The transformer with a current fed full bridge lead to high voltage spike and high current stress across the switches because of the leakage inductance of the transformer. So a snubber circuit is needed to limit the voltage spike and current stress. Snubber circuits used in bidirectional converter are:-

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a) RCD Snubber
b) Active Clamping snubber
c) Flyback Snubber

In RCD snubber, there is power dissipation on the resistor, which results in lower efficiency and is not used for high power operations.Active snubber switches at twice the switching frequency, so the burden of high current stress and associated thermal issues of the active switches and the capacitor add the limitations. Flyback converter together with clamping diode and clamping capacitor forms the flyback snubber thereby we can reduce the current flowing through the active switches[7].

The objective of the paper is to compare bidirectional DC-DC converter with RCD, active clamp and flyback snubber. From the comparison, to prove that flyback snubber in the bidirectional converter is better to reduce the current stress and voltage spikes of the active switches.The Section I give the Introduction of the bidirectional converter for hybrid electric vehicle. Section II is helpful to understand the background of related work. Section III explains the simulations and its results and the lastsection IV concludes the paper and followed by the references.

II. CIRCUIT DESCRIPTION

The proposed isolated bidirectional full-bridge DC–DC converter with a flyback snubber is shown in Fig. 2. The converter is operated with two modes which are buck mode and boost mode. Fig.2 consists of a current-fed switch bridge, a flyback snubber at the low-voltage side, and a voltage-fed bridge at the high-voltage side. Inductor $L_m$performs output filtering when power flows from the high-voltage side to the batteries, which is denoted as a buck mode. On the other hand, it works in boost mode when power is transferred from the batteries to the high-voltage side.

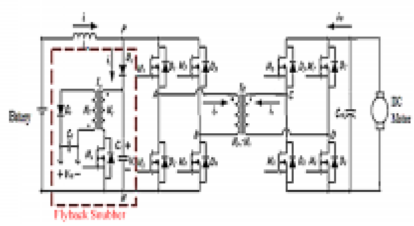

Fig.2 Isolated bidirectional full-bridge DC-DC converter with a flyback snubber [1]

The clamp branch capacitor C_C and diode $D_C$are used to absorb the current difference between current-fed inductor $L_m$and leakage inductance $L_{ll}$and $L_{lh}$of isolation transformer $T_x$during switching commutation. The flyback snubber can be independently controlled to regulate $V_C$to the desired value, which is just slightly higher than V_{AB}. Thus, the voltage stress of switchesM_1–M_4 can be limitedto a low level.A bidirectional DC-DC converter has two types of conversions: step-up conversion (boost mode) and step-down conversion (buck mode). In boost mode, switches M_1–M_4 are controlled,and the body diodes of switches M_5–$M_8$are used as a rectifier. In buck mode, switches M_5–M_8 are controlled, and thebody diodes of switches M_1–M_4 operate as a rectifier.

A. STEP UP OPERATION

First of all switches M_1-M_4 are turned on, so the primary side of the transformer is short circuited and therefore V_{AB}=0. Inductor, L is charged by the battery. At t_1, M_1& M_4 remain conducting, so V_{AB} is present. Clamping diode, Dc continues to conduct until the current difference drops top zero at t_2. Moreover D_5 and D_8 are conducting to transfer the power. During this interval (i_L-i_P) flows into clamping capacitor. So clamp capacitor voltage, V_C is rising at the interval t_1-t_2 and i_p= i_L condition is reached. During t_2 -t_3, D_c stops conduction and flyback snubber starts to operate. C_c is discharging and the flyback switch is turned on and the energy is stored in flyback snubber as flux. In the interval t_3-t_4 energy stored in the inductor is transferred to high voltage side. Over this interval, flyback snubber will operate independently to regulate $V_{C\ to}$ $V_{C(R)}$. Energy stored in the transformer of the flyback snubber is transferred to the output when flyback switch turns off.At t_4, V_c has been regulated to $V_{C(R)}$ and the snubber remains idle. Over this interval the main power stage is still transferring power from low voltage to high voltage side. It stops at t_5 and completes a half switchingcycle operation.

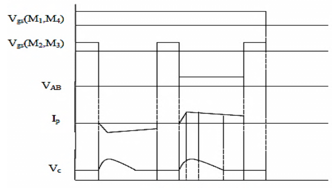

Fig.3 Modes of Operation

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B. STEP DOWN OPERATION

During the time period t_0-t_1, switches M_5 and M_8 are on, while switches M_6 and M_7 are in the off state. High side voltage is immediately exerted on the transformer and the whole voltage is exerted on the transformer causing current to rise. With transformer current, i_s increasing linearly towards the load current at t_1, switches, M_1 and M_4 are conducting to transfer the power and the voltage across the transformer terminals on the current fed side changes immediately to reflect the voltage from the voltage fed side.

At t_1, switch M_8 remain conducting, while switch M_5 is turned off. Diode, D_6 starts to conduct the freewheeling leakage current. Transformer current reaches the load current level at t_1 and starts to decrease during the interval t_1-t_2 and voltage V_{AB} starts to decrease. The clamping diode, D_c starts to conduct during this interval.

At t_2, with diode, D_6 conducting, switch, M_6 can be turned on under ZVS. At t_3, switch M_6 remains conducting, while switch, M_8 is turned off. Diode, D_7 then starts to conduct the freewheeling leakage current.

At t_4, with the diode, D_7 conducting, switch M_7 can be turned on under ZVS. Over this interval, the active switches change to the other pair of diagonal switches and the voltage on the transformer reverse its polarity to balance the flux and to alleviate the transient voltage problem. It stops at t_5 and completes a half switchingcycle operation.

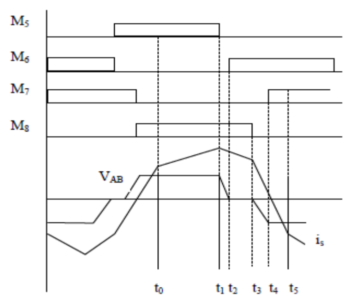

Fig.4 Modes of operation

An isolated bidirectional full bridge DC-DC converter transformer converter had voltage spikes due to the current difference between the current fed inductor and leakage inductance of the isolation transformer. This voltage spike has been alleviated by the flyback snubber. The flyback snubber can be controlled to attain a soft start-up feature. The current stress is reduced under heavy load conditions. This converter has also the advantage of increased reliability and efficiency.

III. SIMULATIONS

The simulation of the proposed paper is carried out using MATLAB software. The closed loop simulation of buck mode and boost mode is done separately. For closed loop simulation, a voltage and current feedback circuit is considered. The isolated bidirectional DC-DC full bridge converter with RCD snubber, active clamp snubber flyback snubber is simulated. The hybrid electric vehicles using isolated bidirectional DC-DC converter with a flyback snubber is also simulated.

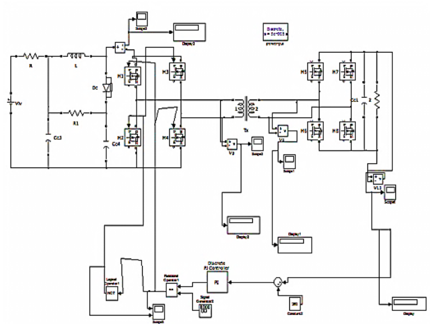

Fig.5 Simulation circuit of bidirectional full bridge DC-DC converter with RCD snubber

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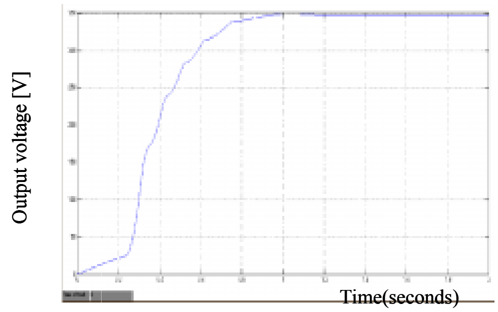


Fig.6 Simulation result of bidirectional full bridge DC-DC converter with RCD snubber

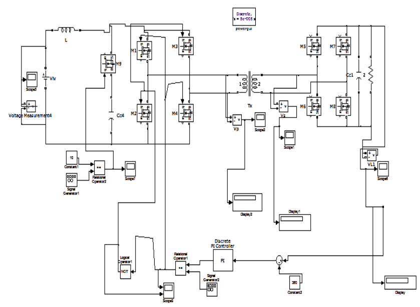


Fig.7 Simulation circuit of bidirectional full bridge DC-DC converter with active clamping snubber

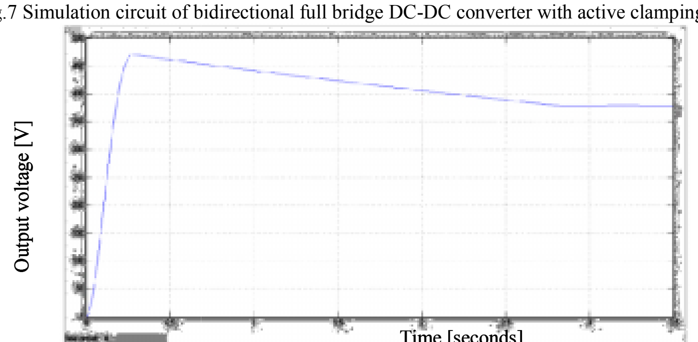


Fig.8 Simulation result of bidirectional full bridge DC-DC converter with active clamping snubber

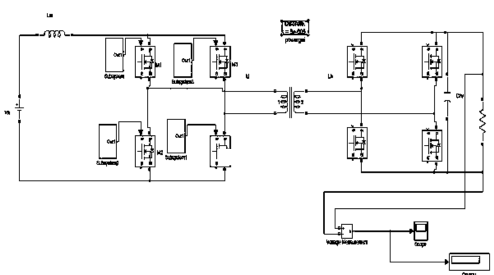
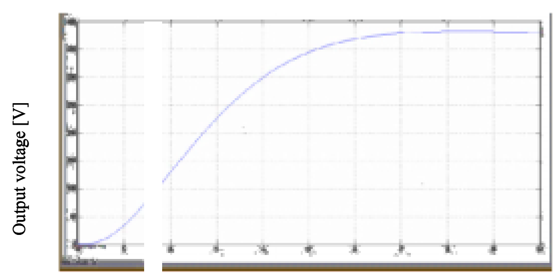


Fig. 9 Simulation circuit of open loop bidirectional full bridge DC-DC converter without flyback snubber- Boost operation



Time [seconds]

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Fig.10 Simulation result of open loop bidirectional full bridge DC-DC converter without flyback snubber- Boost operation

We obtain an output voltage of 381.2V for open loop bidirectional full bridge DC-DC converter without flyback snubber.

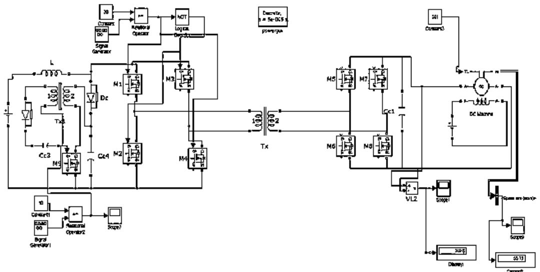

Fig.11 Simulation circuit of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor - Boost open loop operation

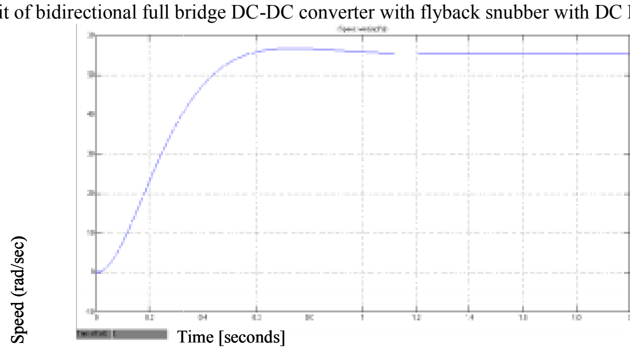

Fig.12 Simulation result of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor - Boost open loop operation

We obtain a speed of 58.1rad/sec for of bidirectional full bridge DC-DC converter with flyback snubber- Boost open loop operation.

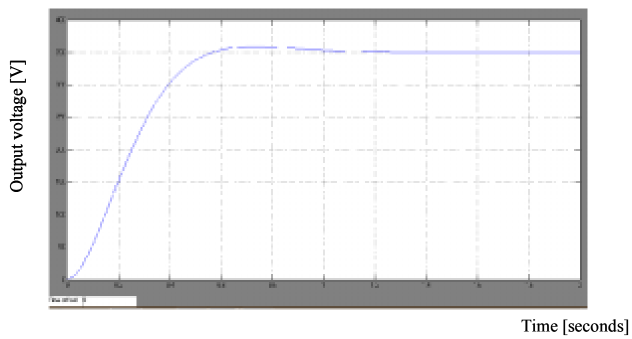

Fig.13 Simulation result of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor - Boost open loop operation with output voltage 350V.

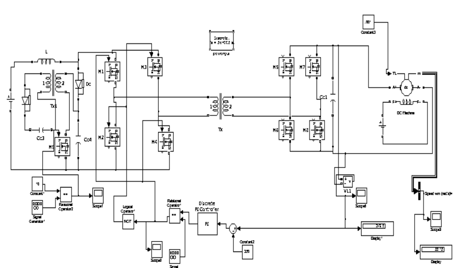

Fig.14 Simulation circuit of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor – Boost closed loop operation

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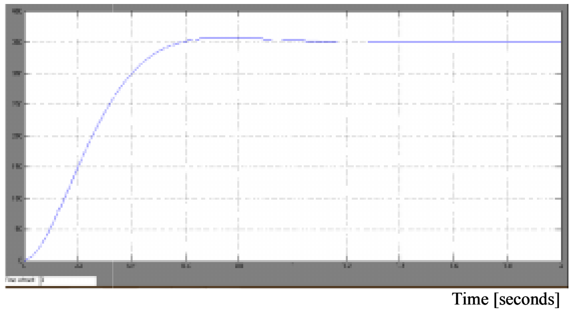

Fig.15 Simulation result of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor – Boost closed loop operation with an output voltage of 350.6V

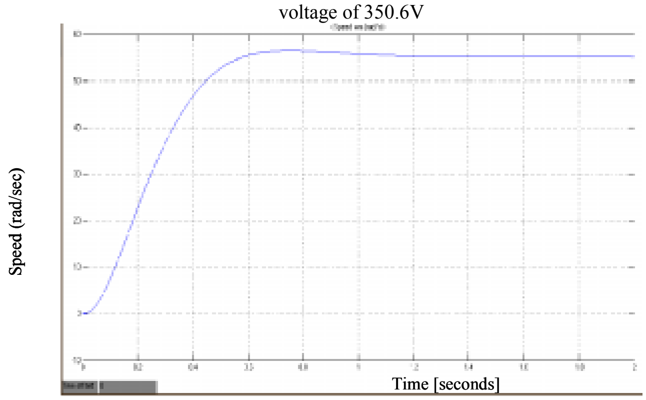

Fig.16 Simulation result of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor – Boost closed loop operation [Speed curve] with a speed of 58.1rad/sec

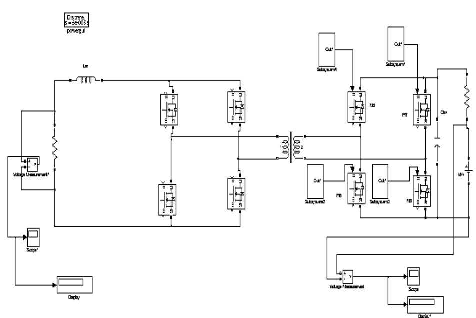

Fig.17 Simulation circuit of open loop bidirectional full bridge DC-DC converter without flyback snubber- Buck operation

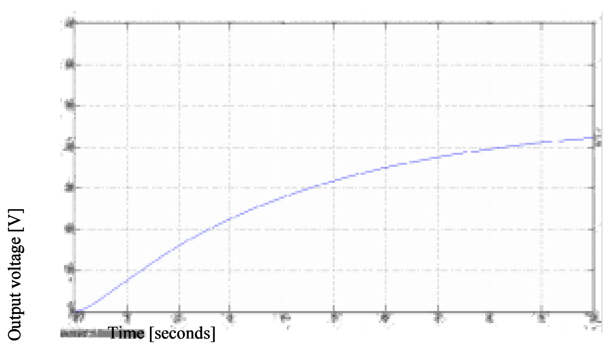

Fig.18 Simulation result of open loop bidirectional full bridge DC-DC converter without flyback snubber- Buck operation

We obtain an output voltage of 42.86V for open loop bidirectional full bridge DC-DC converter without flyback snubber- Buck operation

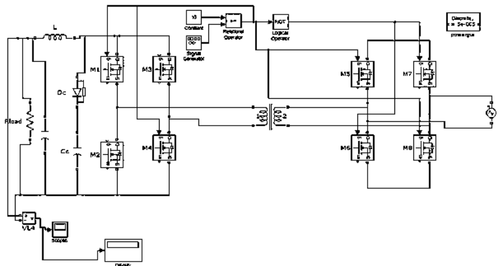

Fig.19 Simulation circuit of bidirectional full bridge DC-DC converter with flyback snubber with DC motor- Buck open loop operation

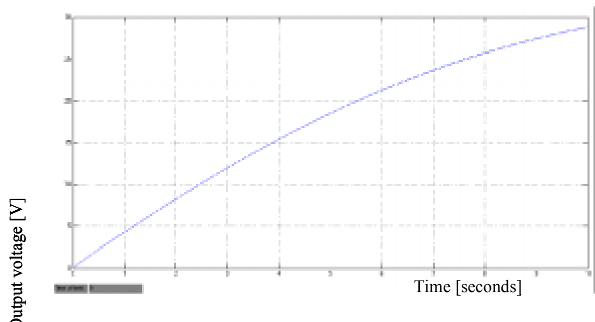

Fig.20 Simulation result of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor - Buck open loop operation with an output voltage of 28.4V.

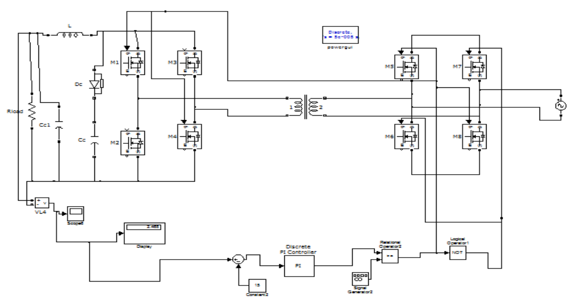

Fig.21 Simulation circuit of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor – Buck closed loop operation

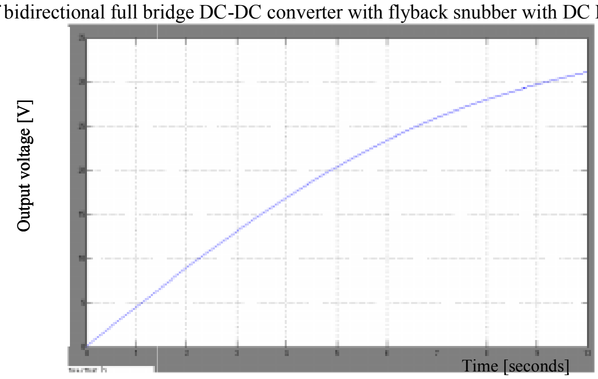

Fig.22 Simulation result of bidirectional full bridge DC-DC converter with flyback snubber with DC Motor – Buck closed loop operation with an output voltage of 32.5V

The simulation results of open loop and closed loop control of isolated bidirectional DC-DC converter with and without flyback snubber for various loads are done. DC motor as a load is used for the simulation in hybrid vehicle application.

The input 230V is stepped down to 15v using a step-down transformer and it is rectified to dc by the bridge rectifier. In boost mode, the output of the rectifier is boosted by a step-up transformer of ratio 12:230. The output is converter into ac by an inverter. The load used is a resistive load of rating 1K, 10W. Fig.23 shows the photograph of the prototype converter.

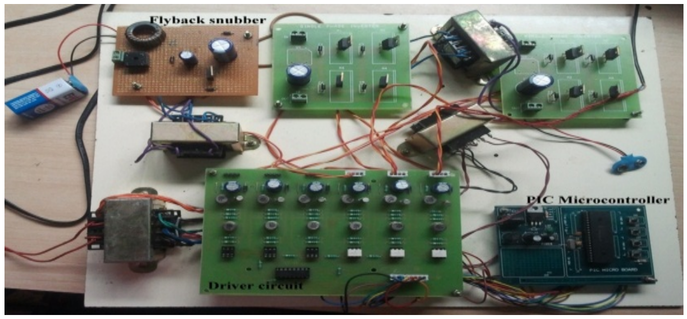

Fig.23 Photograph of prototype converter

IV. CONCLUSION

The bidirectional DC-DC converter with flyback snubber is proposed for hybrid electric vehicles. Compared to RCD and Active clamp snubber, flyback snubber for converter provides the better efficiency. Simulations and experimental setup are described in this paper.

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Biography

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