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V2G Technology to Design a Smart Active Filter for Solar Power System

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ABSTRACT

This paper presents the implementation of Vehicle to Grid (V2G) technology for designing a shunt active filter to improve power quality of solar generation. A system model with solar generation and a dynamic model of PHEVs are introduced here based on third order battery model. A simple battery scheme is proposed for the control of the charging and discharging of the PHEVs using a power electronic interface. The active filter controller is designed based on the instantaneous power theory (p-q theory) to improve the wind generator performance through compensating the oscillating real and reactive power from PHEVs. Simulations have been carried out and demonstrate that PHEVs have the potential to work as active filter with solar power generator to improve power quality, dynamic power factor correction and harmonics current compensation

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1. INTRODUCTION

In recent years there have been major advances in battery and hybridelectric power technologies. This development coupled with energy security obligation, the financial, environmental concern and the rising costs of fossil fuel make plug in hybrid electrical vehicles (PHEVs) a strong alternative to the conventional automobile [1], [2]. It is expected that most of the vehicles manufactured in future will have plug-in option to recharge their batteries and by the year 2030, PHEV penetration will be near 25 percent [3]. A number of researches have been carried out and still going on solar energy to implement the recharging of PHEVs and can be charged from house hold electric connection as well as from charging station, even from the car park during the day. It gives opportunity to design an active filter for photovoltaic generation through smart grid technology using the bidirectional charger.

Photovoltaic energy system is one of the cleanest power-generating technologies available today with very little impact on the environment. When PV operates it converts the sun's rays into electricity, produce no air pollution, waste, or noise. The more use of PV energy to generate electricity from the sun's rays decreases our dependence on petroleum and on imported sources of energy. As a result solar energy can be an effective economic development driver. The world PV market installations reached a record high of 7.3 gigawatt (GW) in 2009, representing growth of 20% over the previous year [4].

Harmonics is one of the main reason for greater power losses in distribution, communication systems and sometimes in operation failures of electronic equipments. For these reason, the power quality delivered to the consumers is an object of great concern and it is mandatory to solve the harmonic problems caused by those equipments already installed [5].

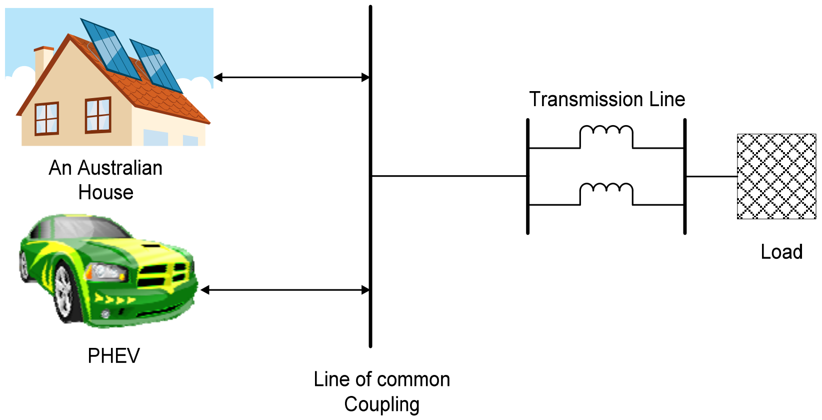

Figure 1. Infrastructure of PHEV's integration with the power grid at a solar based Australian house

In this circumstances this paper explores the possibility of employing PHEVs as an active filter with solar energy sources using PQ theory for control which allows the correction of dynamic power factor as well as the dynamic compensation of harmonics currents. The PHEV’s connection with a solar power system is shown in Figure 1.

The rest of the paper is organized as follows: Section II provides the photovoltaic generator model; dynamic battery model of PHEVs and network interfacing are presented in Section III; Section IV presents the controller design and Section V contains the simulation results. Finally, the paper is concluded by brief remarks and suggestions for future work in Section VI.

2. PV GENERATOR MODEL AND CONTROLLER

A current source anti-parallel to a diode is the simplest representation of an electrical equivalent circuit for a solar cell and is shown in Figure 2. The Kirchhoff's law gives

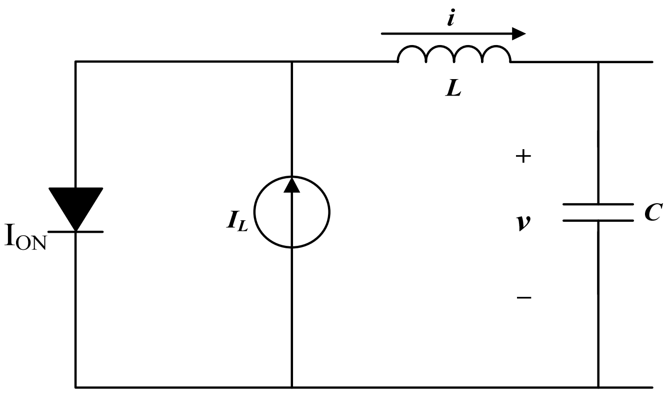

Figure 2. PV equivalent circuit [6]

$$I_L - I_s\{\exp[\alpha(v + L\frac{di}{dt})] - 1\} - i = 0 \qquad (1)$$

where $\alpha = q/nsKT$, $q = 1.6022\times10^{-19}$ is the charge of the electron, $K = 1.3807\times10^{-23}$ J/K the Boltzman's constant, $T = 298K$ the temperature and ns is the number of series cells in the array. However the inputs to the solar PV are the solar radiance $[W/m^2]$, temperature $[^0C]$, and PV voltage [V] while the only output is the PV current supplied by Panel [A]. Therefore the output current can be characterized by $I = f(V)$.

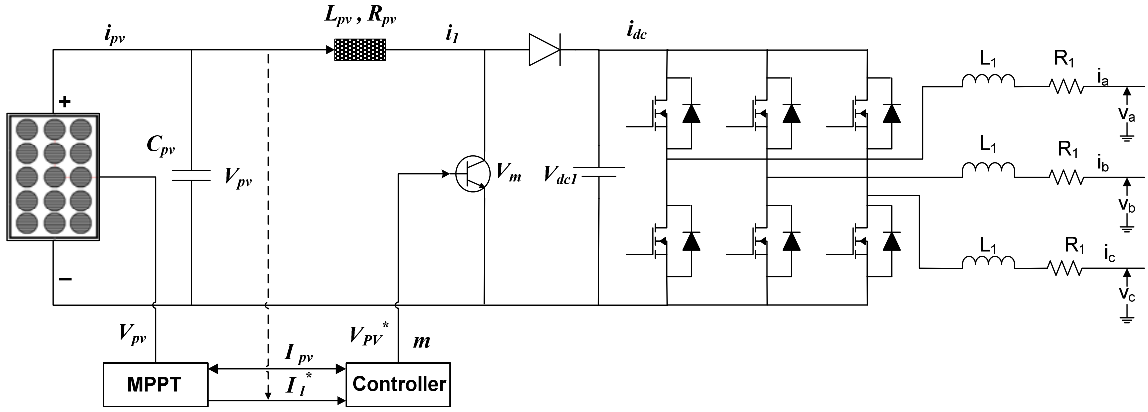

Figure 3. PV equvalent circuit

As PV power varies with climatic conditions, there is no explicit reference power for tuning. Therefore, the PV voltage needs to be adjusted according to the solar radiation to extract the maximum PV current. With regulation of the generator voltage (V_{pv}) and inductor current (I_l) and by varying the transistor's cyclic ratio this adjustment is possible. The regulator measures the PV voltage and current using an intelligent algorithm between the PV array and load as a MPP tracker (MPPT), which ensures the operation of the PV at its MPP. In this work, the Perturb and Observe method (P&O) [7] - [8] chosen for obtaining the MPP, then finds the adequate voltage (V_{pv}^*) which the boost converter imposes on the system. The reference voltage is determined by the calculation of the two adequate controllers and two compensators shown in Figure 4.

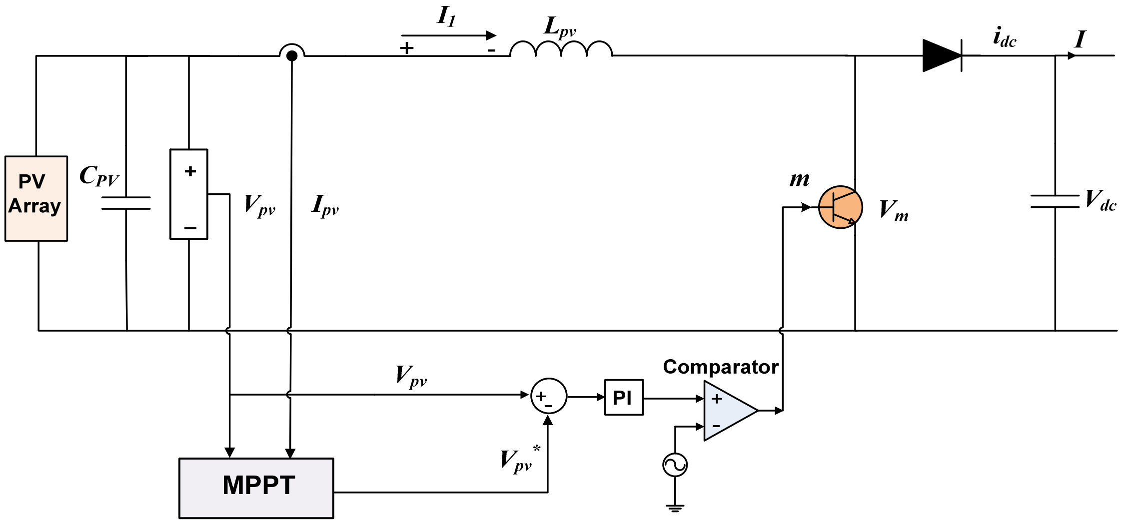

Figure 4. PV converter controller System

The voltage and current in the capacitor (C_{pv}) and inductance (L_{pv}) respectively give optimal command of the current and voltage. The voltage control loop with the PV current compensation gives the current reference (I_l^*) and the current control loop with the PV voltage compensation gives the voltage reference (V_{pv}^*). The controller parameters are chosen to maintain a constant PV voltage and minimize the current ripple.

This PV cell model is implemented in PSCAD for nonlinear simulations, where the PV array is interfaced as a nonlinear current source.

PV energy has radiation and temperature dependent nonlinear P-V characteristic. To utilize the maximum amount of energy from a PV cell, it is important to track its MPP which varies with changing atmospheric conditions. Generally its maximum power output occurs around the knee point of the P-V curve as shown in Figure 5.

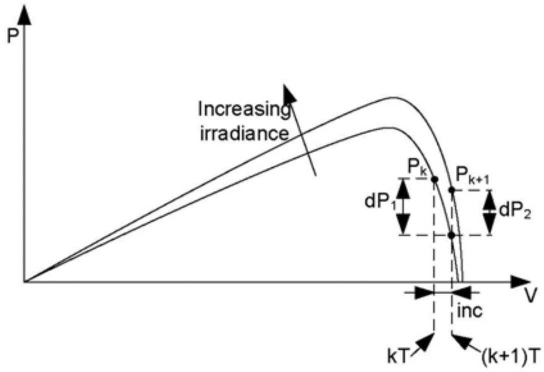

Figure 5. P-V characteristic curve of PV cell with MMP T [7]

In this work the P&O method has been chosen for obtaining MPP, as shown in Figure 6 and implemented in PSCAD, due to its simplicity and low computational demand [7]-[8].

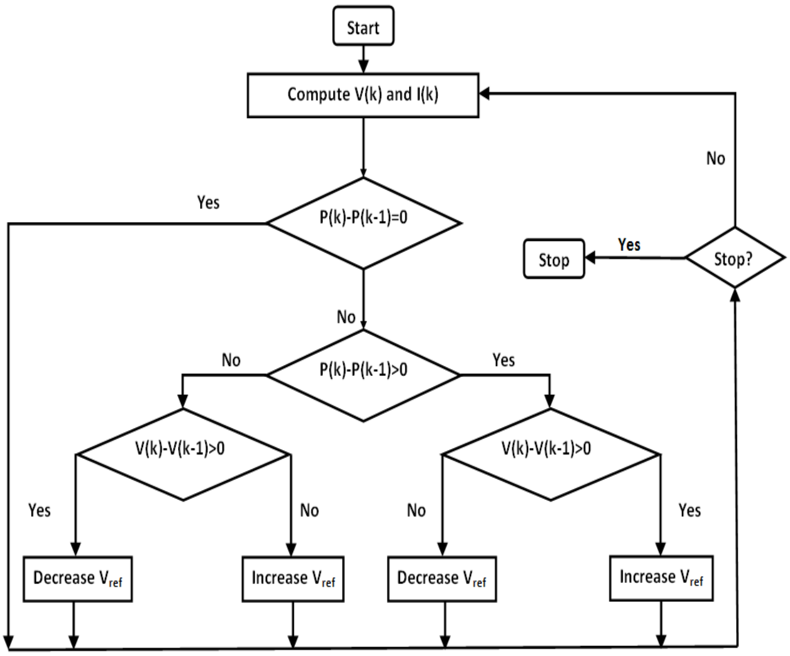

Figure 6. Flowchart of P & O method [7]-[8]

From Figure 3, a mathematical model describing the boost converter connected photovoltaic generator can be written as:

$$\begin{pmatrix} V_m \\ i_{dc} \\ \end{pmatrix} = m \begin{pmatrix} V_{dc} \\ i_1 \\ \end{pmatrix} \tag{17}$$

And the dynamics of PV system are

$$\dot{i}_1 = \frac{1}{L_{pv}}(V_m - V_{pv}) - \frac{R_{pv}}{L_{pv}} i_1 \tag{18}$$

$$\dot{V}_{pv} = \frac{1}{C_{pv}}(i_1 - i_{pv}) \tag{19}$$

And the three phase current from solar PV can be express as follows :

$$\dot{i}_a = [v_{dc1_a} - v_a - R_{11} i_a]/L_1 \tag{20}$$

$$\dot{i}_b = [v_{dc1_b} - v_b - R_{11} i_b]/L_1 \tag{21}$$

$$\dot{i}_c = [v_{dc1_c} - v_c - R_{11} i_c]/L_1 \tag{22}$$

$$\dot{V}_{dc1} = f_{a1} i_a + f_{b1} i_b + f_{c1} i_c \tag{23}$$

f_{a1}, f_{b1}, f_{c1} are the switching functions

3. PHEV BATTERY MODELING AND NETWORK INTERFACING

To connect with electrical distribution systems for battery charging, PHEVs need to have an electronic interface. Along with the dynamic response of electrolyte temperature and battery state-of-charge (SOC), the effect of electronic charger is considered to model the system.

On an average more than 50% cars in U.S. are driven about 25 miles per day [9]. To evaluate the impact of PHEVs we consider the range of driving 40 miles/day, which means the capacity of a PHEV battery will be 12 kWh as 0.3 kWh of battery energy is required to drive one mile [10], [11].

A dynamic model of a lead acid battery [12] has been selected to develop a suitable model of PHEV, where the elements of PHEV's battery are not constant, as they depend on electrolyte temperature as well as on the state-of-charge (SOC). The battery equivalent network represented in Figure 7, where Θ represent electrolyte temperature and SOC is the battery state-of-charge. I_m is an integral part of the total current I.

Another part of the total current pass through the parasitic branch. Parasitic reaction is a continuous process, that draw current but does not participate at main reaction. The voltage at this branch is nearly equal to the voltage at the pin. The power dissipated in real part of impedances Z_m and Z_p is converted into heat. Impedance of main reaction branch increase with charge, as a result the terminal voltage of parasitic branch rise as well as the current I_p. At a full state of battery, the impedance of the main reaction branch approaches to infinite [12]-[14].

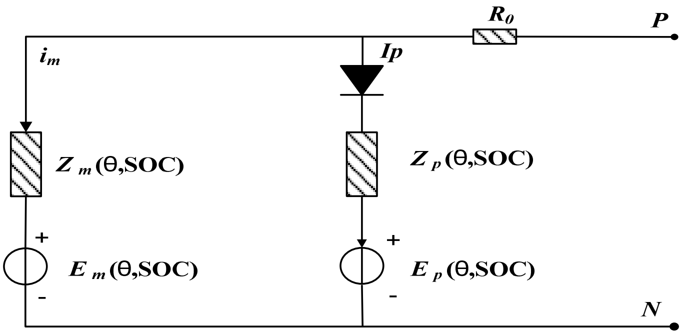

Figure 7. Battery equivalent network with parasitic branch

This battery model can be represented as an RLC network as shown in Figure 8 and the number of R-L-C block can be kept limited as the specific speed of evolution of electric quantities evolve very rapidly for PHEVs [12].

The third order battery dynamic model is designed considering current, electrolyte temperature and state of charge (SOC). The dynamic equations for the model are [12] - [15]:

$$\dot{q}_e = i_{dc}/T_s \tag{10}$$

$$\dot{i}_m = (i_{dc} - i_m)/T_m \tag{11}$$

$$\dot{\theta} = -\frac{1}{C_\theta}[P_s - \frac{\theta - Q_a}{R_\theta}] \tag{12}$$

$$V_{dc} = E_m - V_p(q_e, i_m) + V_e e^{-B_e q_e} - R_0 i_{dc} \tag{13}$$

Where V_e represents the hysteresis phenomenon for the Lead-Acid battery during charge and discharge cycles. The exponential voltage increases when battery is charging, no matter the SOC of the battery. When the battery is discharging, the exponential voltage decreases immediately. And V_p depends on the sign of i_m as follows:

$$V_p(q_e, i_m) = \begin{cases} \dfrac{R_p i_m + K_p q_e}{SOC} & ifi_m > 0(discharge\ ) \\ \dfrac{R_p i_m}{q_e + 0.1} + \dfrac{K_p q_e}{SOC} & ifi_m < 0(charge\ ) \end{cases}$$

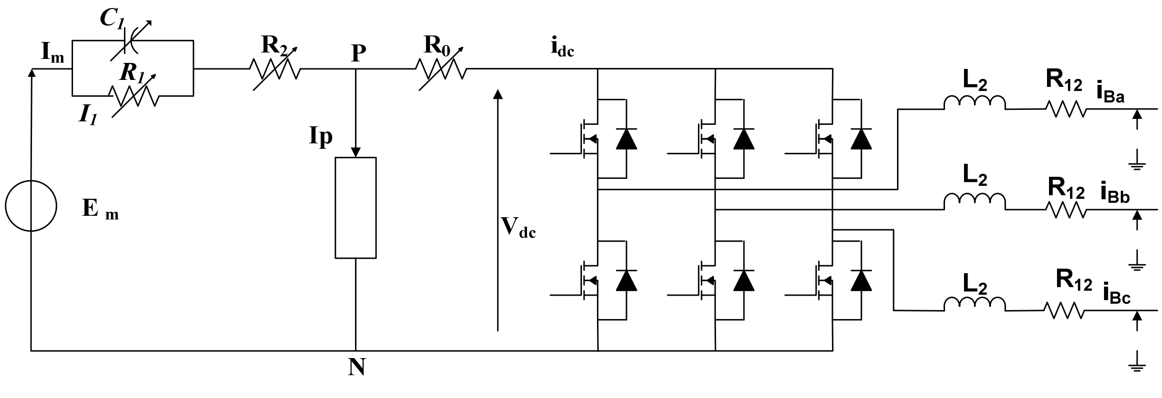

Figure 8. PHEVs connection with power systen network

A complete battery scheme is shown in Figure 9.

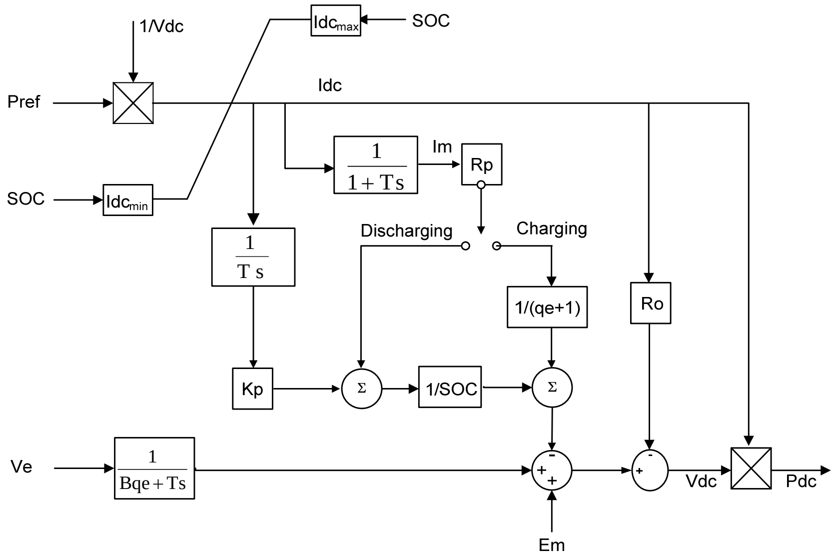

Figure 9. PHEVs battery scheme

The equations for E_m, R_0 are:

$$E_m = E_{m0} - K_e(273+\theta)(1-SOC) \tag{14}$$

$$R_0 = R_{00}[1+A_0(1-SOC)] \tag{15}$$

$$R_1 = -R_{10}ln(DOC) \tag{16}$$

$$R_2 = R_{20}\frac{exp[A_{21}(1-SOC)]}{1+exp(A_{22}I_m/I^*)} \tag{17}$$

E_{m0}, K_e, R_{00} and A_1, are constant for a particular battery.

The state of charge SOC and depth of charge DOC can be express as:

$$SOC = \frac{Q_n - Q_e}{Q_n} = 1 - q_e \tag{18}$$

$$DOC = 1 - Q_e/C(I_{avg}, \theta) \tag{19}$$

where C_Θ and P_s are the thermal capacity and power; R_0 is the thermal resistance; Q_a is the ambient temperature; I^* is the reference current; x_r is the Thevenin equivalent reactance; β_e is the exponential capacity coefficient; Q_e is the extracted capacity in Ah; Q_n is the rated battery capacity in Ah and K_c, E_m, K_e *and* A_1 are constant for a particular battery. The battery parameters are available in [6].

The behavior of the parasitic branch is strongly nonlinear. Therefore the current of the parasitic branch can be express as:

$$I_p = V_p G_p \exp\left(\frac{V_p}{V_{po}} + Ap\left(1 - \frac{\theta}{\theta_f}\right)\right) \tag{20}$$

The computation of R_p gives the heat produce by the parasitic reaction by means of Joule law:

$$P_s = R_p I_p^2$$

Differential equation for DC current

$$\dot{i}_{B_a} = [v_a - R_{12} i_{B_a} - v_{dc_a}]/L_2 \tag{21}$$

$$\dot{i}_{B_b} = [v_b - R_{12} i_{B_b} - v_{dc_b}]/L_2 \tag{22}$$

$$\dot{i}_{B_c} = [v_c - R_{12} i_{B_c} - v_{dc_c}]/L_2 \tag{23}$$

$$\dot{V}_{dc} = f_a i_{B_a} + f_b i_{B_b} + f_c i_{B_c} \tag{24}$$

f_a, f_b, f_c are the switching functions

4. CONTROLLER DESIGN

The P-Q theory is used for the controller design in this work without considering the neutral wire. The P-Q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the a-b-c coordinates to *α-β*. The dynamic equations for current in *α-β* coordinates can be express as [16], [17]:

$$\begin{bmatrix} \Delta i_\alpha \\ \Delta i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \Delta I_a \\ \Delta I_b \\ \Delta I_c \end{bmatrix} \tag{25}$$

The voltage in *α-β* coordinates will be:

$$\begin{bmatrix} \Delta v_\alpha \\ \Delta v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \Delta V_a \\ \Delta V_b \\ \Delta V_c \end{bmatrix} \tag{26}$$

The equation for p, q are :

$$\begin{bmatrix} \Delta p \\ \Delta q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \Delta i_\alpha \\ \Delta i_\beta \end{bmatrix} \tag{27}$$

To generate the reference current for the controller the following equation are used:

$$\begin{bmatrix} \Delta i_{\alpha_{ref}} \\ \Delta i_{\beta_{ref}} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \Delta p \\ \Delta q \end{bmatrix} \tag{28}$$

Based on PQ theory a controller has been developed. The total system with controller is shown in Figure 12. At the first section of the controller the instantaneous value of real and reactive power have been calculated at Figure 10. And then the error current signal have been used to switch the inverter, available at Figure 11.

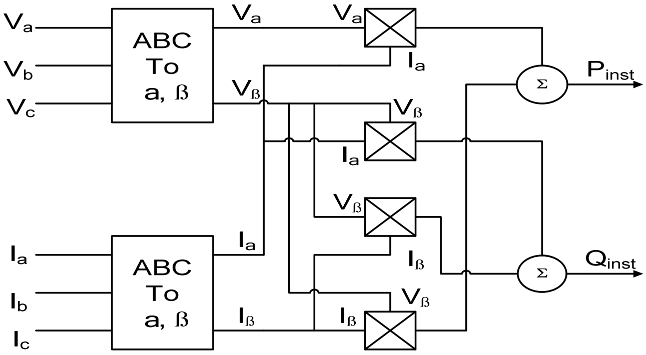

Figure 10. PQ generation in the controller

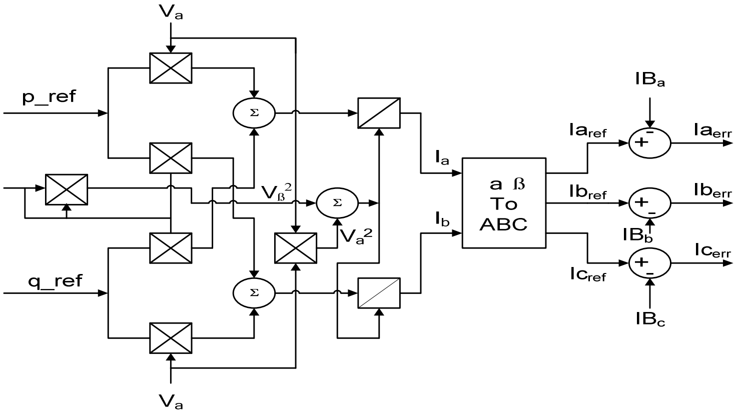

Figure 11. Signal generation for inverter switching

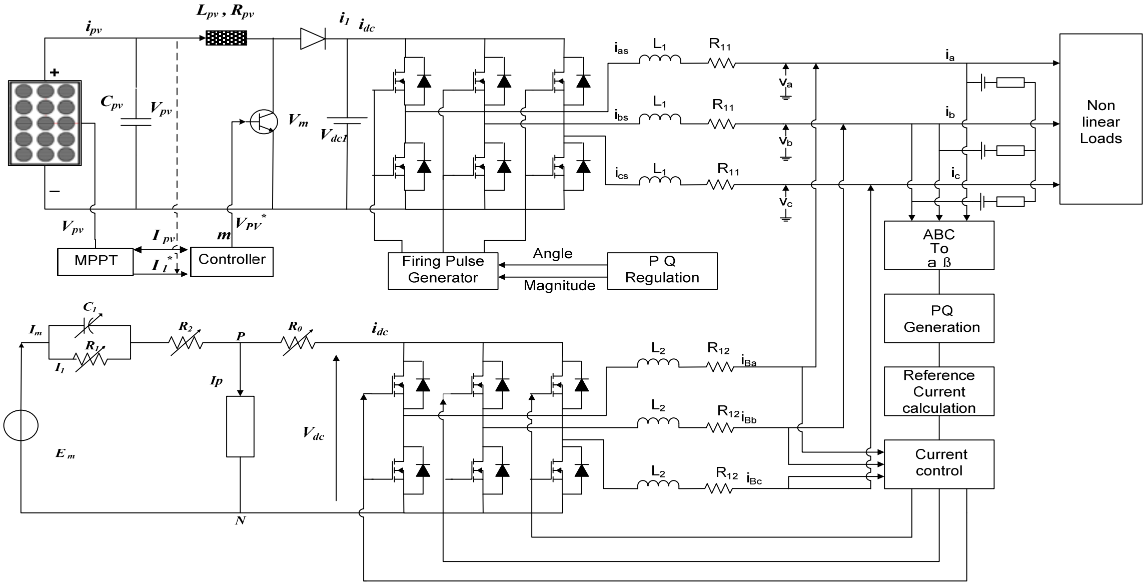

Figure 12. Total system Configuration

5. SIMULATION RESULTS

Simulation results show that the system and load current harmonics decrease with the use of PHEV as active filter in Figure 13 and Figure14. And the power factor also improve with the use of PHEVs in Figure15 and Figure 16**.** The compensating current is presented at Figure17

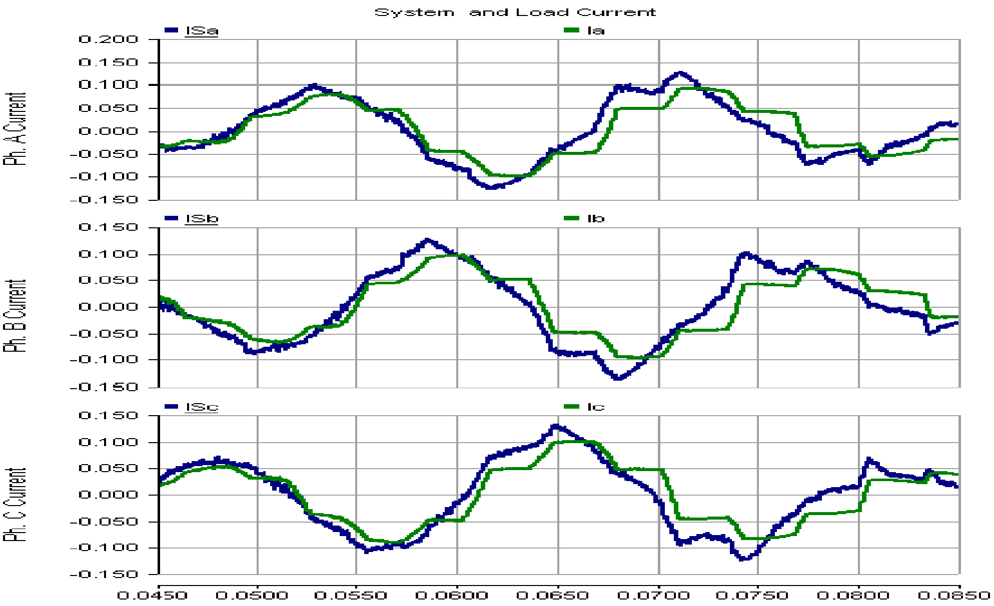

Figure 13. System and load current without filter

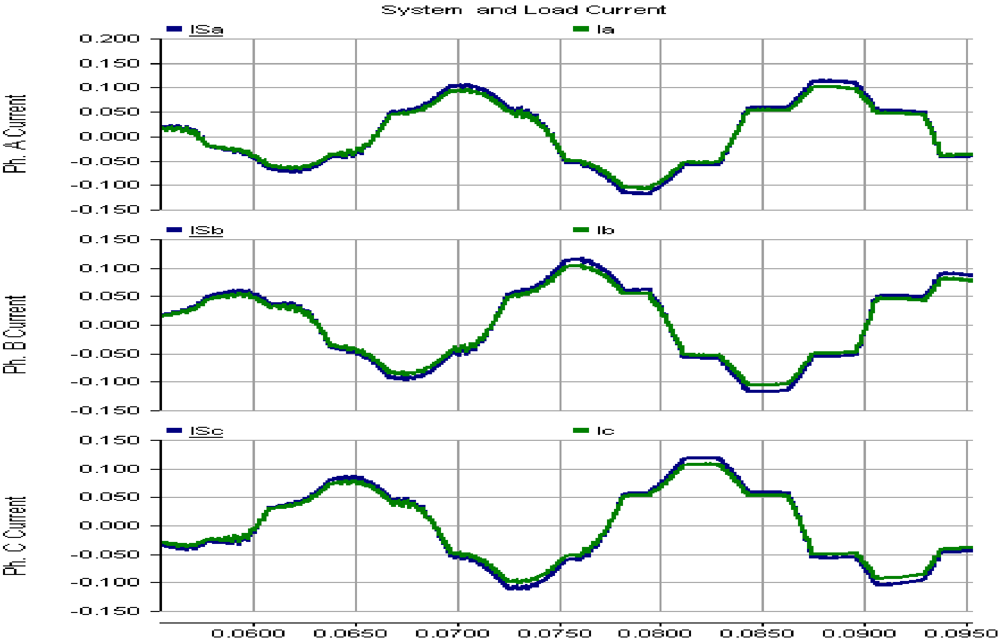

Figure 14. System and load current with filter

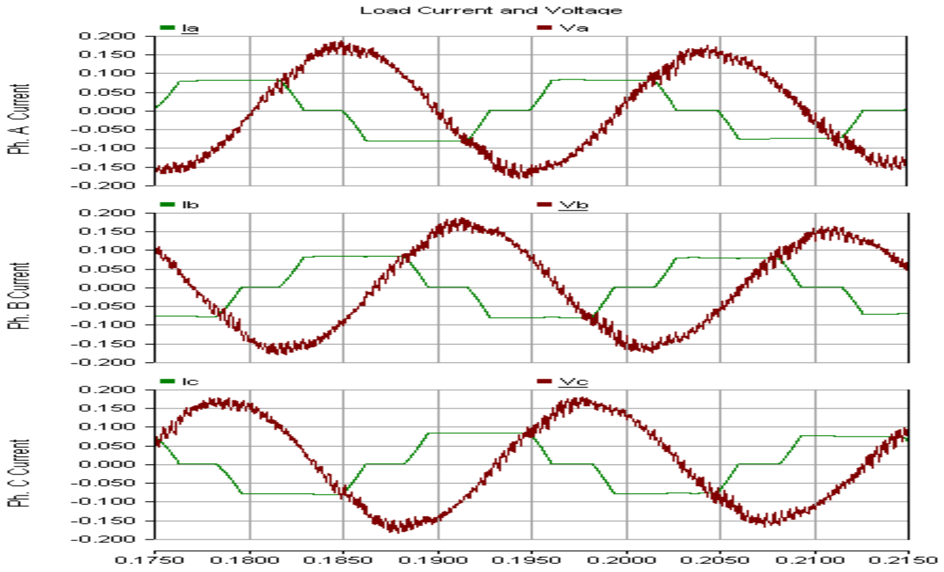

Figure 15. Load current and voltage with filter

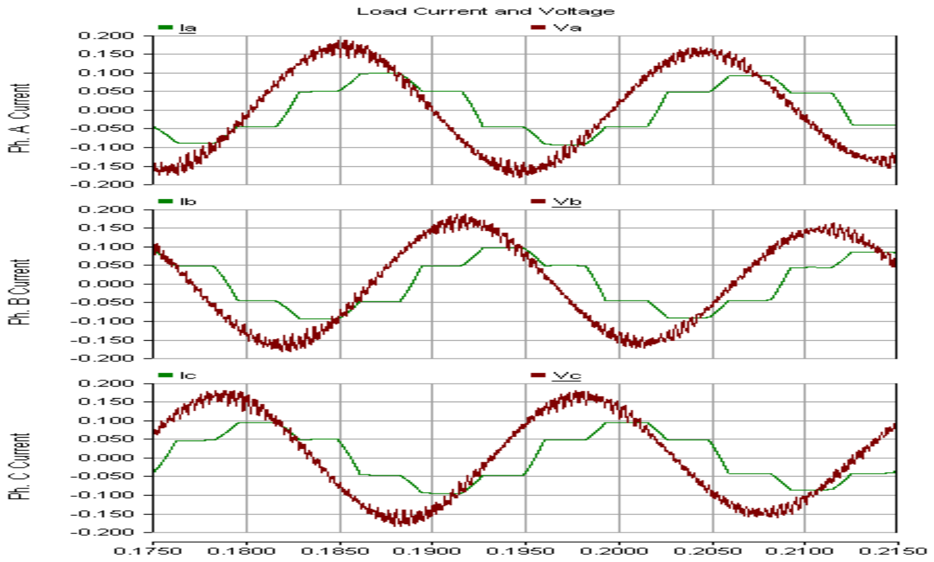

Figure 16. Load current and voltage without filter

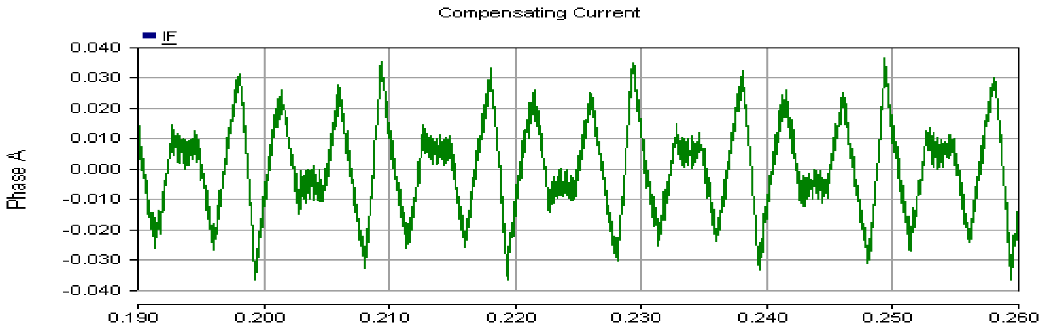

Figure 17. Compensating current at phase A

6. CONCLUSION

The goal achieved via this study is the investigation of the performance of photovoltaic generator with dynamic PHEVs as active filter. Load and system current as well as the load voltage and current with and without using the PHEVs as active filter in the system have been investigated. The obtained results from simulations show that the the power quality improved with PHEV's, used as an active filter. It has been concluded that a lot of future research is needed to study the implementation of V2G technology in a solar power system. Several issues, such as battery ageing consequences, considering the smart grid technology, grid connected operation of solar generator, islanding operation of solar power with PHEV's as a source and an active filter could be the interesting topics in the future work

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Hemanshu R. Pota received the B.E. degree from SVRCET, Surat, India, in 1979, the M.E. degree from the IISc, Bangalore, India, in 1981, and the Ph.D. degree from the University of Newcastle, NSW, Australia, in 1985, all in electrical engineering. He is currently an Associate Professor at the University of New South Wales, Australian Defence Force Academy, Canberra, Australia. He has held visiting appointments at the University of Delaware; Iowa State University; Kansas State University; Old Dominion University; the University of California, San Diego; and the Centre for AI and Robotics, Bangalore. He has a continuing interest in the area of power system dynamics and control, flexible structures, and UAVs.