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V2G and G2V Energy Transfer via Bidirectional Converter

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ABSTRACT
The proposed paper deals with vehicle to grid (V2G) and grid to vehicle (G2V) energy transfer via bidirectional converter. Bidirectional converter can be AC-DC or DC-DC. AC-DC converter is used to convert 230 Volt AC supply to 380 Volt DC supply and DC-Dc converter used in charging/discharging battery of Plugged Hybrid Electric Vehicle (PHEV). Converter can either be used in buck mode or in boost mode according to charging/discharging preference of our battery. Further, for controlling the charging current and voltage, Proportional Integral has been used. A simulation has also been done over MATLAB to confirm the effectiveness and feasibility of proposed algorithm.

***Keywords* -** Bidirectional Converter, G2V, PHEV, V2G

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I. INTRODUCTION

Basic concept of V2G energy transfer is to provide energy to grid when vehicle is parked. The vehicle used here is electric drive vehicle which may be battery electric vehicle, plug hybrid vehicle or fuel cell vehicle. Electric Vehicle make use of battery and a converter capable of generating voltage at 50 Hz. When energy transfer takes place from grid to vehicle, it is called as G2V energy transfer and when this transfer is from vehicle to grid, it is called as V2G energy transfer.

Now a days, traditional vehicle is being replaced by Plugged Hybrid Electric Vehicle commonly termed as PHEV. During peak hour, energy transfer could be done from PHEV to grid and during lean hours, energy could be transfer from grid to PHEV. Thus, can lead in earning some revenue as during peak hour cost of energy is more compared to lean hour. Electric vehicle parked has sufficient amount of stored energy in the battery which may up to 10 KW, equal to average power drawn by nearly 12 houses. Plugged Hybrid Electric Vehicle make use of grid electricity instead of fuel as in [1]. For carrying out energy transfer in PHEV, converter need to be operated in buck/boost mode. The presented paper makes use of bidirectional power converter.

This system can charge the battery at 120 Volt to 10 Amp and is composed of two part, 1-phase Rectifier converter and Chopper converter. For checking the feasibility of presented system, battery charging/discharging can be used.

The proposed paper is carved out in the following manner: Section II will discuss the system description and principle of operation, Section III will deal with explanation of design system, Section IV will deal with control algorithm of presented system followed by MATLAB simulation and conclusion.

II. SYSTEM DESCRIPTION

System description is shown by below figure consisting of 1-phase AC-DC and DC-DC converter, PWM controller and a battery as mentioned in reference [2].

Buck-Boost converter is represented by figure 2. During charging operation, it must be taken care to keep DC bus voltage higher as compared to battery voltage so that it operates in buck mode. Charging current in buck mode can be controlled through Pule Width Modulation (PWM) duty ratio.

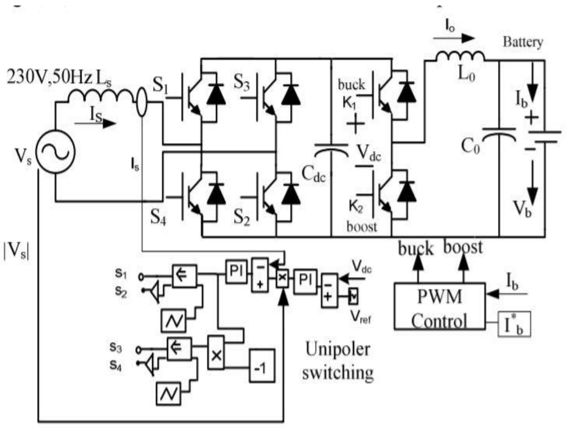


Fig. 1 System description

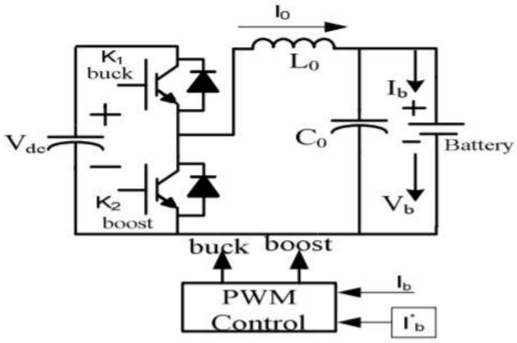


Fig. 2 Bidirectional DC-DC converter

A. Interaction of Grid with AC-DC Converter

For transferring energy from G2V and from V2G an interaction must be set up between grid and converter. For transfer of energy from Grid to converter, positive current direction is assumed. Grid voltage is given as

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

Where V_s (t) = rms grid voltage
ω = angular frequency in rad/sec.

Fundamental component of AC converter can be given as

$$v_c(t) = \sqrt{2}V_c Sin(\omega t - \delta) \quad (2)$$

Where, V_c = Converter rms voltage.

Grid current can be represented by equation (3) as

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

Where, I_s (t) is grid source current.

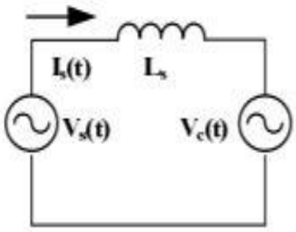
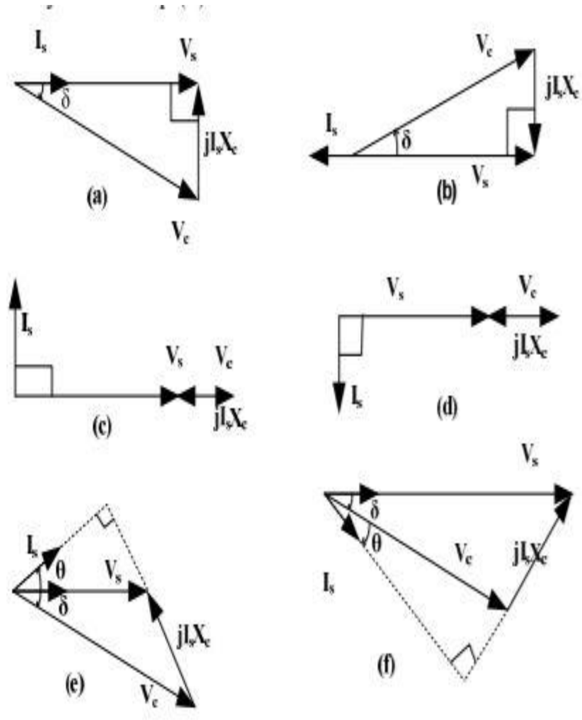


Fig. 3 Grid Connected with Charger

As provided from Fig. 4(a) to Fig. 4(b) as in reference [3]-[4], real power is delivered to converter by grid whenever, converter voltage lags grid voltage and real power is supplied by converter to grid whenever, converter voltage lead grid voltage. As, both converter and grid voltage are sinusoidal in nature, grid current I_s (t) also become sinusoidal. Phase angle θ is used here for determining the direction of reactive power.

Reactive power is sent to grid whenever θ is positive and reactive power is delivered by the grid whenever θ is negative. Inductive and Capacitive operating mode for charging is indicated by Fig. 4(c) to Fig. 4 (f) as in reference [5]-[6].

Fig. 4 Different operating mode vector diagram: (a)&(b) Charging/Discharging (c) L- mode (d) C-mode (e) C-charging (f) L-charging



III. SYSTEM DESIGNING

Various component used in designing the system are: 1-phase bidirectional converter and a battery storing device.

A. *Designing of bidirectional Converter*

For bidirectional power flow, converters are being used which further helps in improving power quality of the system including grid and also result in power factor to be at higher side and reducing the value of Total Harmonic Distortion (THD). Here, we have designed a 3KW bidirectional AC-DC converter.

Fundamental voltage of converter is denoted by V_c and is given by equation (4) as

$$V_c = \frac{mV_{dc}}{\sqrt{2}} \quad (4)$$

Here, m (modulation index) = 0.9 and V_{dc} = 380 volt., V_c value obtained by equation (4) as 241.86 Volt. Relation between V_c and V_s is given by equation (5) as

$$V_c = \sqrt{V_s^2 + (I_s^2 * X_l^2)} \quad (5)$$

Where, V_s is grid rms voltage and is equal to 230 volt, I_s is the grid rms current. From equation (5), value of grid inductance obtained is as 2.12 mH.

DC link capacitor can be represented by equation (6) as

$$C_{dc} = \frac{I_{dc}}{2 * \omega * v_{dcripple}} \quad (6)$$

Value of DC link capacitor obtained by equation (6) is 1mF.

B. *1-Phase Bidirectional DC-DC converter designing*

From Fig. 2, it is cleared that if we want buck operation switch K_1 need to b used and if want to work in boost mode for boost mode operation switch K_2 need to be used. In buck boost mode, frequency in term of inductance is given by equation (7) as

$$f = \frac{1}{2 * P * L}\left(\frac{1}{\frac{1}{V_{dc}} + \frac{1}{V_b}}\right) \quad (7)$$

Here, conversion power is denoted by P, input voltage is denoted by V_{dc},

Output voltage is denoted by Vb and switching frequency is denoted by f and its value is equal to 50 Hz. Here value of P is 3 Kw, V_{dc} is 380 Volt and V_b is 120 Volt, Value of L obtained from equation (7) by putting the above value is 1.9 mH as in reference [8]-[9].

C. *Battery Design*

Here, we have used Lead-acid battery as given in reference [10]. Thevenin equivalent of battery storage is denoted by Fig. 5. Equivalent capacitor C_{bb} can be given by equation (8)

$$C_{bb} = (kWh*3600*1000)/\{0.5(V_{ocmax}^2 - V_{ocmin}^2)\} \quad (8)$$

V_{ocmax} = Maximum Terminal Voltage at battery
V_{ocmin} = Minimum Terminal Voltage at battery

From Fig. 5, R_s is battery equivalent resistance and is taken equal to 0.01ohm. Self discharging of battery is represented by a parallel circuit consist of R_b and C_{bb}. Value of R_b chosen is 10KΩ, battery peak capacity is for 12 hour having 1.2 KW. Value of C_{bb} obtained by equation (8) is 14281 F after putting the above chosen value.

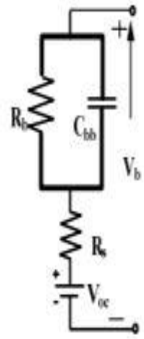


Fig. 5 Thevenin equivalent of storage battery

IV. CONTROL ALGORITHM

The Various block depicted in system description uses control algorithm which are depicted below by different section as:

A. *Control Algorithm of 1-Phase AC-DC Converter*

In this control algorithm, unipolar switching scheme is used, where carrier waveform used is in triangular waveshape and is compared with reference signals. The purpose of using PI controller is to track the reference voltage (V_{ref}) and for minimizing the error V_e (k) which is generally a voltage, a control signal (I_P). The combined relation among these are given by equation (9) as

$$V_e(k) = V_{ref}(k) - V_{dc}(k) \quad (9)$$

At K_{th} instant, I_p (k) which is the output of controller is given by equation (10) as

$$I_p^*(k) = I_p^*(k-1) + K_{pv}\{V_e(k) - V_e(k-1)\} + K_{iv}V_e(k) \quad (10)$$

Here, K_{pv} is used to depict proportional gain and K_{iv} is used to depict integral gain of controller, Current error in term of reference current (I_P^* (k)) and sensed current I_P (k) is given by equation (11) as

$$I_e(k) = I_p^*(k) - I_p(k) \quad (11)$$

For amplifying the current error mentioned in equation (11), gain "K" can be used The above current error can be used as

$$V_{cs}=kI_e(k) \quad (12)$$

B. *Control Algorithm of 1-Phase DC-DC Converter*

For controlling charging/discharging mode of battery, Pulse Width Modulation technique is proposed here. Output current of battery can be controlled by a Proportional Integral Controller. Function of PI voltage controller used here is tracking of reference current and to produce a control signal helpful in minimizing current error I_{eT} (k) as:

$$I_{eT}(k)=I^*_b(k)-I_b(k) \quad (13)$$

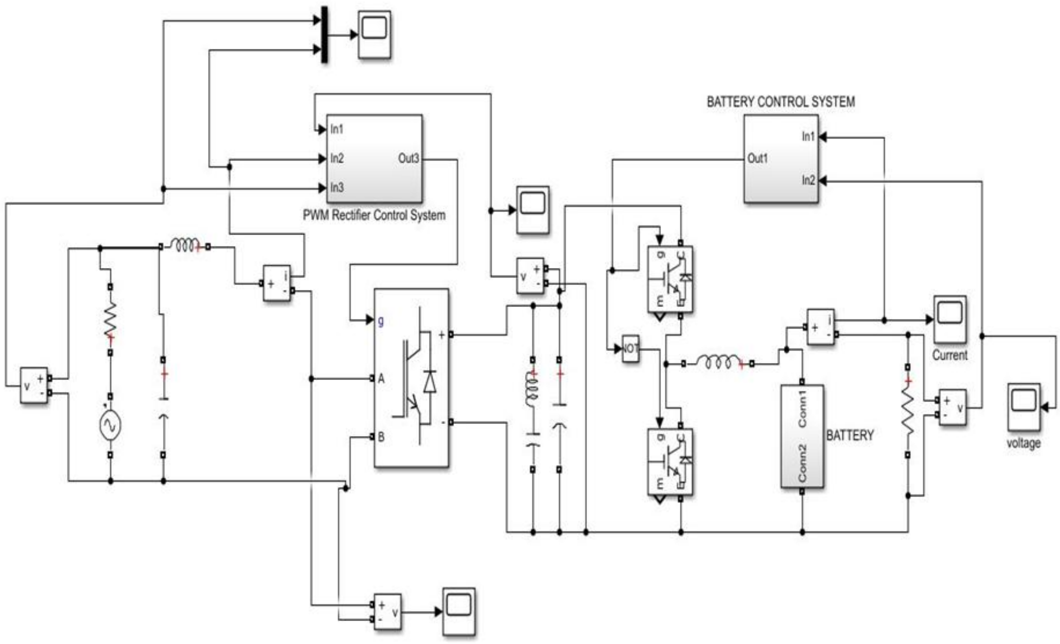
Headings PI controller output at Kth instant is given as:

$$V_T(k)=V_T(k-1)+K_{pv}\{I_{eT}(k)-I_{eT}(k-1)\}+K_{iv}I_{eT}(k) \quad (14)$$

Here, K_{pv} is used to depict proportional gain and K_{iv} is used to depict integral gain of controller.

V. MATLAB MODELLING

MATLAB model of proposed system is shown by Fig. 6. This proposed model make use of 1-phase bidirectional converter designed for power of 3.8 KW. DC-DC converter is used in charging/discharging purpose of battery of plugged hybrid electric vehicle. Battery energy storage system used here consist of 1.32 KW having voltage variation from 106 volt-136 volt



VI. RESULT AND DISCUSSION

Result obtained from the MATLAB model of proposed system are given from Fig. 7 to Fig. 9. Current obtained here is sinusoidal and in phase with grid voltage thus making the system to operate at unity power factor by eliminating the current harmonics. When power is delivered to grid, injected current has 180degree phase difference compared to grid voltage. It is to note that, zero crossing of injected current and grid voltage matches each other.Charging and Discharging of plugged hybrid electric vehicle can be easily understood through Fig. 7 obtained from the simulation result of MATLAB model.

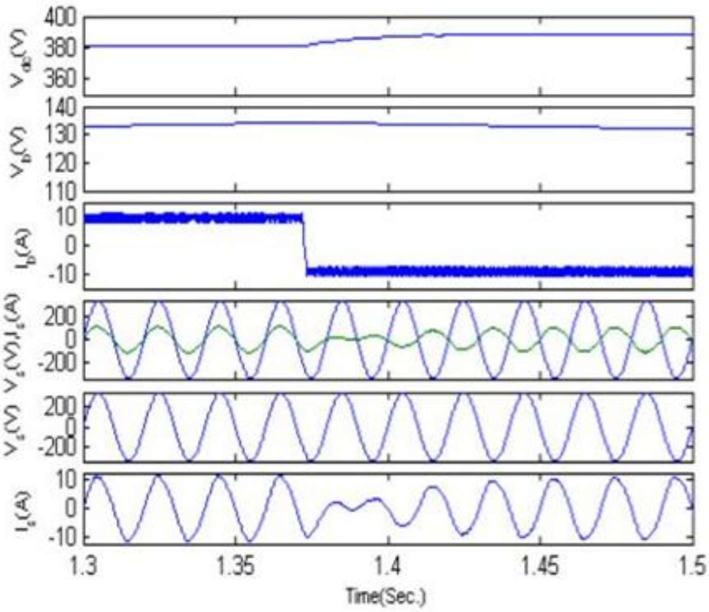


Fig. 7 Plugged Hybrid Electric Vehicle – Charging and Discharging Result

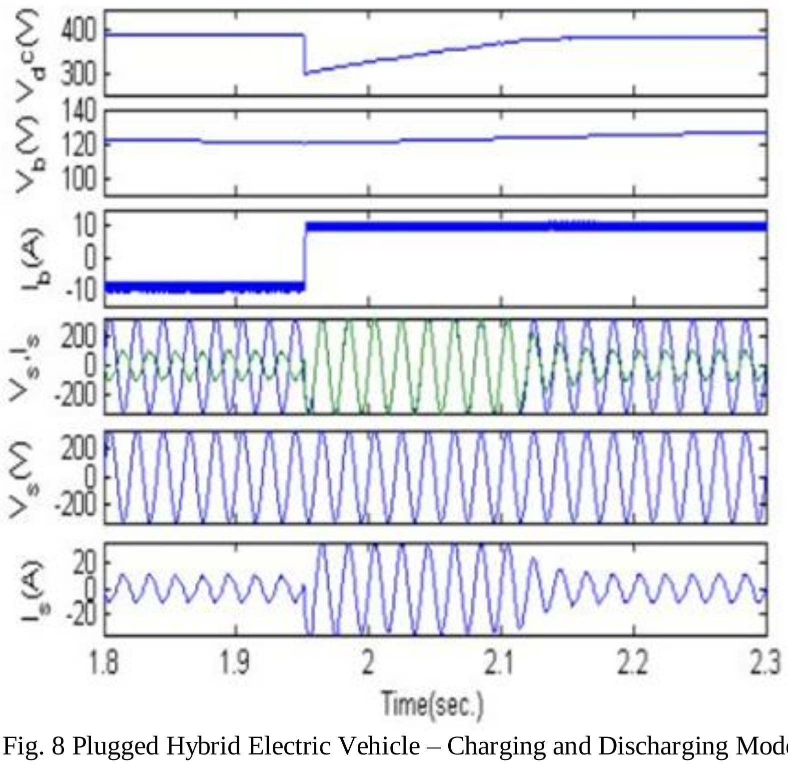


Fig. 8 Plugged Hybrid Electric Vehicle – Charging and Discharging Mode

From the above result obtained, it can be concluded that, converter maintains 380 Volt even if voltage transient occurred during load changing condition. When battery charges, voltage increases and when it discharge voltage get decrease which can be seen from Fig. 8 respectively having time from 1.35 second to 1.45 second. From Fig. 9, at 1.9 second, discharging mode can be seen and at same time, current has 180 degree phase shift.

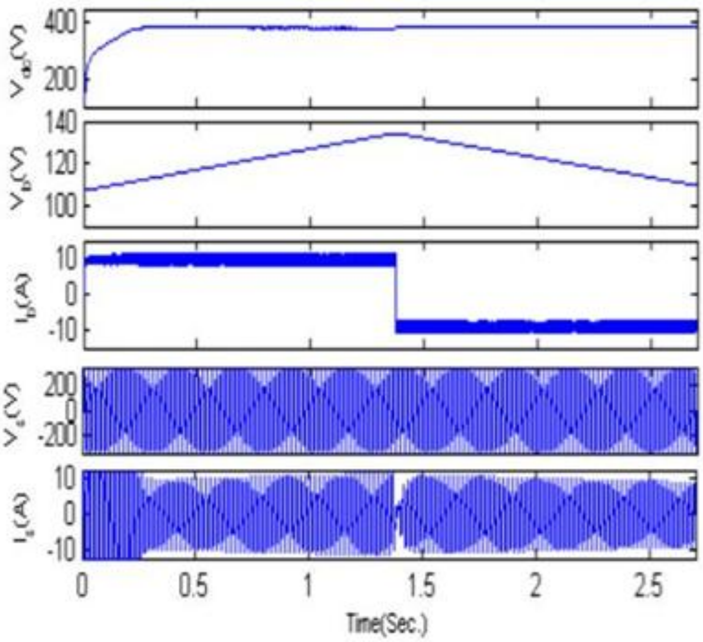


Fig. 9 Plugged Hybrid Electric Vehicle – Charging and Discharging operation at unity power factor

Total Harmonic Distortion of proposed system is obtained as shown by Fig. 10 and Fig. 11 respectively, where it can be concluded that, THD obtained by proposed system also satisfy the IEEE standard 519 and 1547 i.e below 5%.

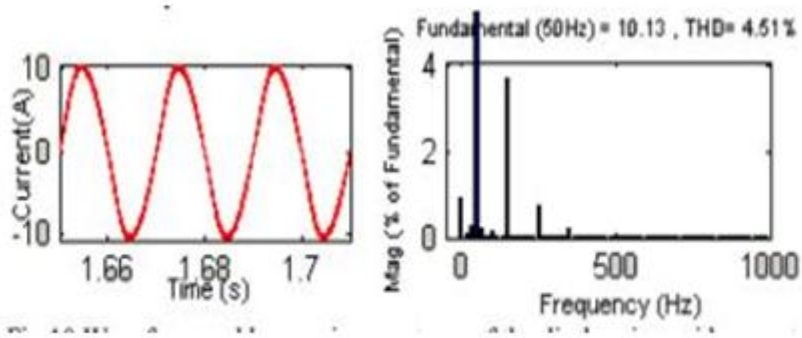


Fig. 10 THD Calculation – Discharging Mode

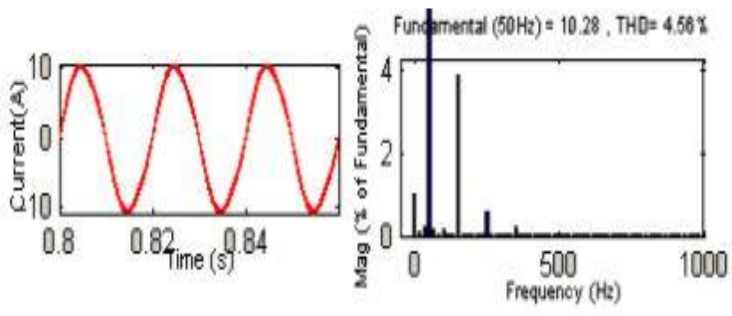


Fig. 11 THD Calculation – Charging Mode

VII. CONCLUSION

The proposed system can effectively delivered AC current to/from the current by maintaining the unity power factor and can efficiently eliminate the current harmonic that arises during the process. The proposed system also satisfy IEEE standard 519 and 1547 as THD obtained is well below 5% limit.

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