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Implementation of Bidirectional DC/AC and DC/DC Converters for Automotive Applications

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Abstract: In this paper, a configuration of bi-directional converters which are used to charge the battery of the vehicle and to supply energy back to the grid using same converter network is proposed. Thus the single phase converter used act as both AC/DC and DC/AC converter. Buck/Boost converter is used to charge and discharge the battery. Simulated results validate the effectiveness of proposed configuration and the feasibility of system. The proposed system is based on the energy transfer between the grid to vehicle and the vehicle to grid. Bi-directional AC/DC and DC/AC converters is used, in the grid to battery mode operation the battery of the vehicle is charged in this operation AC/DC converter is used to convert the single phase AC supply in to pulsed DC and a DC/DC buck converter steps down the voltage level to charge the battery. The energy stored in the battery can be used to drive the vehicle and cold be used to supply energy back to the grid when required. The use of bi-directional AC-DC and DC-DC buck/ boost converters, bi-directional converters use the same H-bridge network for converting AC-DC, DC-AC and the DC-DC buck/boost networks used to charge and discharge the battery respectively. The simulation of the proposed system is done using Matlab, required results are obtained and the graphs are plotted using the scope function, soc of the battery are obtained in both charging and the discharging operation of the battery. And the voltage level of the converters are obtained and plotted. The hardware system of the proposed converter is implemented using a PIC micro-controller.

Keywords: Plug-In Hybrid Electric Vehicles, Grid-to-Vehicle, Vehicle-to-Grid, Vehicle-to-Home.

1. INTRODUCTION

The current system in both power generation and automobile uses fossil fuels which are in depletion rate and produce more waste affect the environment, power plants use coal and nuclear energy which cause more pollution and nuclear power plants are very dangerous when they go out of control. They require more cost to build and the maintenance cost are also high. The Fuels used in the automobiles have become more in cost and the supply of the fuel has been reduced and the consumer have become very large in number. These fuels produce more pollution and they are in the depleting rate. The plug-in hybrid electric vehicle is a hybrid electric vehicle with an energy storage system that can be recharged by connecting the vehicle plug to an external electric power source Furthermore, Hybrid Electric Vehicles, especially PHEV[1-5] have become an interesting alternative to conventional vehicles due to their capability of reducing fuel consumption, Zero-exhaust emissions.

The proposed system is based on the energy transfer between the grid to vehicle and the vehicle to grid. Bi-directional AC/DC and DC/AC converters is used, in the grid to battery mode operation the battery of the vehicle is charged in this operation AC/DC converter is used to convert the single phase AC supply in to pulsed DC and a DC/DC buck converter steps down the voltage level to charge the battery[6-9]. The energy stored in the battery can be used to drive the vehicle and cold be used to supply energy back to the grid when required. When the energy from the battery is supplied to the grid, the converter works as inverter the battery energy is given to the boost converter since the nominal voltage level of the battery is lower to that of the grid voltage, then to the bi-directional converter which act as DC/AC converter then supplied

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to the grid. The battery could be charged while the vehicle is running .whenever the brake is applied the motor act as a generator the flow of current is reversed and thus the battery is charged. The advantages of such a system includes reduced dependency fossil fuel, the energy stored in the battery can be used to drive the vehicle and cold be used to supply energy back to the grid when required.

2. MODEL DISPCRIPTION

The use of bi-directional AC-DC and DC-DC buck/boost converters, bi-directional converters use the same H-bridge network for converting AC-DC, DC-AC and the DC-DC buck/boost networks used to charge and discharge the battery respectively. Both the H-bridge and buck/boost networks uses MOSFET switches and switching controlled with the help of the PWM block, lead-acid battery is used as the energy storage device[10]. In the charging mode the converter act as a Rectifier converts AC into DC and to the buck converter which is used to charge the battery, in discharging mode energy from the battery is raised with the help of the boost converter and converted in AC and given to the grid where the H-bridge network act as inverter.

3. MODES OF OPERATION

A. **Grid-to-Vehicle (G2V) Operation Mode:** During this operation mode the full-bridge AC-DC bidirectional converter operates as active rectifier with sinusoidal current and unitary power factor. The reversible DC-DC converter operates as buck converter. In the energy transfer mode from the grid to vehicle and vehicle to the grid the interaction between the grid and bidirectional AC-DC converter is the main issue. These types of converters are developed to meet the requirements of applications of bidirectional power flow in addition to improved power quality at the grid in terms of high power factor and low THD with well-regulated output DC voltage..

B. **Vehicle-to-Grid (V2G) Operation Mode:** In order to the full-bridge AC-DC bidirectional converter deliver back to the power grid the energy stored in the batteries, the DC link voltage must be slightly greater than the peak value of the power grid voltage. For such intent, the reversible DC-DC converter has to operate as a boost converter, once the traction batteries voltage is smaller than the required to the DC link voltage. The traction batteries voltage does not suffer significant variation during short time periods, consequently the regulation of the active power delivered back to the power grid can be done by the absorption of a constant current from the traction batteries. However, as the batteries voltage decreases along the discharging process it is necessary to increase the reference current to maintain the active power constant.

C. **Vehicle-to-Home (V2H) Operation Mode:** During the V2H operation mode the full-bridge AC-DC bidirectional converter synthesizes a sine-wave voltage with the desired amplitude and frequency to feed the home loads. As in the V2G operation mode the reversible DC-DC converter operates as a boost converter in order to maintain the DC link voltage with adequate amplitude for the proper operation of the full-bridge AC-DC bidirectional converter.

4. CIRCUIT MODEL

Figure.1 shows the circuit diagram of the Bidirectional converter. The system is configured with the bi-directional converters with both AC/DC and DC/DC converter the AC/DC converters are used to convert the grid supply into DC and convert the DC into AC and supply back to grid. DC/DC converters are used to step down/ step down the voltage to charge and discharge the battery. Since the battery voltage is lower than that of the grid, the supply from the AC/DC converter could not be directly taken from the grid. Hence buck converter is used to step down the voltage and charge the battery. In the same time Boost converter steps up the voltage and gives to grid.

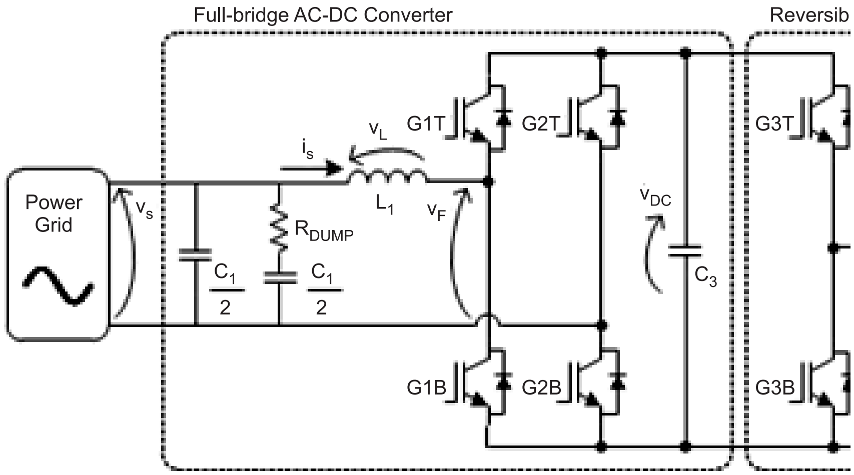

Figure 1: Bi-directional converter

5. SOFTWARE DESCRIPTION AND IMPLEMENTATION

The simulation of the proposed system is done using Matlab, required results are obtained and the graphs are plotted using the scope function, soc of the battery are obtained in both charging and the discharging operation of the battery. And the voltage level of the converters are obtained and plotted.

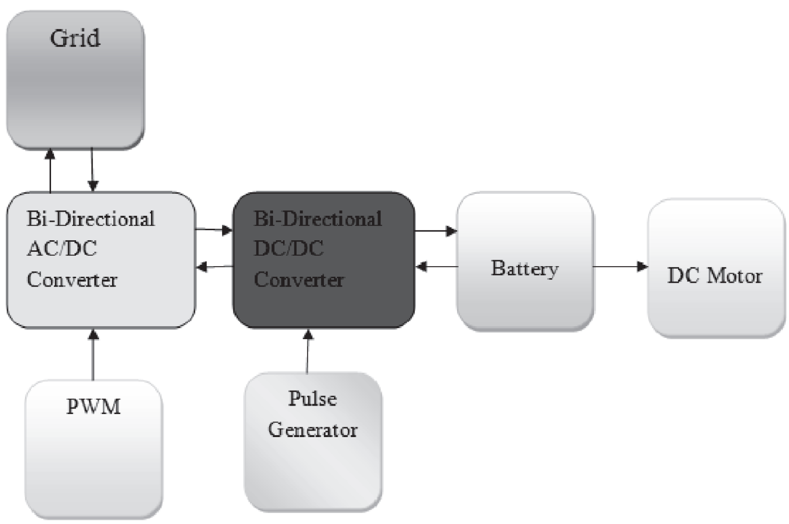

Figure 2: Block Diagram

The block diagram representation and the simulation setup of the proposed system is given in Figure 2 and Figure 3. The proposed system has the above blocks and elements connected in an arranged manner. To provide a required system that transfer energy from the grid to battery and battery to grid. Ideal switch are manually triggered to switch the mode of the converter.

The system is designed such that the user could switch the mode when it is required in grid to battery mode the ideal switch IS1 and IS2 are kept on and the converter act as a rectifier and gives it to the buck converter and the battery is charged. In the battery to grid mode the ideal switch IS3 is kept on and IS1, IS2 are in off state, in this mode the battery is discharged through the boost converter where the boost converter raise the voltage level to the grid's voltage level, the H-bridge converter act as a inverter in this mode of operation the load connected between the H-bridge network is considered to be the grid load and to be in constant demand always. The MOSFET M1, M2, M3, M4 of h-bridge are controlled with the PWM generator. This h-bridge network act as inverter and rectifier, M4 M5 switch of buck and boost converter are controlled with the pulse generator. The battery voltage, current, SOC are measured in both the mode of operations.

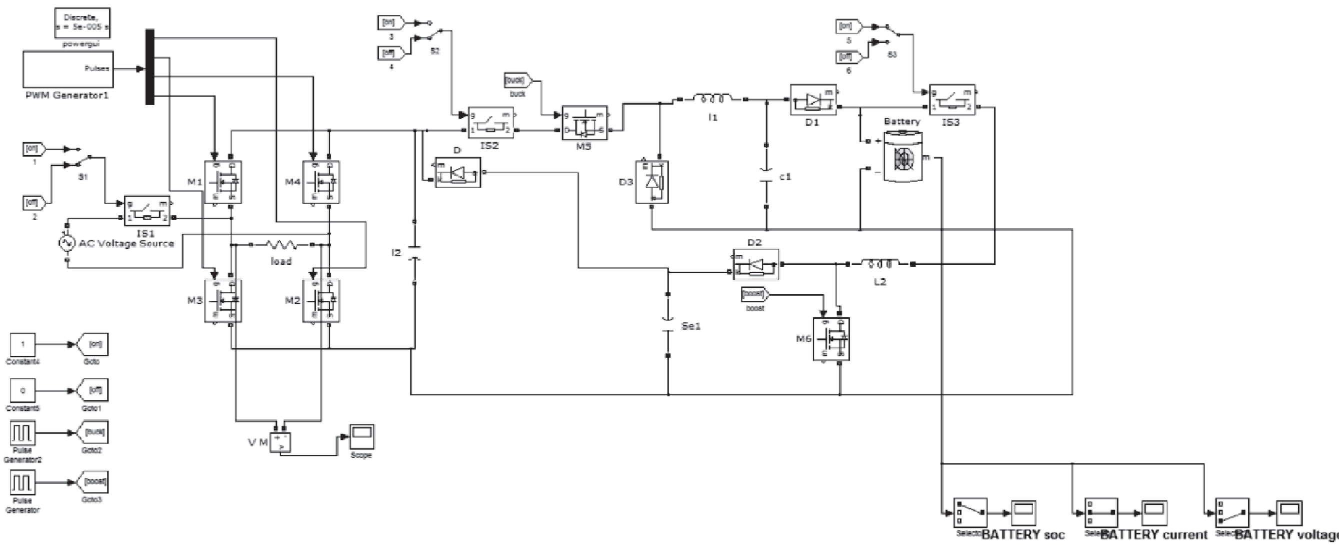

Figure 3: Proposed simulation diagram

The input voltage is given as 230V and 50Hz supply. The H-bridge network MOSFET switch is controlled with the PWM generator in both the mode of operations. The battery of nominal voltage 150V, 24Ah with initial charge percentage of 25% is considered in the charging mode. In the discharging mode initial charge percentage is taken as 100%. On the requirement of the user the modes of operation can be switched or changed by controlling the ideal switches.

6. HARDWARE IMPLEMENTATION

Figure.4 and Figure.5 describes the hardware model of the system. The hardware system of the proposed converter is implemented using a PIC micro-controller. The software system like Proteus, Mplab, and Micropro is used for the system design for coding the pulses in to the PIC controller. The power supply circuit is designed that will control the PIC and driver circuit to drive the pulses to the MOSFET.

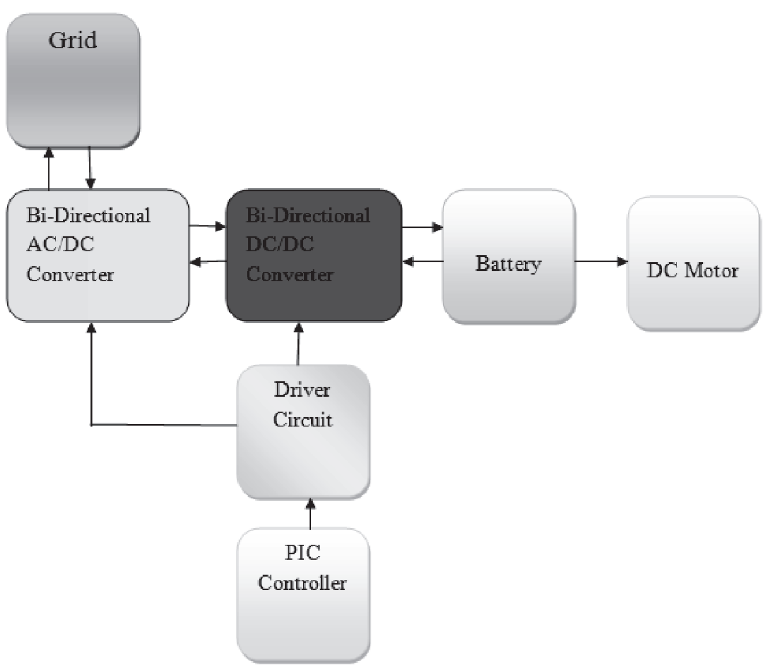

Figure 4: Hardware block diagram

7. RESULTS

A. Simulation Results

SOC of the battery of nominal voltage of 150V 25% of initial charge is considered and charged through a buck converter the Figure.5 graph shows the charging rate in terms of percentage.

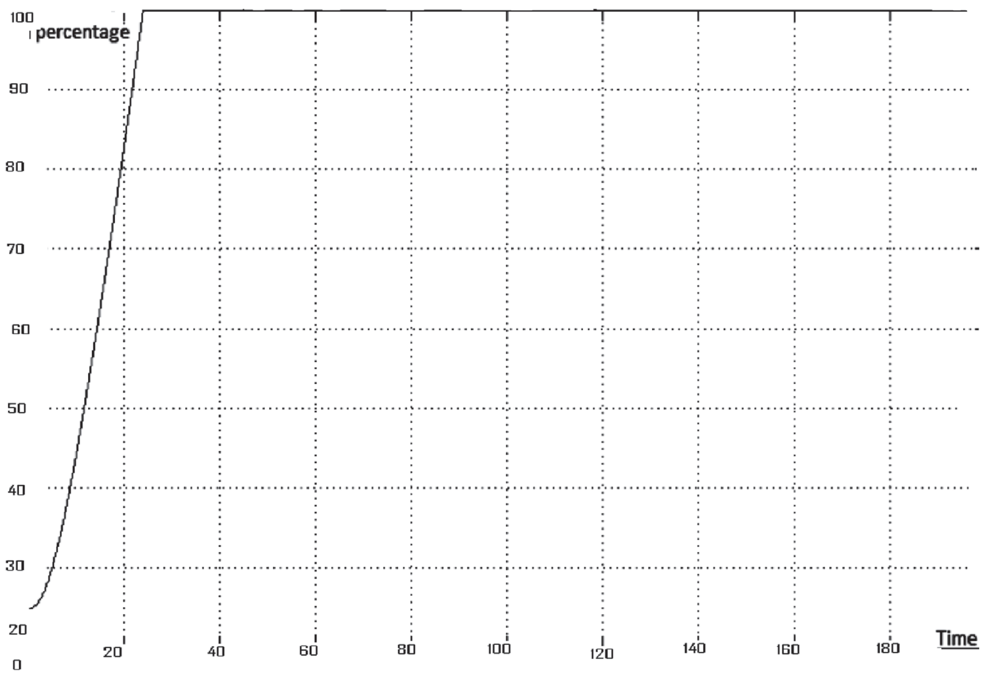

Figure 5: SOC in charging mode

The discharging characteristics of the battery in the mode two is show in Figure 6 graph where the initial charge percent is considered to be 100%.then it gradually decreases as the power is dissipated.

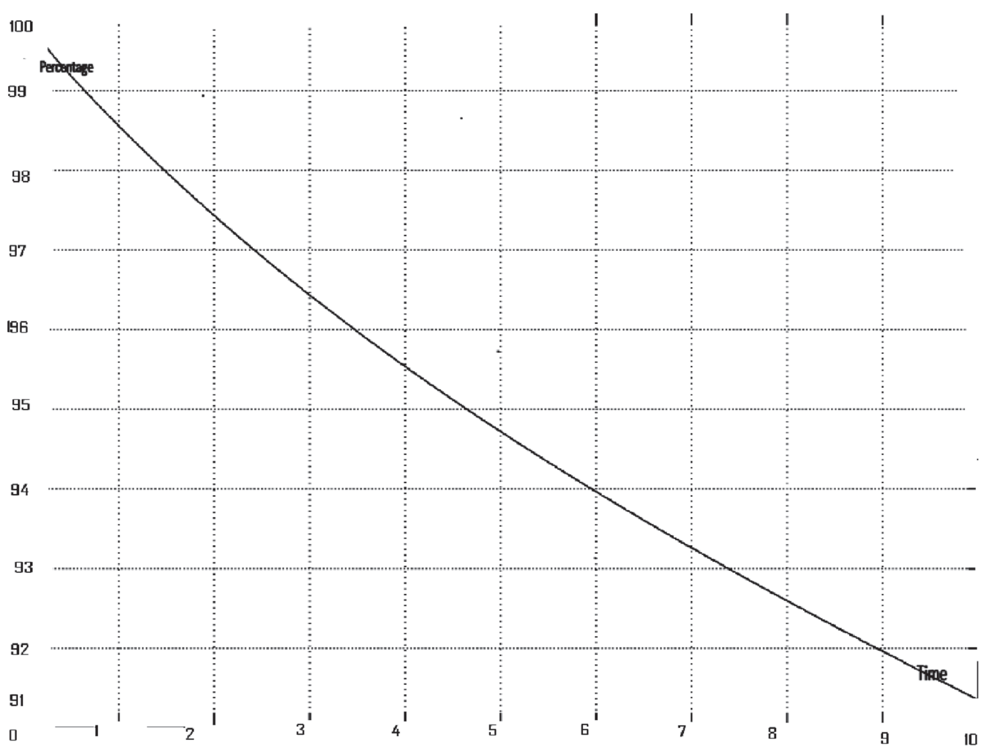

Figure 6: SOC in discharging mode

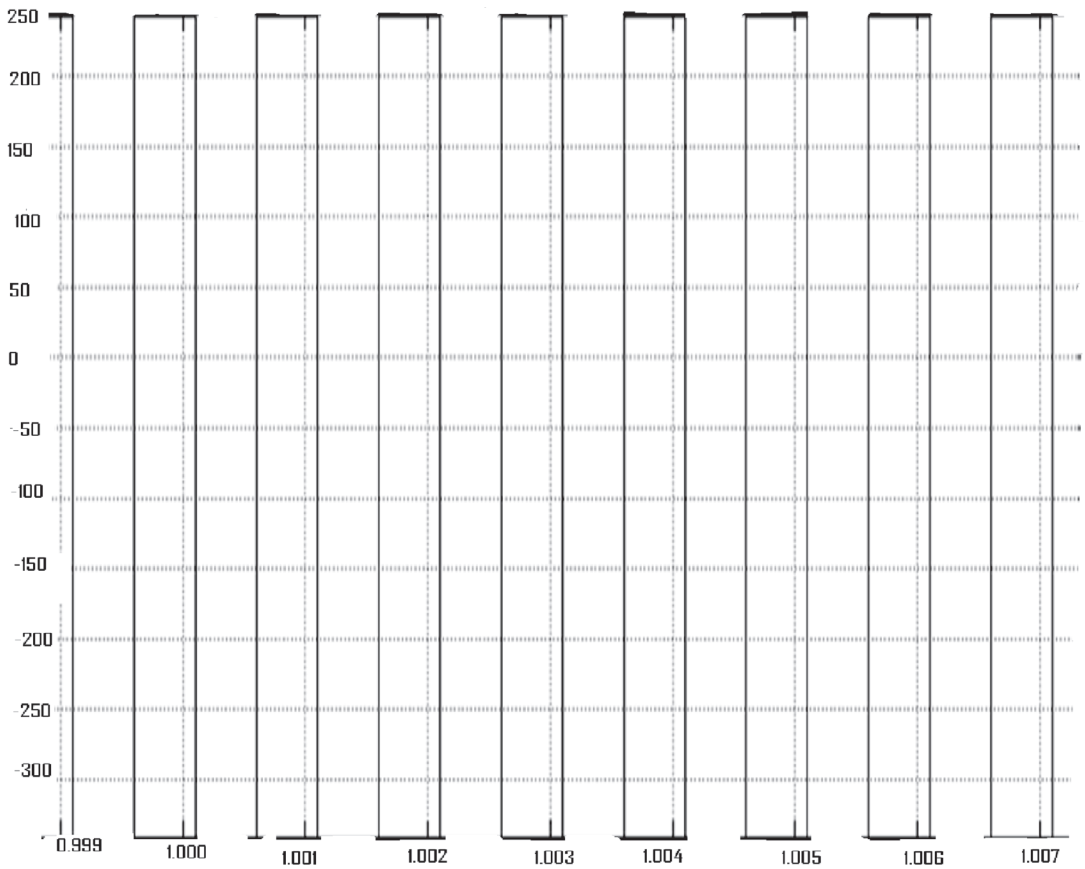

Figure 7: Output waveform in Battery to grid mode

The Figure 7 shows voltage waveform of the grid load in the BATTERY TO GRID mode operation. Square wave form of the h-bridge inverter is obtained

B. Hardware Output

Figure 8: PIC controller output

Above Figure.8 are the micro-controller indications in the different mode of operation in which the first figure represents the GRID TO BATTERY MODE of operation and the second figure represents the BATTERY TO GRID MODE of operation. Both the modes are controlled with the help of the micro-controller.

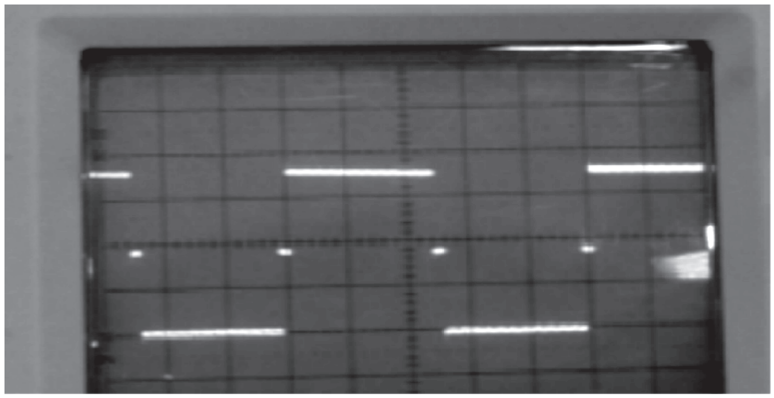

Figure 9: Voltage waveform output in Battery to Grid mode

The output of the hardware module shows a stepped square wave in the BATTERY TO GRID MODE of operation. Output of about 24V AC voltage is obtained that is given in Figure 9.

8. CONCLUSION AND FUTURE ENHANCEMENTS

The proposed converter has delivered the AC current to/and from the grid at unity power factor and at very low current harmonics which ultimately prolongs the life of the converter and the battery and minimizes the possibility of distorting the grid voltage. It also enables V2G interactions which could be utilized to improve the efficiency of the grid.

Finally, the results have demonstrated that the proposed configuration, PEI, has achieved both modes of operation successfully and it promises significant savings in component count with high performance for PHEVs compared with other topologies. Therefore, it can be expected that this study can be utilized for development of high efficiency PHEV system. The experimental implementation to evaluate the proposed system will be performed in the near future as well. Sun is the most mean of renewable energy available by using solar collector PV station can be built. Through which the vehicles battery could be charged and at the same time the PV station can also be connected to grid when it is not used to charge the vehicles. Even the PV cells can also be mounted on the top of the vehicles such that Battery could be utilized more efficiently.

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