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Bidirectional Electric Vehicle Charger For Vehicle to Home(V2H) System

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Abstract : The objective of this project is to implement an electric vehicle charger module which effectively controls the flow of power between the utility and storage devices such as an Electric Vehicle battery. The bidirectional converter circuit is cascaded AC-DC converter and a bidirectional Buck-Boost converter to a common DC link. The topology used to interface DC link to battery side is effective in bidirectional power flow control. In battery charging mode the converter works as a Buck converter and during battery discharging mode of operation the converter works as a Boost converter. The circuit operation was simulated using Matlab-Simulink and is hardware implemented with the help of a dsPIC30F4011 controller.

Keywords: Point of common coupling, Power Quality, Total harmonic voltage distortion, Total harmonic current distortion.

1. INTRODUCTION

Conventional Vehicles which ply on fossil fuels play a major role in the environmental hazards we see around us in day today life. This situation is expected to aggravate as vehicles population is bound to escalate in the coming years. The popularity of electric vehicles has not yet reached a threshold level. The main reason for the lack of popularity of electric vehicles among the general public is because of the high cost factor.

On the other hand, The Power and energy sectors across the world has been under severe pressure to meet the day today load demand of the countries ever growing industrial or household loads.The concept of vehicle to grid or home system becomes prominent in this context.

The development of various smart cities explores the use of a cluster of electric vehicles as a power resource. It has to address many a technical challenges before becoming a widespread commercially implementable option.

Electric vehicle charger plays a crucial role in the implementation of this novel technology. Since, the conventional chargers only avail a unidirectional flow of power, by the use of a bidirectional charger that can possibly communicate as well as transfer power from and to the electric vehicle is the major part of the V2G system. A bidirectional charger constitutes of a bidirectional converter that could help in attaining desired battery charging voltage as well as utility voltage level.

In [1], the authors explores the impact of vehicle to grid operation on the power grid, its potential to reduce peak demand and various challenges which needs to be addressed to facilitate practical implementation of the same.

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In [2], the authors discusses about a practical strategy for implementing V2H in an urban housing complex thereby resulting in multiple benefits such as improved transformer sizing, reduced distribution losses, and reduced transformer losses and financial incentives through V2G transactions.

In [3], the author discusses a topology of an onboard bidirectional battery charger for electric vehicle enabling power transfer from vehicle to grid, grid to vehicle and grid to home based on control algorithm.

In [4], the authors explores the possibility of utilizing the bidirectional charger for reactive power compensation.

In [5], the authors explore the possibility of using V2H meeting various optimization objectives such as residential load levelling, operating cost minimization subject to constraints such as vehicle availability, battery SOC limits etc.

In [6], the authors experimentally analyses the operation of an electric vehicle in UPS mode during power outages.

In view of these multiple opportunities offered by EVs, this paper attempts to implements a Bidirectional electric vehicle charger which could be used to transfer power from the utility to vehicle and vehicle to home. The excess power in the electric vehicles during standstill condition could be used either as a backup power source or a mode to cater peak demand load of the utility. Thereby, reducing the stress in the total grid. The converter that is developed could charge the batteries of electric vehicles or discharge the battery to home depending on the condition of power supply present and the state of charge present in battery.

2. V2H–SYSTEM OVERVIEW

The system designed is a bidirectional converter circuit with the help of a logic controller in order to operate either in Grid to vehicle mode or Vehicle to home mode of operation. Fig.1. shows the overall block diagram of the system to be implemented.

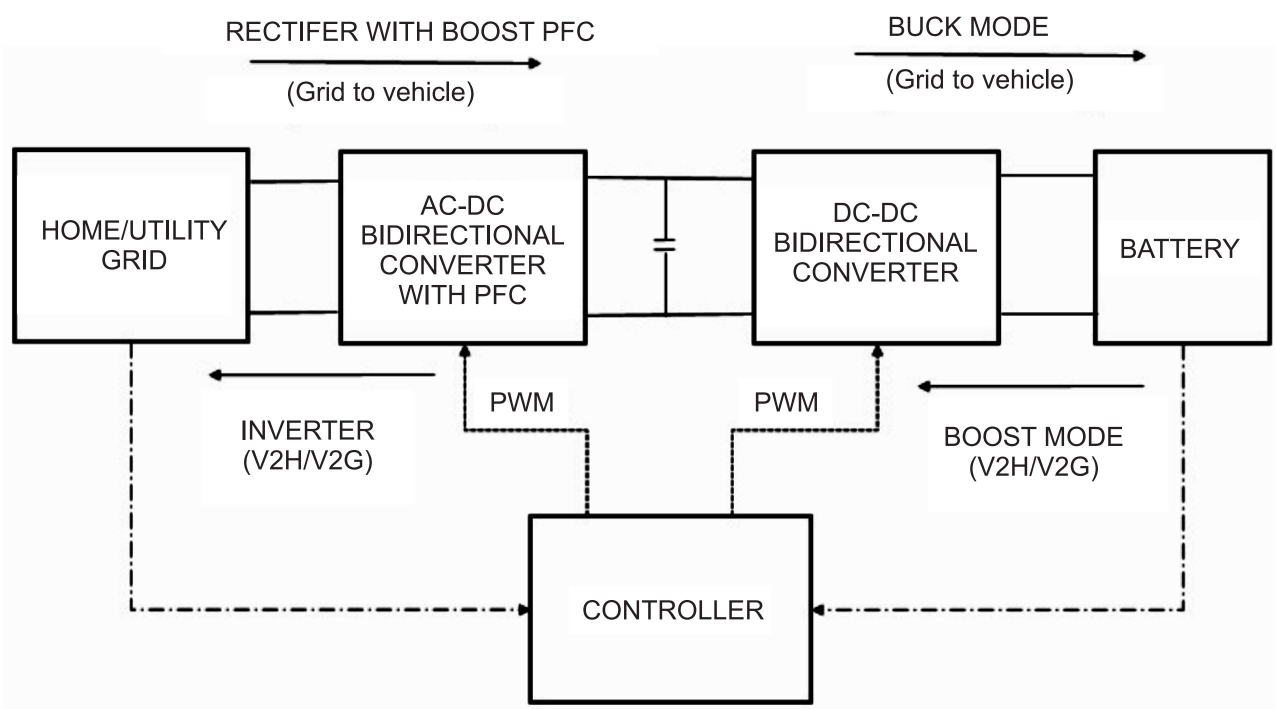

Figure 1: Block Diagram of Vehicle to Home System

The presented battery charger is composed of two power converters that share a DC link. One converter is used to interface the power grid with the common DC link capacitor and next converter interface the DC link with vehicle batteries. In order to interface the power grid a full-bridge AC-DC bidirectional converter is used. This converter act as a rectifier with sinusoidal current and unitary power factor during the G2V operation mode and as an inverter in the V2G and V2H operation.Interfacing the DC link capacitor with vehicle battery is done by the use of a bidirectional Buck Boost Converter,which can work in buck mode of operation during charging battery and in boost mode during discharging of the vehicle battery.

Modes of Operation

Grid to Vehicle

In G2V mode of operation the charging of battery happens.

This is done by the help of Rectifier operation of AC-DC converter with power factor correction circuit which keeps the power factor at 0.99.The rectified output is compared with a reference sinusoidal wave in order to draw unity power factor signal from the source.

The control strategy used is a method of reference current control, the switches are turned on and off such that the actual input current follows a reference current. In this control the inductor current i.e., the input current is compared with a reference current derived from output voltage.

At first the switch is turned on, the inductor current increases charging the inductor when actual current hits or equals reference current.

The switch is turned off, the inductor discharges so,inductor current reduces at start of the next period till the switch is turned on again and cycle repeats.

By the use of above method we could attain near unity power factor waveforms in the input.The output of PFC is fed to the DC link.

The DC link caters the balancing between the AC-DC converter and DC-DC converter. During this mode of operation the DC-DC converter operates in buck mode of operation which steps down the DC link voltage on to nominal battery voltage required for charging the batteries.

Vehicle to Home Mode

In this mode operation the vehicle battery starts discharging to the load connected to the Inverter output terminal acting as a backup power source.

The DC-DC converter works in the Boost mode stepping up the battery voltage on to DC link voltage. The boost converter pulses are provided through a PI controller which takes the feedback in order to limit the current drawn from the battery to a nominal value,

The AC- DC converter acts in inverter mode of operation with sine PWM switching scheme to obtain sinusoidal voltage and current waveform across the load.

In this switching Sinusoidal waveform is compared with triangular signal in order to create the PWM signals.The advantage of Sine PWM is that it reduces injection of harmonics on the grid to a great extent.

Control Algorithm

The control algorithm for the bidirectional charger for vehicle to home system is discussed. Fig. 2 represents the flowchart of the control algorithm used in making decision for providing triggering the MOSFET's in the circuit.

From flowchart,if there is no power supply present in home while the vehicle is connected to the charger it checks for the state of charge whether its above 80% or below that value.

If the SOC is above 80% charger works in Vehicle to home mode of operation when there is no power supply at home load or else no operation is carried out.If there is supply present at home during vehicle plugged in and if SOC is above 80% charger works in Home to vehicle mode of operation charging the vehicle batteries or else no operation is done.

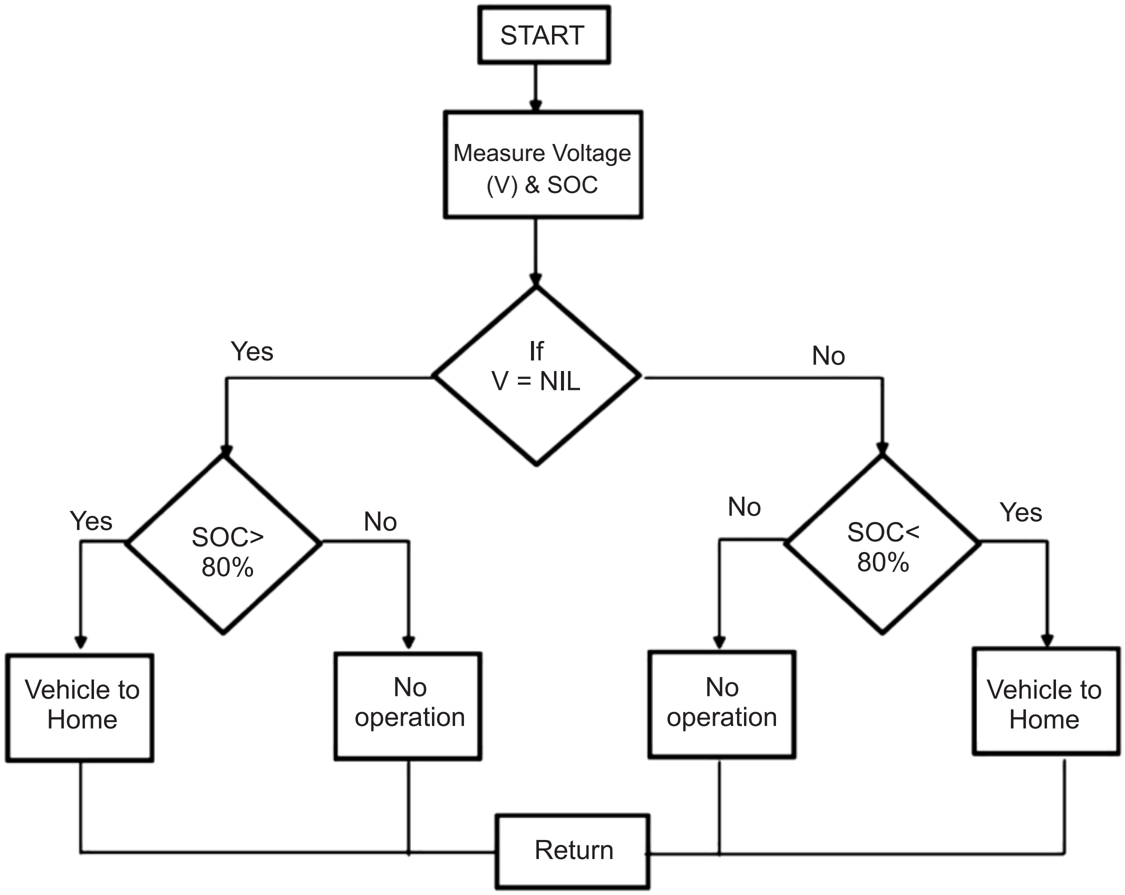

Figure 2: Flow Chart of Control Algorithm

3. DESIGN SPECIFICATIONS

Design of Line Inductance for AC-DC Converter

The output voltage of inverter is given as in..3

$$V_c = 0.707 * mV_{dc} \tag{1}$$

Where *m* is modulation index, *m* = 0.9,V_{dc} is the output voltage to DC Link = 400 V, For a Power output of 800 W substituting all the values in the above equation we get,

Inverter output voltage is obtained as,V_c = 254 V. Substituting the value for V_c in equation (2)to calculate the inductance value

$$V = \sqrt{V_c^2 + I^2 * X_t^2} \tag{2}$$

For an RMS value of V = 325V and current, I = 5A, Inductor value L = 8.65mH

Design of inductance for PFC

The inductance value to be used for performing the power factor corrected circuit can be calculated using equation

$$L = \frac{1}{\%\text{ripple}} * \frac{V_{\text{acmin}^2}}{P_o}\left(1 - \frac{\sqrt{2} * V_{\text{acmin}}}{V_o}\right)\frac{1}{f_{sw}} \tag{3}$$

For an output power of 800W and voltage of 400V,

Input AC Minimum value $V_{\text{acmin}} = 210$ V

Switching frequency $f_{sw} = 20$kHz.

Considering 20% ripple in output.Substituting the values weget L = 3.54 mH. Considering 125% of the calculated inductance value L= 4.425mH = 5mH.

Design of DC Link capacitor

The DC link acts as the interlink between the AC-DC converter and DC-DC converter.The design of DC link capacitor is found by the following equation

$$C_o = \frac{P_o}{2\pi f_{line}\,\Delta V_o V_o} \quad (4)$$

For an output power P_o = 800 W, line frequency, f_{line} = 50 Hz, voltage ripple of 10% and voltage, V_o = 400 V.

DC link capacitor value is obtained as C_o= 788μF.

Design Bidirectional Buck-Boost Converter

For buck converter Source voltage is the DC link Voltage and Output voltage is battery voltage.

$$V_b = V_{dc} * D \quad (5)$$

Where V_b is battery voltage and V_{dc} is DC link Voltage, D is the duty ratio. From the above equation,

For V_b = 48 V,

V_d = 400 V and duty ratio

D = 0.12

Let, switching frequency F_{sw} = 20 kHz, battery charging current i_L = 16 A. For a 20% ripple in inductor current i_L,

Inductance value is given by $$L = \frac{V_b * (1 - D)}{\Delta i_L f_{sw}} \quad (6)$$

By substituting the values in the equation inductance value is obtained as L = 700μH.

For Boost converter Source voltage is Battery Voltage and Output voltage is DC Link Voltage {8}

$$V_{dc} = \frac{V_b}{(1 - D)} \quad (7)$$

Where V_b, battery voltage and V_{dc}, DC link Voltage, D is the duty ratio.From the above equation

For V_b = 48 V,

V_d = 400 V,

D = 0.86

switching frequency of f_{sw} = 20kHz,Battery discharging current i_L =16 A. For a 20.% ripple in inductor current, i_L,

Inductance value is given by

$$L = \frac{V_b D}{\Delta i_L f_{sw}} \quad (8)$$

L = 660 μH. Hence, The Inductance value of Bidirectional Buck Boost is chosen as 700 μH.

4. SIMULATION ANALYSIS

The section deals with the simulation study of the vehicle to home system that is carried out in MATLAB-Simulink using this controller operation is verified and compared.

The simulation diagram shown in Fig.3 verifies the bidirectional operation of Vehicle to Home system where the simulated home is connected to a Lead-acid battery of capacity 48V,80Ah capacity.

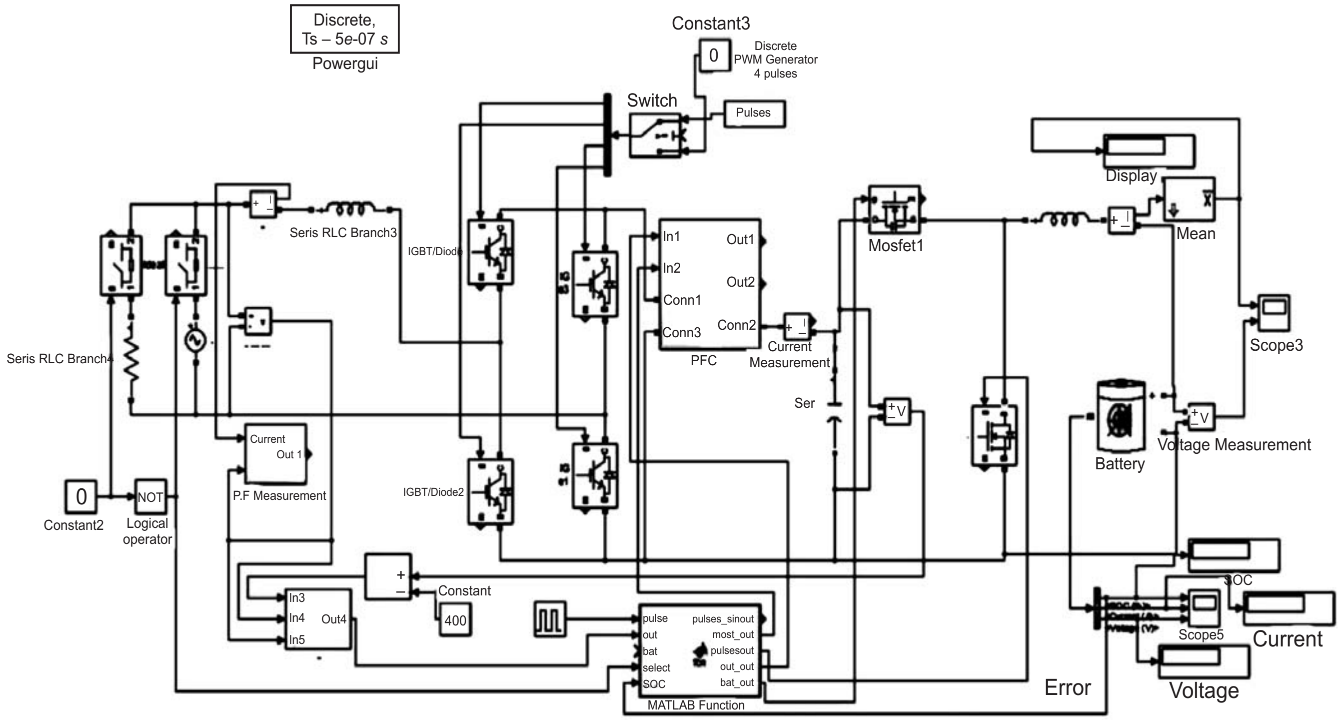

Figure 3: Simulation Diagram of Vehicle to Home system

Grid to Vehicle Mode

When the system detects state of charge of battery is less than 80% with power supply present at home side,circuit works in grid to vehicle mode of operation.The input current and voltage drawn by the circuit in this mode of operation is shown in Fig. 4.

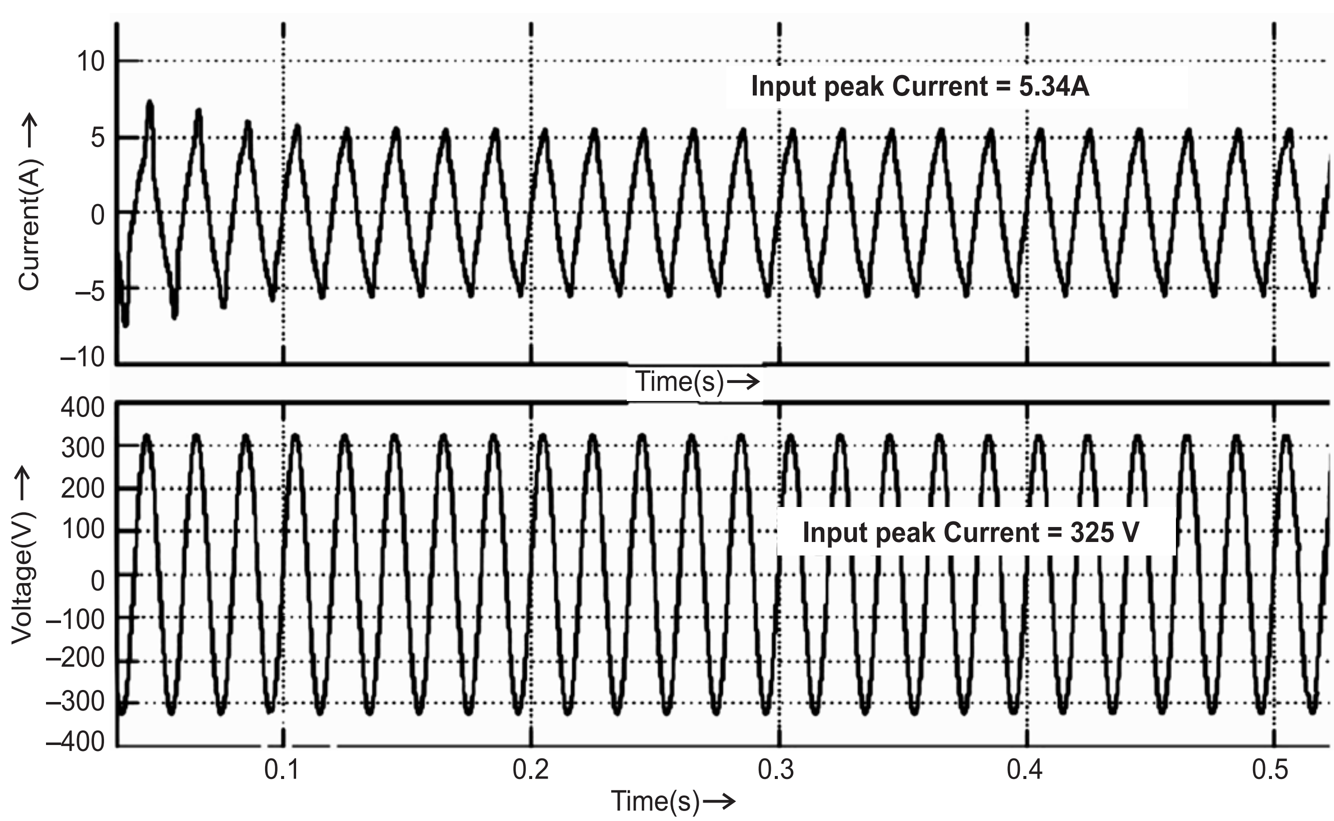

Figure 4: Input Voltage and Current waveforms(G2V Mode)

In simulation, the peak input current drawn by the battery during grid to vehicle mode of operation is found to be as 5.34A with a peak voltage of 325V. Here the AC-DC converter was in the synchronous rectifier mode of operation and bidirectional buck boost converter in the buck mode of operation. From the waveform it is observed that the current waveform is slightly a peaky waveform which could cause increase in harmonic profile of the data.The current and voltage waveforms are in phase with each other from the graph.The output of the circuit during grid to vehicle mode of operation is the battery charging voltage and current.

The output current drawn by battery for charging is found to be 16A which is in this case is high.A PI controller is used to control the current drawn by the battery which limits the battery charging current to 8A.For a lead acid battery during charging and discharging the nominal voltage value varies from 47V to 52V where 52V is the full charged voltage condition,In the grid to vehicle mode of operation the state of charge of battery is simulated as less than 50% hence,the voltage across the battery is found to be 47V in the starting condition and is found to be increasing steadily by the progress of time.In the case of charging current of the battery it is in the steady state value of 16A.

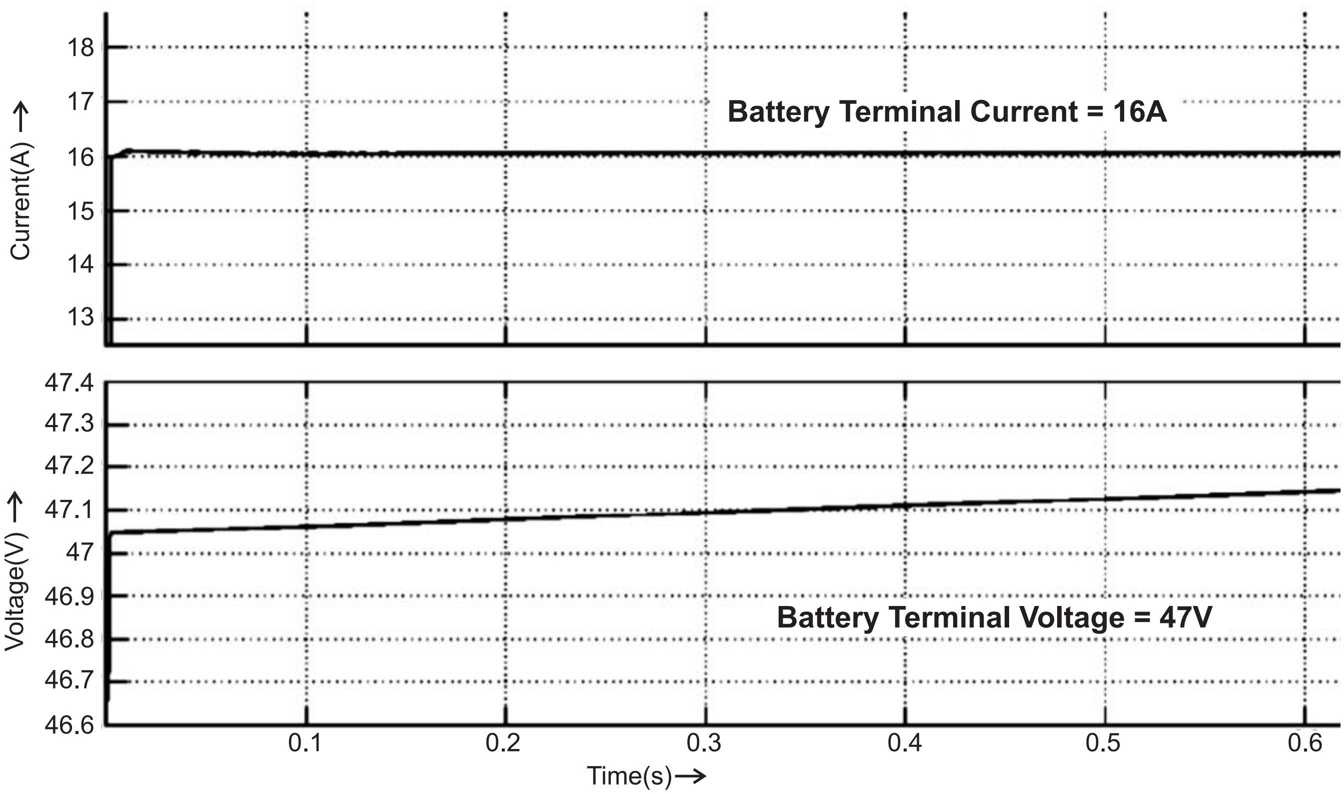

Figure 5: Battery charging current and voltage waveforms(G2V Mode)

The THD of input current is obtained using the FFT block in MATLAB Simulink model,and the harmonic profile of the input current during grid to vehicle mode is shown in Fig.6.

After the FFT analysis of the input current waveform in grid to vehicle mode.The current THD is found to be 10.85% where third and fifth harmonics are found to be predominant with 7.5% and 6% of the fundamental respectively. During this mode of operation the power factor drawn by the circuit is found to be 0.98,which considerably higher compared to the IEC standard value of 5% harmonics. Improvement in the choice of inductor windings,components and switching techniques used in the circuit can help in reducing the power factor to the permissible value.

Vehicle to Home Mode

When the system detects absence of voltage and a state of charge greater than 80%, circuit works in vehicle to home mode of operation.The battery starts discharging towards the home side,output voltage and current waveforms of the circuit during vehicle to home mode of operation is shown in Fig. 7.

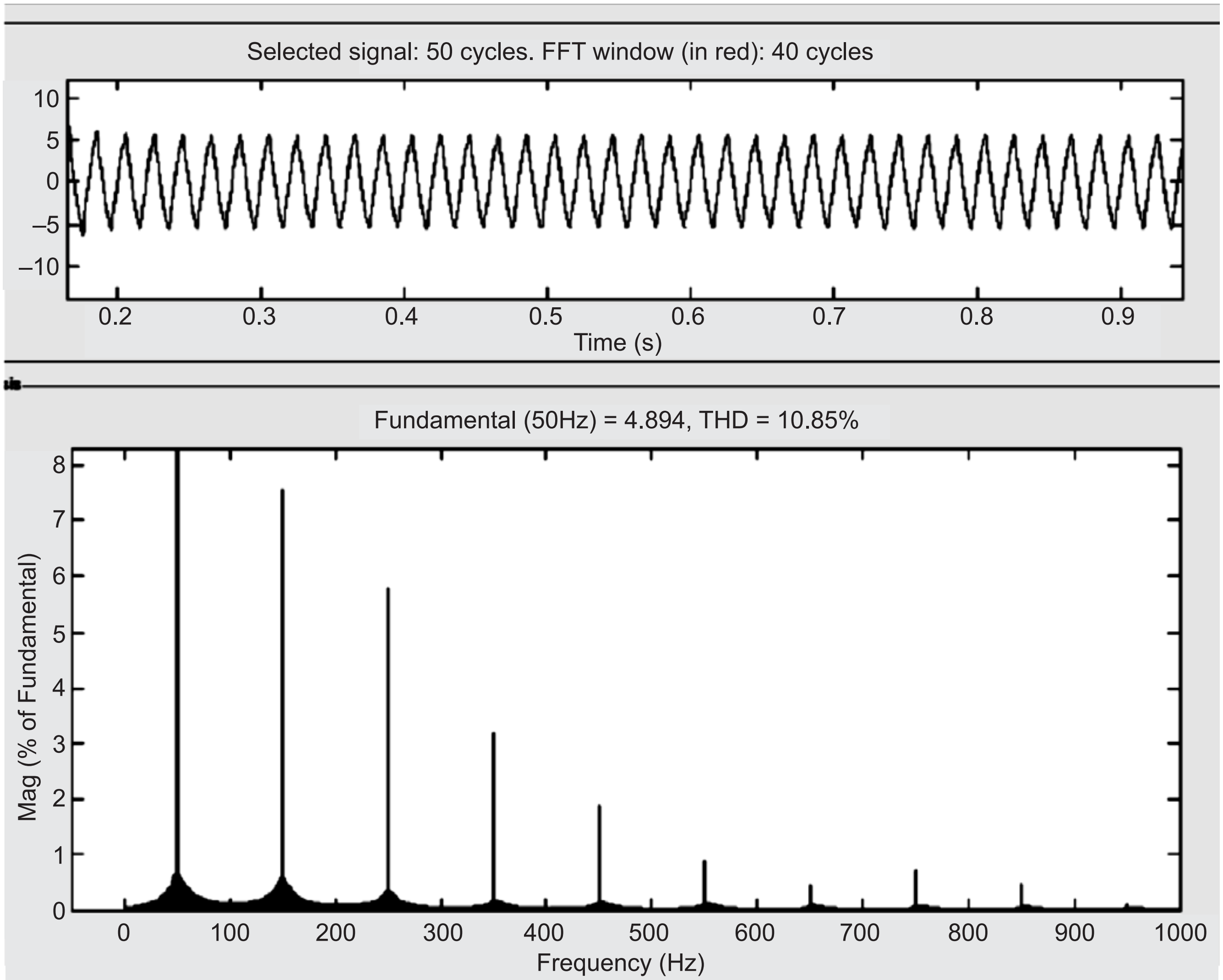

Figure 6: Harmonic profile of input in G2V Mode

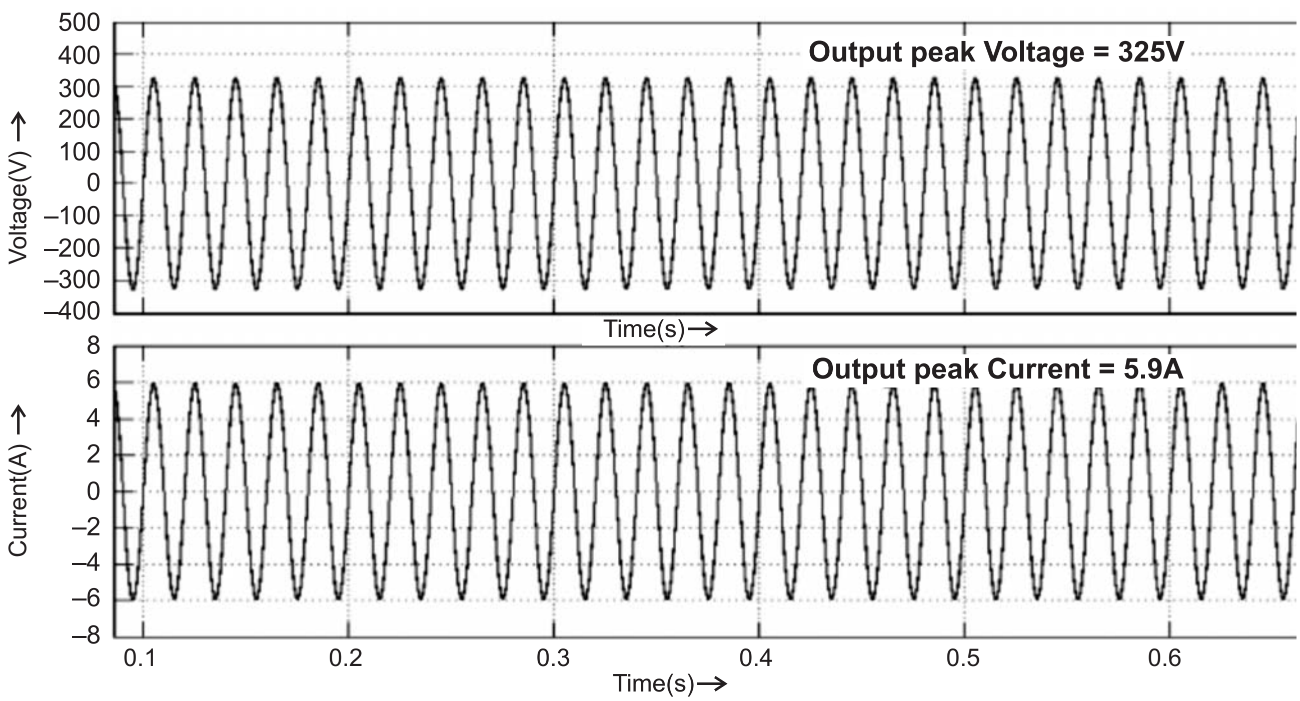

Figure 7: Output Current and Voltage waveforms(V2H Mode)

In simulation,while the system detects absence of voltage and a state of charge greater than 80%, circuit works in vehicle to home mode of operation the peak output current in the output of AC-DC converter in the Inverter mode of operation with a switching frequency of 20kHz and modulation index of 0.812,the Buck Boost converter in the boost mode of operation,the AC-DC converter is fed by the voltage in the DC link capacitor that is boosted from the battery using the bidirectional buck boost converter working in boost mode.During Vehicle to home mode of operation peak current is found to be as 5.9A with a peak voltage of 325V. From the waveform it is observed that the current waveform is found to be sinusoidal. The current and voltage waveforms are in phase with each other from the graph.

The input to the circuit during vehicle to home mode of operation is the battery voltage and current. The battery starts discharging in this mode of operation with a current of 20A.A PI controller is used to control the current drawn from the battery which limits the battery charging current to 8A.For a lead acid battery during charging and discharging the nominal voltage value varies from 47V to 52V where 52V is the full charged voltage condition, In the vehicle to home mode of operation the state of charge of battery is simulated as 100% hence,the voltage across the battery is found to be 52.0V in the starting condition and is found to be decreasing steadily as the time progress.

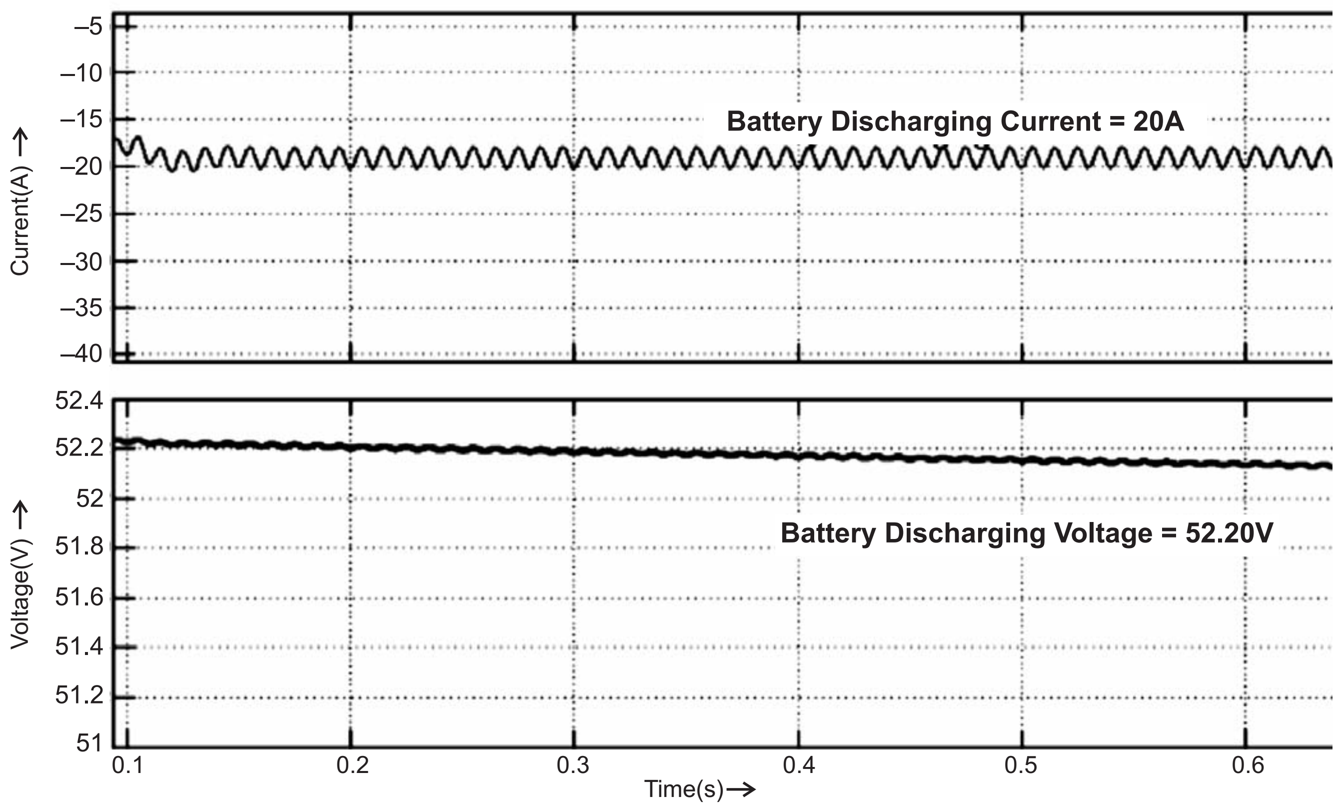

Figure 8: Battery discharging current and voltage waveforms(V2G Mode)

In the case of discharging current of the battery it is found to have ripples present in the waveform which feeds the bidirectional buck boost converter

The THD of output current of the circuit is calculated using the FFT block in the powergui of the MATLAB Simulink model,and the harmonic profile of the output current to the home side during vehicle to home mode is shown in Fig 9.

After the FFT analysis of the output current waveform in vehicle to home mode. The current THD is found to be 1.35% where third is found to be predominant with 0.6% of the fundamental. During this mode of operation the power factor drawn by the circuit is found to be 0.99. In the vehicle to home mode of operation the current injected to the home is found to contain very less amount of harmonics and with good power factor.

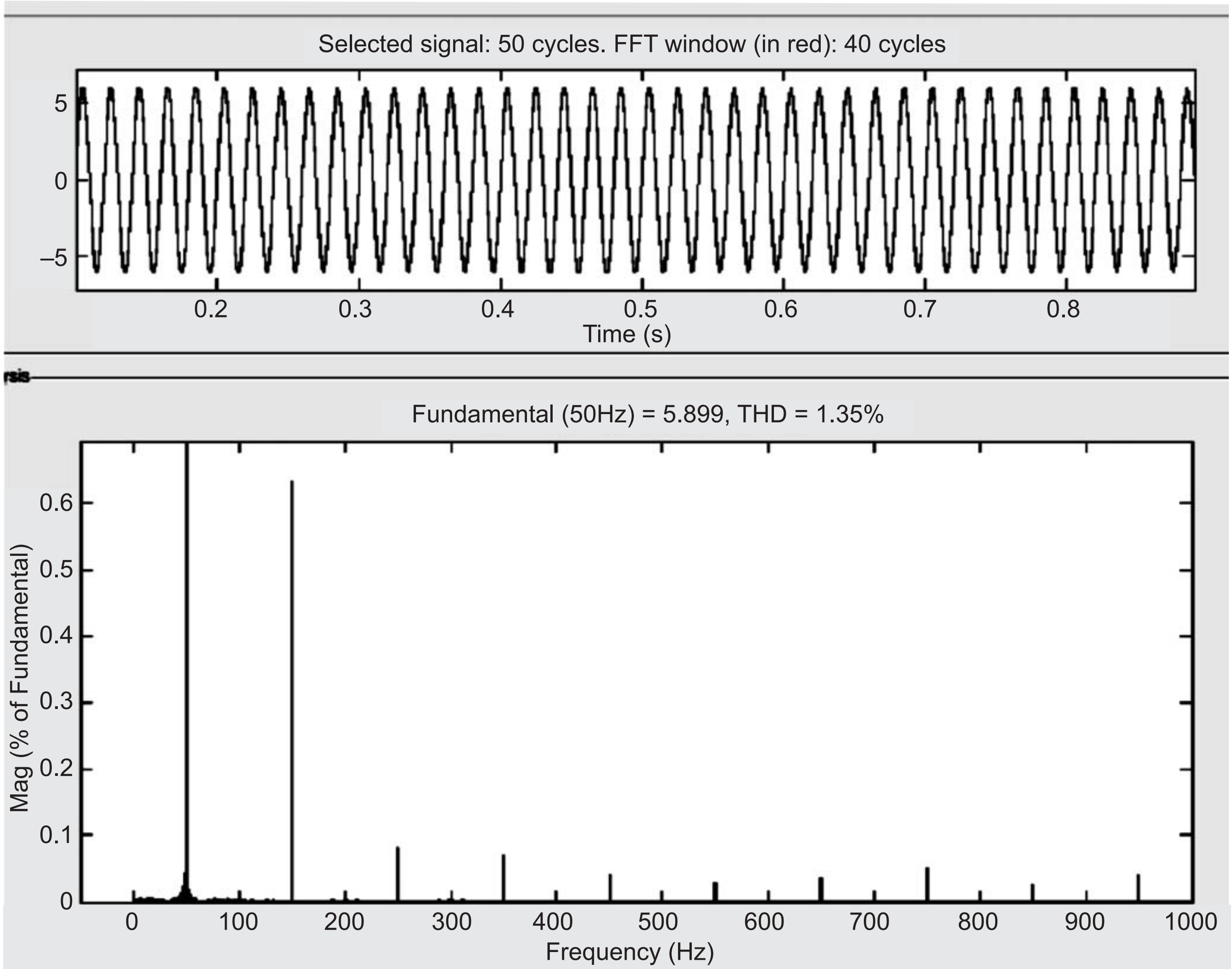

Figure 9: Harmonic profile of output in V2H Mode

5. HARDWARE TEST RESULTS

The hardware test circuit were setup with the following components as shown in Fig. 10.

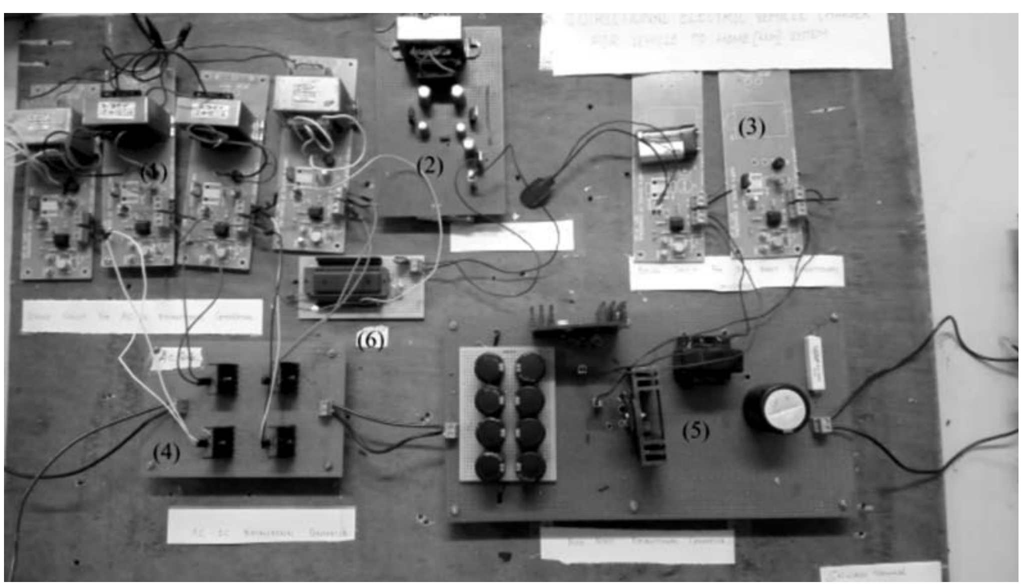

Figure 10:Vehicle to Home Hardware Test setup

1. Driver circuit for MOSFET in AC-DC converter
2. Power supply circuit for dsPIC
3. Driver circuit for MOSFET in DC-DC converter
4. AC-DC Bidirectional converter
5. Buck-Boost Bidirectional converter
6. dsPIC Board

First the AC-DC converter circuit is fabricated using MOSFET's.During grid to vehicle mode the AC-DC converter act as a rectifier. During the Rectifier mode of operation the MOSFETs are triggered making it work as a synchronous rectifier.

Fig. 11 shows the AC-DC converter in the inverter mode of operation.The dsPIC30F4011 produced sine PWM pulses which was fed to the complementary legs of the converter circuit in order to make the converter work in inverter mode of operation.

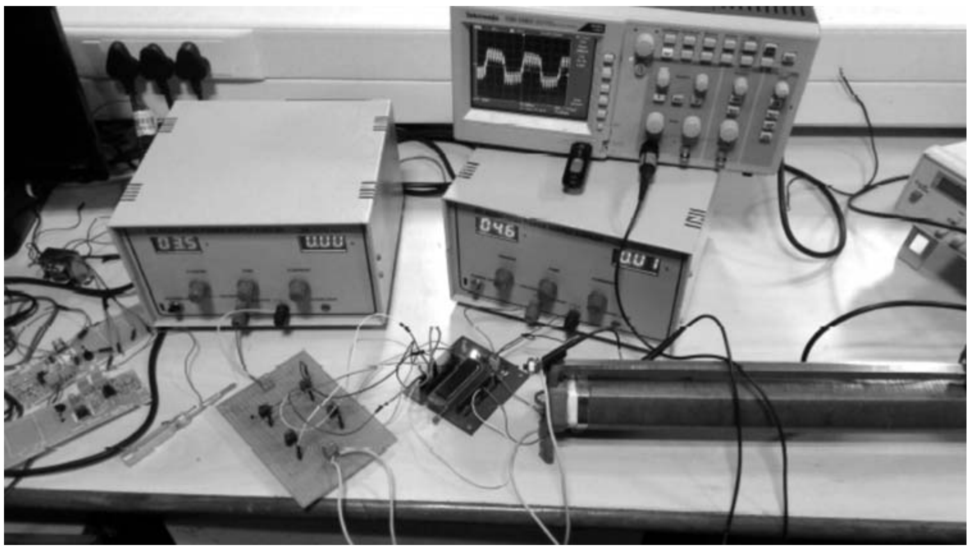

Figure 11: AC-DC converter circuit test

Fig.12. shows the working of AC-DC bidirectional converter in rectifier mode of operation.

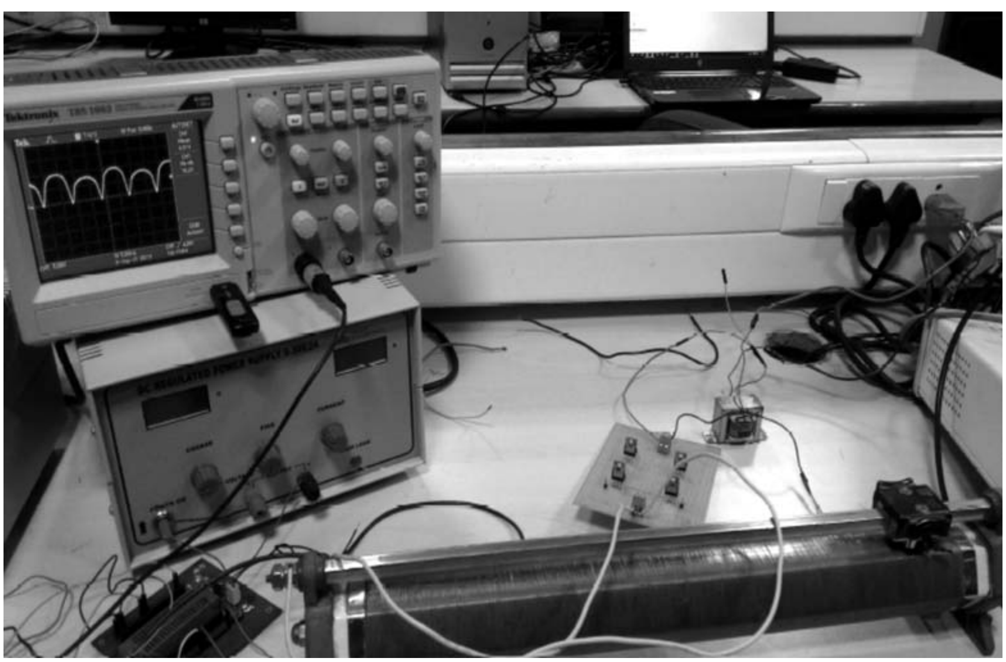

Figure 12: AC –DC Converter in rectifier mode

During the Rectifier mode of operation, the AC waveform is rectified by the MOSFET by the method of synchronous rectification and producing a pulsated DC waveform at the output to the DC link capacitor which provides that DC voltage to the Bidirectional Buck-Boost converter which then steps it down to nominal battery charging voltage.

Fig 13 and 14 shows the AC-DC converter output waveforms in inverter mode of operation and in rectifier mode of operation.

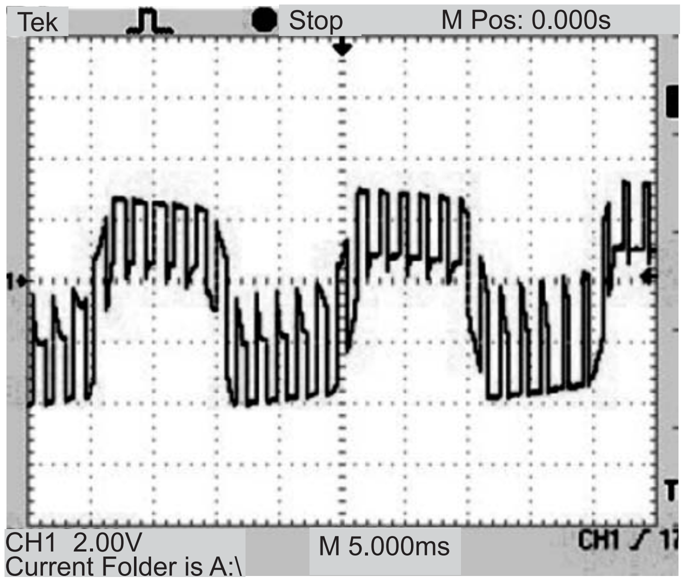

Figure 13: Output in Inverter mode of operation

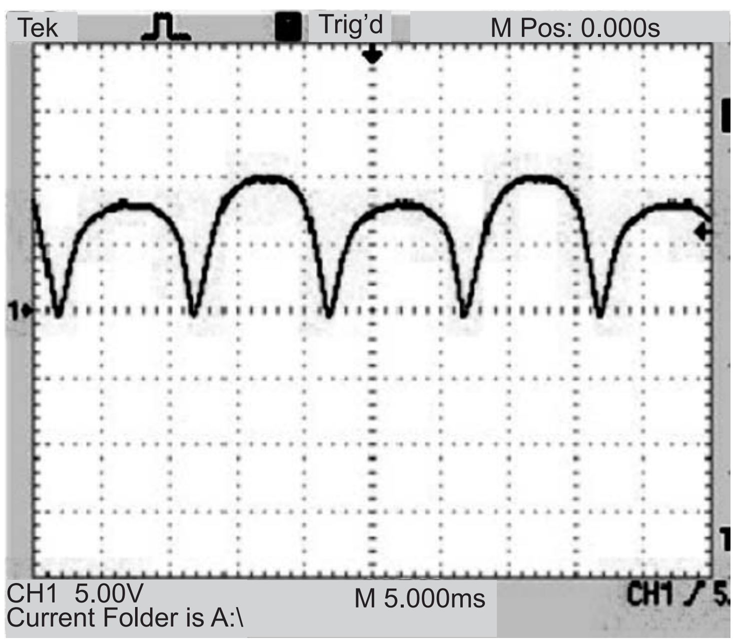

Figure 14: Output in rectifier mode of operation

A Bidirectional Buck boost converter hardware setup was fabricated. First the inductor used in circuit is made by the appropriate core and winding wire from the design values.

Fig15 shows the hardware test setup of Buck-Boost bidirectional converter and Fig. 16 shows its output voltage in buck mode of operation for an input voltage of 10V and duty ratio 0. ,output of 2.87V and 0.6A is obtained.

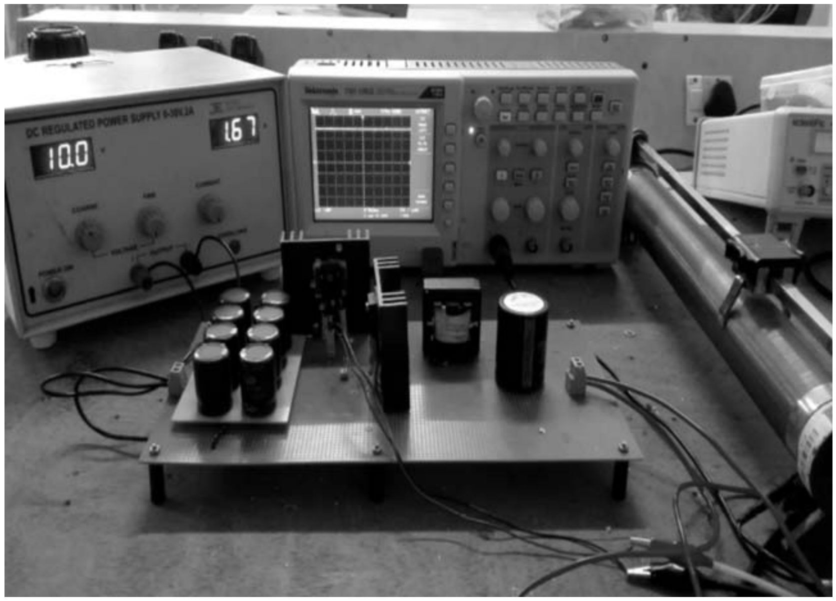

Figure 15: Hardware setup for Bidirectional Buck Boost converter

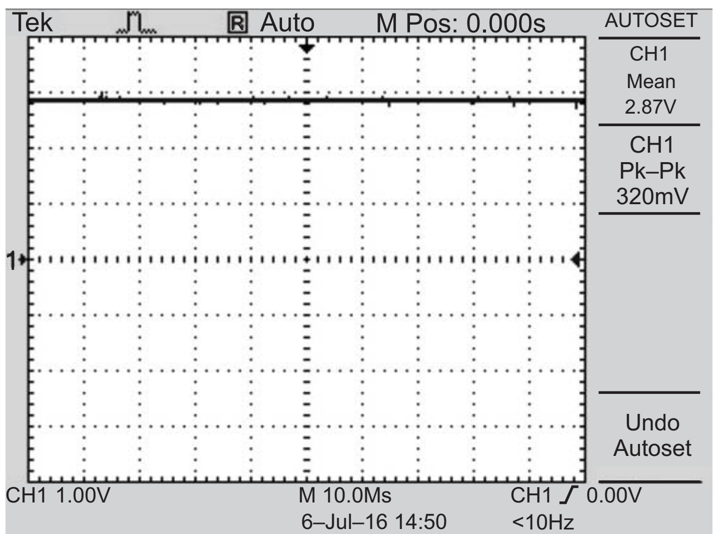

Figure 16: Output of Buck converter

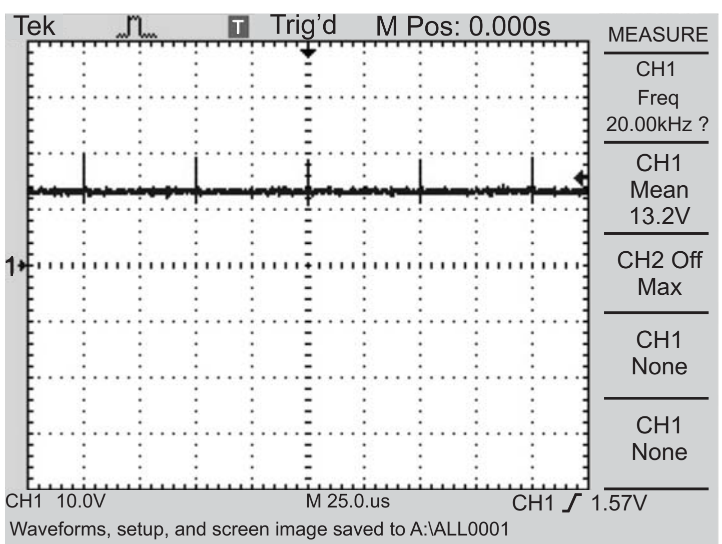

Figure 17: Output current waveform of converter in Boost Mode

Fig17 shows output voltage of Buck-Boost bidirectional converter in boost mode of operation for an input voltage of 4V and duty ratio 0.7 output of 13.2V and 0.01A is obtained.Thus, the desired output current and voltages for bidirectional buck boost converter is obtained by applying proper duty ratio in each modes of operation.

In buck mode of operation for a duty ratio of 0.3 bidirectional circuit worked perfectly stepping down the voltage to nominal value, same way in boost mode of operation for a duty ratio of 0.7 voltage is stepped up to a desired value corresponding to the input voltage.

Thus sine PWM signals are successfully generated using dsPIC30F4011 microcontroller and it is fed to the inverter circuit to produce a sinusoidally varyingwaveform at 50Hz frequency, with the addition of inductor and capacitor on to the output side of the bidirectional converter the waveform can be smoothened to more perfect shape. Thus, the hardware test setup of both AC-DC bidirectional converter and Buck-Boost bidirectional converter is verified. Topology used was found to be effective and desired output is obtained by cascading the converters high current is drawn by the inverter circuit causing the short circuit of MOSFET in the circuit.

6. CONCLUSION

The bidirectional power transfer scheme from vehicle to home (V2H)and grid to vehicle(G2V) is developed. The system operation is verified in simulation. The topology is developed to meet the performance parameters such as power quality and power factor within acceptable limits. The system is hardware implemented and the bidirectional power flow is established.

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