Energy Transfer between Grid and Vehicle using Bidirectional AC - DC and DC - DC Converters

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Abstract - *The conventional i.e. IC engine based vehicles produces pollution and having very less effective output, hence electric vehicles are used nowadays. The charging of these electric vehicles are very important area for researchers. In this chapter, a single-phase bidirectional AC-DC converter and bidirectional DC-DC converter scheme is configured for transferring electrical power from grid to an electrical vehicle (EV) has been analyzed. It is having two stages, at first stage, a single-phase bidirectional AC-DC converter converts 230 V, 50 Hz ac supply into 360 V dc supply. At second stage, the obtained 360 V dc supply charges the battery of the Plug-in Hybrid Electric Vehicle (PHEV) by using a bidirectional DC-DC buck-boost converter. The charging current of the battery and its voltage is controlled by proportional integral (PI) controller. The proposed model has been developed in MATLAB/Simulink. The analysis of the developed model presents the effectiveness and feasibility of proposed configuration. The simulation result shows that the power is efficiently transferred from grid to vehicle along with power factor of the grid is being improved.*

Key Words: Grid, AC to DC Converter, Buck-Boost converter, Plug-in Hybrid Electric Vehicle (PHEV), Controller.

1.INTRODUCTION

Now a days, limitations of fuels and increasing greenhouse gases is a major and serious issue so Electric Vehicles are coming into existence to deal with this issue as a promising Technology. Due to environmental awareness and government support, Electric Vehicles are being continuously evolved. However, these vehicles are restricted to widely adopt. The main reason is limited availability of electric vehicle battery chargers[1].

Plug-in hybrid vehicles has electric motor as well as internal combustion engine (ICE). IC engine requires petroleum while battery packs supply power to Electric motor. These battery packs are charged by grid power and also through regenerative braking So effective charging and discharging is necessary for battery life, reliability and safety [2].

EDVs (Electric Drive Vehicles) use the basic idea of vehicle-to-grid power to transfer electric power to the grid when the vehicle is stationary. A battery–electric car, a fuel cell vehicle, or a plug-in hybrid vehicle are all examples of EDVs. Plug-in hybrid EDVs are capable of operating in either mode. EDVs contain stored electrical energy in the battery as well as power converters capable of producing the 50 Hz AC voltage needed to power our offices and homes. V2G(Vehicle to Grid) refers to the addition of connections to enable electricity to flow from Vehicles to power lines. G2V(Grid to Vehicle) refers to the addition of connections to charge the battery of EDVs from grid . PHEVs (Plug-in Hybrid Electric Vehicles) are gaining popularity as a feasible alternative to conventional automobiles. The idea of smart grid is visualized by the energy transfer from the grid to the vehicle and from the vehicle to the grid. When a PHEV is parked during peak hours, energy can be transferred to the grid, and energy can be taken back from the grid during lean hours.

The bidirectional power transfer of a Plug-in Hybrid Electric Vehicle(PHEV) battery is proposed in this paper using a single-phase half bridge bidirectional power converter. the storage battery can be charged with a current of up to 10A at 300V. the battery can return back the energy to 230V at the rate of 15A. A single-phase bidirectional AC-DC converter and a DC-DC converter are included in the proposed system. a single-phase bidirectional AC-DC converter is used for converting AC voltage into DC voltage. When charging the storage battery, the DC-DC converter is operated in buck mode, and when discharging the storage battery, it is operated in boost mode. The battery's charging and discharging show the effectiveness of system.

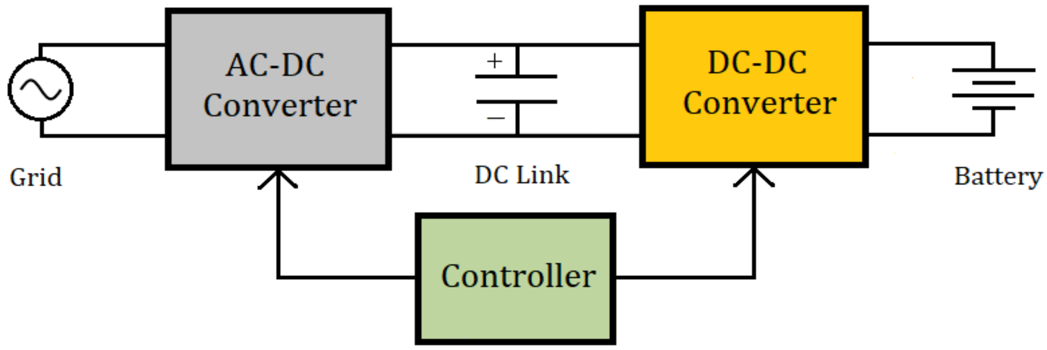


Fig.1 Architecture of Proposed system

2. CONFIGURATION OF PROPOSED SYTEM

The system is configured as shown in Fig. 2. The system contains a AC-DC bidirectional converter and a bidirectional DC-DC buck-boost converter. This system uses an inductor to link single-phase AC to a bidirectional AC-DC converter, which boosts the dc output to keep the DC bus voltage at 360V [2].The battery charging and discharging are done with the help of buck and boot mode respectively. The Battery voltage must be lower than the DC Bus voltage in charging mode, and it works in buck mode. The charging current is regulated by controlling the PWM duty ratio in the buck mode.

2.1 Proposed Single phase AC-DC Converter

The bidirectional grid-connected AC/DC converter is an essential component of the V2G system, allowing bidirectional power flow while meeting the requirements of grid power quality. It makes the power flow bidirectional between electric vehicles and the grid. The grid voltage is a sinusoidal voltage and is expressed as,

$$V_s(t) = \sqrt{2}V_s Sin(\omega t) \qquad (1)$$

where $V_s(t)$ is instantaneous grid voltage and Vs is rms value . The voltage of AC converter is given as,

$$V_c(t) = \sqrt{2}V_c Sin(\omega t - \alpha) \qquad (2)$$

where $V_c(t)$ is the rms value of converter voltage, and α is phase angle between $V_s(t)$ and $V_c(t)$. The grid current is expressed as,

$$I_s(t) = \sqrt{2}V_s Sin(\omega t - \theta) \qquad (3)$$

where θ is an angle between $V_c(t)$ and $I_s(t)$.

The direction of active power depend upon the angle between $V_c(t)$ and $V_s(t)$, the grid provides active power when $V_s(t)$ leads $V_c(t)$, and it sends active power to the grid when $V_c(t)$ leads $V_s(t)$. The direction of reactive power flow is determined by its phase angle.

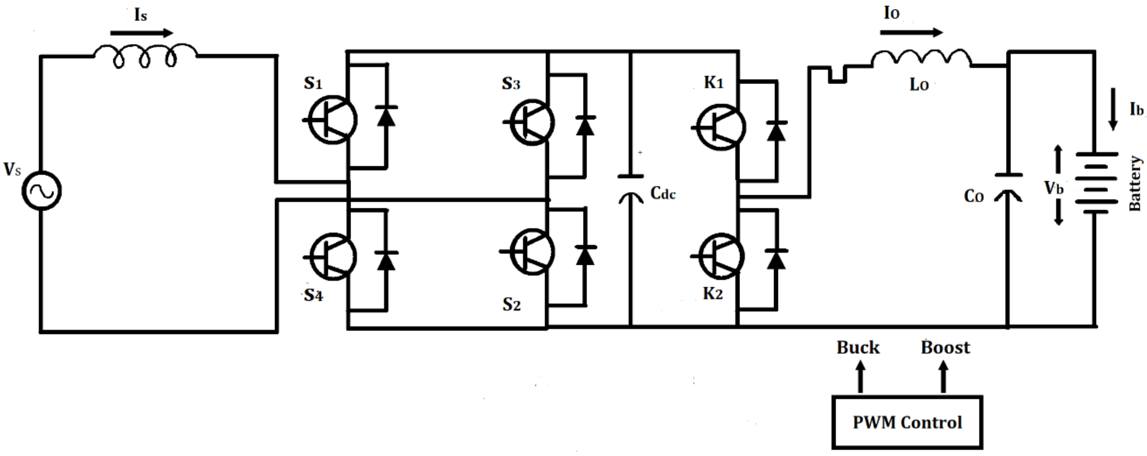


Fig. 2 Proposed configuration for V2G and G2V Energy transfer

2.2 Proposed DC-DC Converter

There are various EV configuration like Battery EV,Plug-in Hybrid EV and fuel Cell EV but all configuration require DC/DC converter to connect the Fuel Cell, Battery to the DC-link. the battery voltage and battery current is regulated through DC-DC converter so it is essential. A bidirectional converter can transfer power in either direction, which is effective in applications that require regenerative braking. The duty cycle is adjusted to regulate the amount of power flowing between the input and the output. This is usually performed to regulate the output voltage, input current, output current, or to keep the power constant.

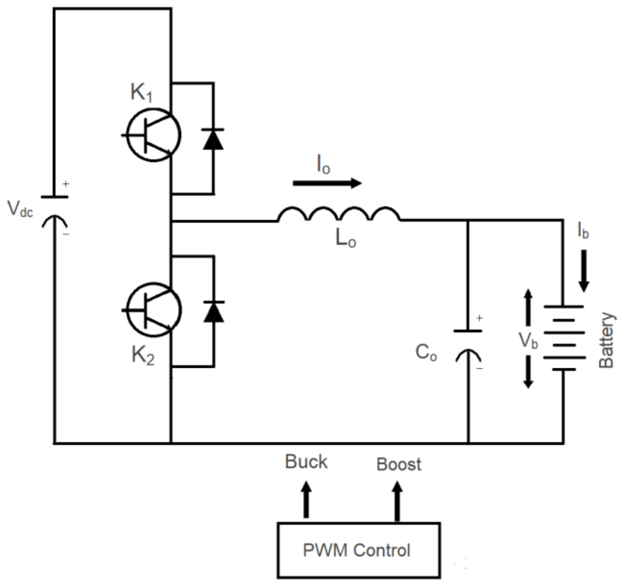


Fig.3 Bidirectional DC-DC buck-boost Converter

3. DESIGNING OF PROPOSED CONVERTER SYSTEM

A single-phase bidirectional AC-DC converter, a DC-DC bidirectional boost converter and a battery storage system are various components of proposed system. The designing detail of these parts are mention below.

3.1 Designing of Single phase Bidirectional AC-DC Converter

Bidirectional power flow requires such types of converters. These converters also improves power quality by increasing the power factor and reducing the THD with well-regulated output voltage. This bidirectional converter has been designed for a 4.5KW.

The fundamental converter voltage V_c is defined as:

$$V_c = \frac{mVdc}{\sqrt{2}} \quad (1)$$

Where m is called modulation index. The value of modulation index is assumed as 0.9 and taking DC link voltage V_{dc} as 360, which gives the fundamental converter voltage (V_c) 230V. the grid inductance is calculated by following equation:

$$V_c^2 = V_s^2 + (I_s^2 \times X_L^2) \quad (2)$$

where V_s indicates grid RMS voltage and the value of V_s is taken as 230 V and I_s indicates grid RMS current. So the value of grid inductance is found to 1.2mH from equation (2).

The value of dc link capacitor can be calculated by following equation:

$$C_{DC} = \frac{I_{DC}}{2 \times \omega \times V_{DCripple}} \quad (3)$$

Where ω is the angular frequency and I_{dc} is obtained by $\frac{P_{DC}}{V_{DC}}$. The $V_{DCripple}$ is considered as 5% of V_{DC}. therefore the value of C_{DC} is obtained as 4.7mF.

3.2 Designing of Bidirectional DC-DC Buck-Boost Converter

The buck boost converter is a switch mode power supply which is used to regulate to DC output. A buck-boost converter circuit combines elements of both a buck converter and a boost converter. Bidirectional Dc-Dc buck boost converter is shown in figure, the switch K_2 is operated for boost mode whereas Switch K_1 is operated for Buck mode. The switching frequency can be calculated as

$$f = \frac{1}{2*P*L}\left[\frac{1}{\frac{1}{V_{DC}}+\frac{1}{V_b}}\right]$$

Where P is power conversion, V_{dc} and V_b are input and output voltage respectively. Switching frequency f has value of 25khz. P is taken as 4.5 kw. Input voltage V_{dc} is 360V and V_b is 300 V. The value of L is calculated as 7.5 mH from equation.

3.3 Designing of Battery Storage System

Since the electrical energy is not stored directly in AC system so battery storage is used to store the energy. Battery storage is an important part because it powers the motor and makes the Electric vehicle move hence charging and discharging are done. Energy in KWh can be stored in capacitor whose equivalent capacitance can be calculated as

$$C_b = \frac{KWh * 3600 * 1000}{\{0.5(V_{max}^2 - V_{min}^2)\}}$$

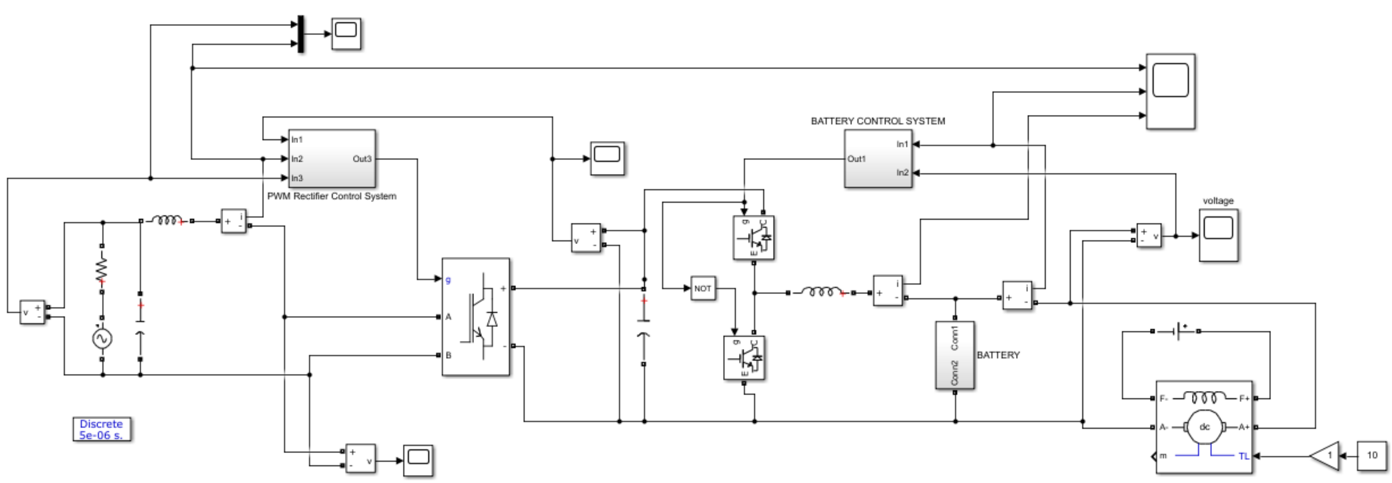
Where V_{ocmax} represents maximum terminal voltage while the battery is fully charged and V_{ocmin} is minimum terminal voltage at the time of full discharging. Equivalent resistance R_s in thevinin equivalent circuit is shown in figure, which has usually small value. Self-discharging of battery is represented by the parallel combination of R_b and C_b. The value of R_b has been taken as 10 kilo ohm.

4. CONTROL STRATEGY

A unipolar switching scheme based on PWM control is employed under the control of a single-phase bidirectional AC-DC converter. In this scheme, the two reference signals i.e. positive and negative signals are compared with triangular carrier waveform. Proportional integral voltage controller provides a control signal to decrease voltage error and closely monitoring the reference voltage. Similarly proportional integral current controller provides a control signal to decrease current error and closely monitoring the reference current.

The Bidirectional Buck boost converter is governed through two PI (Proportional integral) controller, each of which is regulated by current reference. The inductor current is compared with reference current in each mode of operation. The proportional integral controller provides a switching signal to each switches according to mode in which DC-DC converter operates. PWM control strategy is employed to have desired operation in buck and boost mode. Battery current and battery voltage is controlled by Proportional integral controller.

5. MATLAB SIMULINK MODEL



6. SIMULATION RESULTS AND DISCUSSION

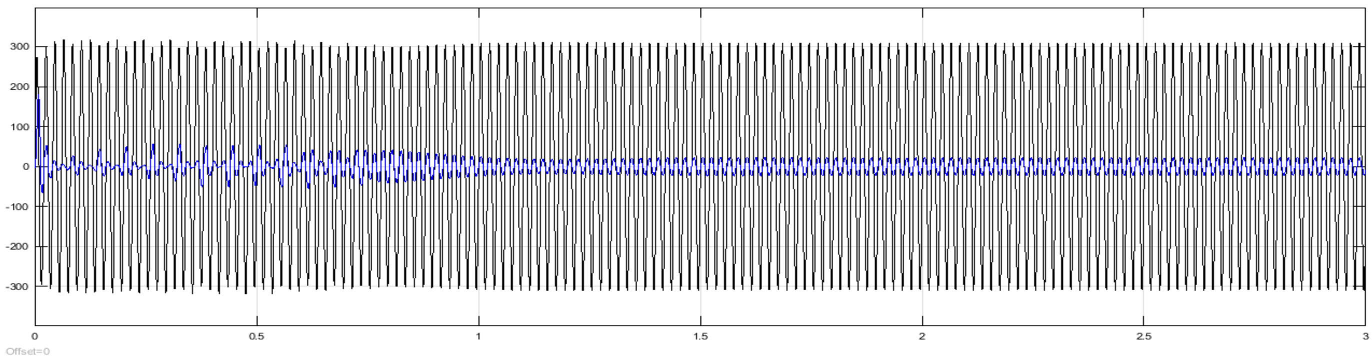


Fig.4 Grid Voltage and Grid Current

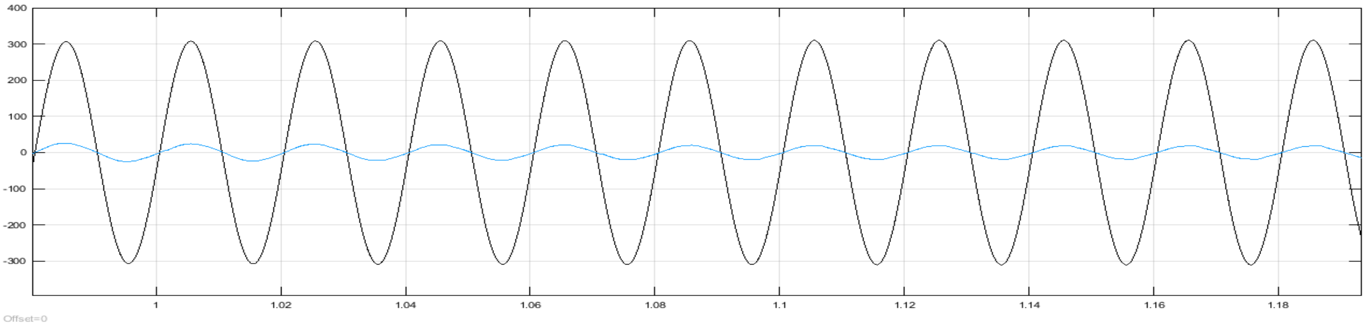


Fig.5 Grid Voltage and Grid Current(in large view)

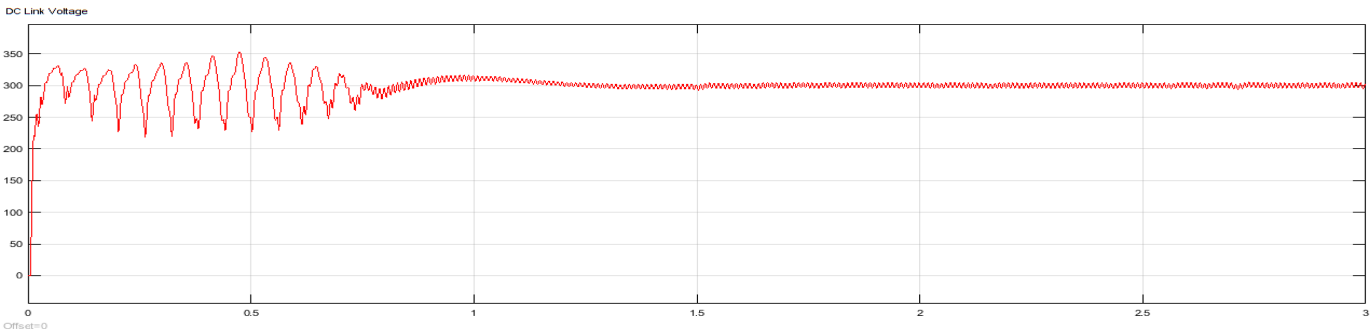


Fig.6 DC Link Voltage

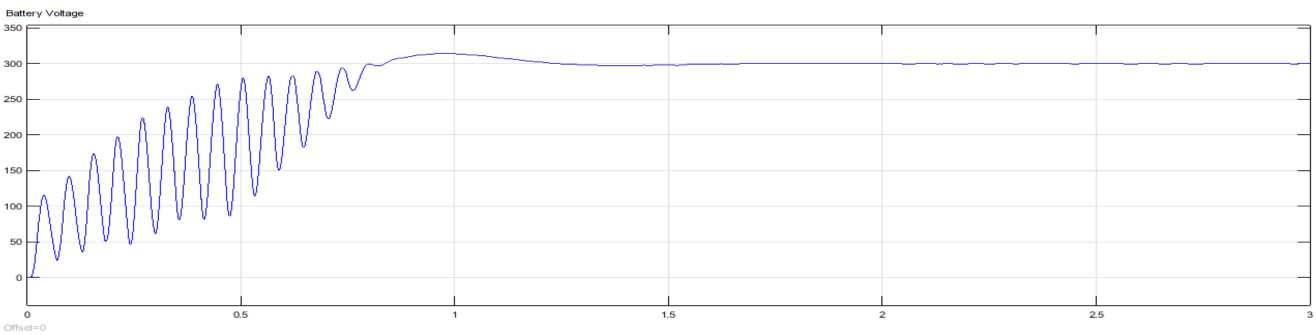


Fig.7 Battery Voltage

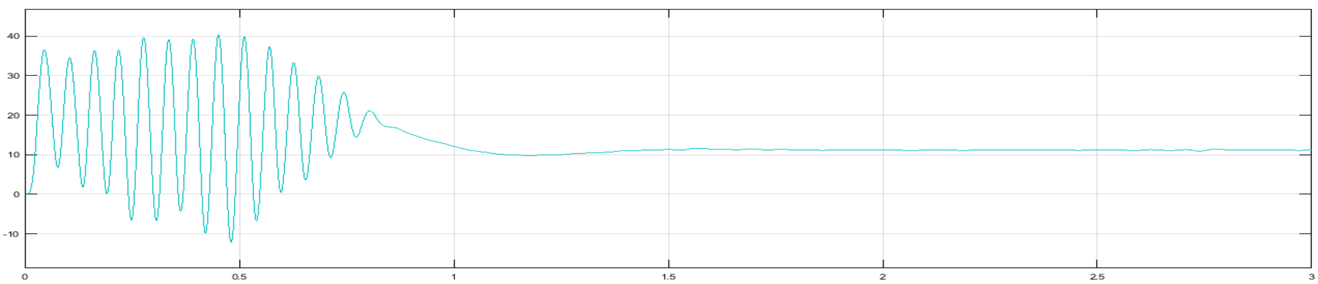


Fig.8 Battery Current

In this part, simulation using the MATLAB/SIMULINK model are used to validate the proposed configuration and technique. Figure shows a schematic diagram of the single phase bidirectional converter that is used in the simulation. The performance of proposed converter is shown in fig that are Simulation results. The grid voltage, grid current, DC link voltage, battery voltage and battery current are shown in order from top to bottom. In charging mode, The grid current is shown to be sinusoidal and in phase with the grid voltage. This reduces harmonics and keeps the power factor unity. In discharging mode, the input currents and grid voltages are 180 degrees out of phase.

7. CONCLUSION

The proposed bidirectional converter has been designed. The bidirectional converter has been made up of two parts i.e. Single phase Bidirectional AC-DC Converter and Bidirectional DC-DC Buck-Boost Converter that have been controlled by PM technique. Electrical Energy has been transferred between grid and vehicle over unity power factor with less harmonics which increases the life of converter and battery and reduces the possibility of voltage distortion to a great extent. The waveforms of battery voltage and current has been presented and verified the performance of the designed converter.

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