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Design a Simulation of Power Systems Stability in Presence of Photovoltaic Systems

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Abstract: The use of renewable energy resources has gained so much attention and popularity in the world as alternative energy to the conventional thermal, hydro and nuclear energy. But the increasing use of fossil fuels like coal, gases and petroleum product will create a deficiency in future along with some other issues like increasing price, environmental pollutions. Again increasing demand of electrical energy for a luxurious society forces the power engineers to think of alternative energy sources in the form of wind, solar, biomass etc. Among these resources, solar energy is the most promising and emerging as popular source of electrical energy in society having potential utilization for remote rural communities. However, there are many potential use of solar photovoltaic (SPV) being a sustainable solution. There is a lot of opportunity for such technologies to provide a cost effective solution to demand of electricity for the rural poor peoples of developing nations. In addition, development and increasing number of micro grids and standalone off grid and on grid challenges which needs to be addressed for effective and operation requires improvements in system design and control. However, installation of solar photovoltaic (PV) for electricity generation might be not a good mitigation for the problem whereby some internal issues to be rectified and to be stabilized for the better power quality to be generated. Therefore in this paper we use one of the method for the better power quality. This paper presents the design and simulation of an active power filter (APF) supported by a PV plant by using P-Q theory algorithm to control APF.
Keywords: Power System, Solar System, Active Power Filter, Photovoltaic(PV), PQ theory, Power Quality.

I. INTRODUCTION

The weather exchange and the new technology may also initiate foremost changes in electricity technology and intake patterns. The gadget connected to the distribution network is turning into more diversified including the use renewable energy supply, like solar panels or wind turbines, amongst other technology. A photovoltaic (PV) System immediately converts sunlight into electricity. The obtained energy depends on solar radiation, temperature and the voltage produced within the voltage module. Also, one of the most common troubles while connecting small renewable energy systems to the electric grid is that PV can inject harmonic additives that may become worse the electricity high-quality.

Thus, it is crucial to investigate voltage stability within the grid when it is associated with PV generation. As far as voltage is concerned, it is one of the important parameters in a system which plays a major role in power plant and the voltage stability has to be taken care to avoid major problem occurrences. Due to the probabilistic in nature of PV generation and significant difference from conventional synchronous generators, a significant increase in solar generations in the grid may present technical challenges and major impacts on system stability. Various studies have been conducted to simulate and investigate the effects of solar power on power system stability.

In PV penetrating rate is one of the causes which can influence the voltage stability. The PV penetration will improve the stability performance of a power system.

PV will increase the real power and improves the reactive power of a particular power system. Grid connected solar photovoltaic system is where the power system is being energized by the photovoltaic panels installed in particular buildings and the power source is supplied via utility grid.

In this the control algorithm proposed permits the implementation of APF with the three different stages, first, there is no APF and also no solar power is given to it. Second, there is system use available solar power to energize the DC link and the load fed from grid. Means available PV and APF. And third the system use all the PV power energize DC link to supply the load power, additionally, the excess PV energy is exported to the grid, means available PV with APF and the Excess PV energy to the grid.

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II. ACTIVE POWER FILTER OPERATION.

Some equipment, generally known as active filters (AF) are also called active line conditioners (APLC), instantaneous reactive power compensator (IRPC), active power filters (APF) and active power quality conditioners (APQC) [4].

There are basically two types of active filters: the shunt type and the series type. It is possible to find active filters combined with passive filters as well as active filters of both types acting together. The most common and widespread filter is the shunt active power filter (APF). APF are suitable to act in three phase systems with three or four wires. The theory for four wire systems is demonstrated with detail. The principal objective of an APF is to compensate harmonic currents, to improve the power factor, to balance the phases in the system and to eliminate the power flowing through neutral wire. In order to achieve those goals shunt power filters has to be controlled in a way that acts as a current generator giving to the load the undesirable power components, thereby, the grid only has to provide the fundamental sinusoidal components. An APF is essentially a power converter with a DC side and AC side, the controller maintain the capacitors in DC side with an stable voltage, the APF has to drain active power from the source to work properly, In it is possible to provide active power from RES to the load through the APF, interfacing the intermittent nature of RES with the load and the grid in a secure way and incrementing the quality of the system.

A. *Instantaneous Power Theory applied to Active Power Filter.*

The P-Q theory or ”The Generalized Theory of the Instantaneous Reactive Power in three-Phase Circuit” was proposed by Akagi et al, the theory for four wires was developed later by Aredes and Watanabi et al. Allowing to do the neutral current compensation possible. The three phase p-q theory use the Clarke transform (alpha-beta) to put the three phase coordinates in –0 coordinates, equation. Thus, it is possible to calculate the instantaneous real power, imaginary power and the zero sequence power equations.

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

$$p = v_\alpha . i_\alpha + v_\beta . i_\beta \quad (2)$$

$$p_0 = v_0 . i_0 \quad (3)$$

$$q = v_\alpha i_\beta + v_\beta i_\alpha \quad (4)$$

Above equation can form the matrix in equation.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (5)$$

Power component can be separated as:

$$p = \tilde{p} + \bar{p} \quad (6)$$

$$\bar{q} = \bar{q} + \tilde{q} \quad (7)$$

Where those instantaneous power component can be differentiated as follow.

1) $\bar{p}$ is the average value of the instantaneous real power p. Is the energy per unit time that is transmitted from the source to the load. It is the desired power component that should be transmitted through the a, b, c phases.
2) $\tilde{p}$ It is the alternating value of the instantaneous real power. It corresponds to the energy per unit time that is exchanged between the power source and the load.
3) $\bar{q}$ Is the average value of the instantaneous imaginary power.
4) $\tilde{q}$ It is the alternating value of the instantaneous imaginary power.
5) $\bar{p}_0$It is the mean value of the instantaneous zero-sequence power.
6) $\tilde{p}_0$Is the alternating value of the instantaneous zero sequence power. With the $\bar{p}_0$ corresponds to the energy per time transferred from and to the load trough the zero sequence components.

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When RES are working it is possible to transmit RES power to the load trough the APF, to accomplish this, it is necessary to include the component P_{res}.

Considering above equations and components next equation is constructed, to eliminate harmonics components of active and reactive power ($\tilde{p}$) and ($\tilde{q}$), the result is the reference compensation currents i_α* and i_β*.

$$\begin{bmatrix} i_{\alpha^*} \\ i_{\beta^*} \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} -\tilde{p} \\ -(\bar{q} + \tilde{q}) \end{bmatrix} \tag{8}$$

In the case of the zero sequence it must be compensated completely, thus.

$$i_{c0^*} = i_0 \tag{9}$$

Compensating current can be derived using the (α – β) coordinate plane system. Equation 8 turns into.

$$\begin{bmatrix} i_{c\alpha^*} \\ i_{c\beta^*} \end{bmatrix} = \frac{1}{V_\alpha{}^2 + V_\beta{}^2} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} -\tilde{p} \\ -(\bar{q} + \tilde{q}) \end{bmatrix} \tag{10}$$

Finally, the three phase compensating currents a,b,c is calculated with the Clarke inverse transformation [2].

$$\begin{bmatrix} i_{a^*} \\ i_{b^*} \\ i_{c^*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c0^*} \\ i_{c\alpha^*} \\ i_{c\beta^*} \end{bmatrix} \tag{11}$$

$$i_{cn^*} = -(i_{a^*} + i_{b^*} + i_{c^*}) \tag{12}$$

The Shunt active power filter allows the power source to deliver $\bar{p}_0$ to the load from the phase and other power components $\tilde{p}$, $\tilde{p}_0$, are compensated and provided by the APF.

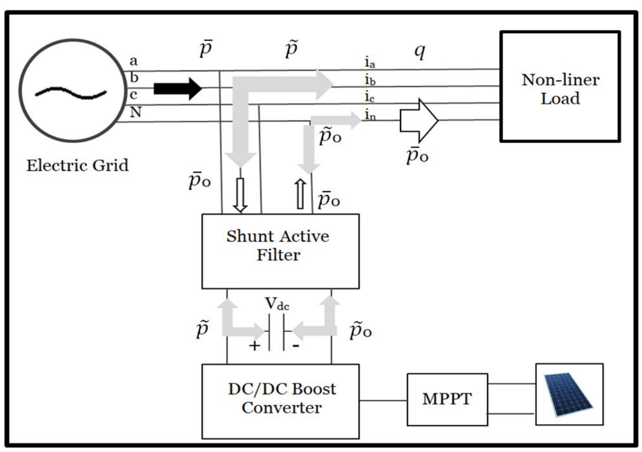

Fig.1 Block Diagram of System.

B. Power System with APF

In this situation, the power required by the DC link is depleted from the grid, this is where there is no PV power and the system do not count with a storage system. The control calculation should utilize (14) to produce the reference currents. Moreover the DC link is directed with a PI controller to lessen the error between the ideal DC voltage V_{DCref} and the measure DC bus voltage V_{DCmeas}, the filtered output is the regulated power variable ~ P_{reg}. The reference power P_{ref} is the sum of the regulated power also, the alternating value of the instantaneous power (13).

$$P_{ref} = -\bar{p}_L + \tilde{P}_{reg} \tag{13}$$

$$Q_{ref} = -(\bar{q} + \tilde{q}) \tag{14}$$

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With this consideration (10) transforms into.

$$\begin{bmatrix} i_{c\alpha^*} \\ i_{c\beta^*} \end{bmatrix} = \frac{1}{V_\alpha{}^2 + V_\beta{}^2} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} P_{ref} \\ Q_{ref} \end{bmatrix} \quad (15)$$

C. Power System with APF & PV (Available)

In this situation, the power required by the DC link is given by the PV system, this is where there is PV power accessible however insufficient to control the loads, the PV power is utilized then just to give the ability to quality control purposes. The grid power is estimated to get Pgrid. Grid power is then deducted from the equation.

$$P_{ref} = -\bar{p} + \tilde{P}_{reg} - P_{grid} \quad (16)$$

D. Power System with APF & PV (Excess)

In this situation, the PV power is utilized to control the APF activity which is quality control and to fed the loads. In case where there is over production and no storage system, the excess PV power is sent out to the grid. (16) is change considering that the real power of the loads should be provided by the PV system.

$$P_{ref} = -\bar{p}_L - p + \tilde{P}_{reg} - P_{grid} \quad (17)$$

III. SHUNT ACTIVE FILTER SIMULATION

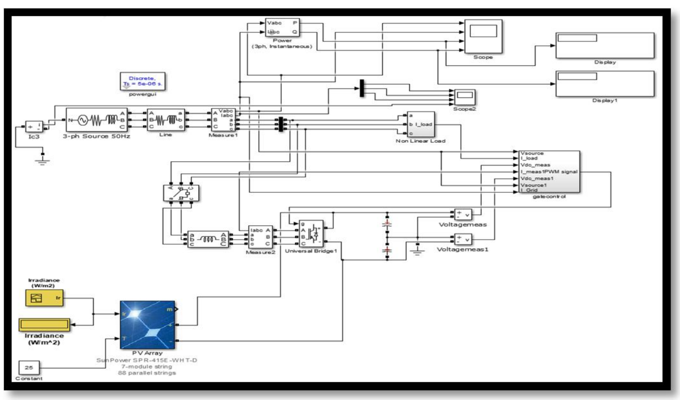

Fig.2 Simulation of Power System with APF in Presence of PV System.

Above chapter all the equations where implementing here with help of Matlab/Simulink with SimPowerSystems toolbox, to simulate the operation of the Shunt APF of Fig. 1, the general control strategy is presented in blocks in Fig. 2.

A. Power Source and Load Section

For simulate the operation of the APF, a sinusoidal power source is connected to a non-linear group of loads. The parameters of the systems are listed in table I: For each phase a non-linear load is placed, in phase a a single phase rectifier with a RL load, in phase b a single phase rectifier with a RC load and in phase c a single phase rectifier with pure R load is placed. In order to perform the simulation of harmonic injection to the system, each phase a; b; c is connected to a current source, with 50 A of magnitude and 2f; 3f and 5f harmonic order respectively.

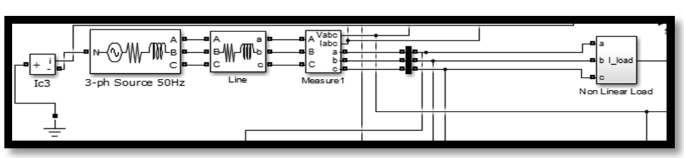

Fig.3 Simulation Blocks of Power Source and Load Section.

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B. Controller Block

Controller block follows the structure show in Fig. 2. Compensating currents ia*; ib*; ic* are compared with the actual current value and a the hysteresis current control technique is performed [7]. Current decay and rises between a lower and upper hysteresis band. The DC bus is constructed with two capacitors grounded to create the neutral reference of the shunt APF.

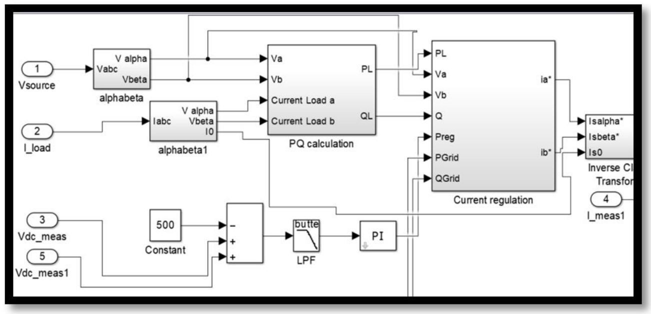

Fig.4 Simulation of Control Strategy & PQ theory SIMULINK.

Three-phase Source	Vph = 208V; 50Hz
Phase A-N non-linear load.	DC rectifier R = 3; L = 5mH
Phase B-N non-linear load.	DC rectifier R = 4; C = 100uF
Phase C-N non-linear load.	Harmonic injection 3f; 5f & 7f
Coupling Inductor	Ls = 2mH

Table.1 System Parameters.

C. Implementation of PQ theory applied to Active Power Filter

As seen before, $\bar{p}$ is usually the only desirable p-q theory power component. The other quantities can be compensated using a shunt active filter. As shown by Watanabe et al., $\bar{p}_0$ can be compensated without the need of any power supply in the shunt active filter. This quantity is delivered from the power supply to the load, through the active filter. This means that the energy previously transferred from the source to the load through the zero-sequence components of voltage and current, is now delivered in a balanced way from the source phases.

It is also possible to conclude from Fig. 5 that the active filter capacitor is only necessary to compensate $\tilde{p}$ and $\tilde{p}_0$, since these quantities must be stored in this component at one moment to be later delivered to the load. The instantaneous imaginary power (q), which includes the conventional reactive power, is compensated without the contribution of the capacitor. This means that, the size of the capacitor does not depend on the amount of reactive power to be compensated.

To calculate the reference compensation currents in the α-β coordinates, the expression (5 in PQ theory) is inverted, and the powers to be compensated ($\tilde{p} - \tilde{p}_0$and q) are used:

$$\begin{bmatrix} i_{c\alpha^*} \\ i_{c\beta^*} \end{bmatrix} = \frac{1}{{V_\alpha}^2 + {V_\beta}^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} \tilde{p} - \tilde{p}_0 \\ q \end{bmatrix} \quad (1)$$

Since the zero-sequence current must be compensated, the reference compensation current in the *0* coordinate is i_0 itself:

$$i_{c0^*} = i_0 \quad (2)$$

In order to obtain the reference compensation currents in the a-b-c coordinates the inverse of the transformation given in expression (1) is applied:

$$\begin{bmatrix} i_{ca^*} \\ i_{cb^*} \\ i_{cc^*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c0^*} \\ i_{c\alpha^*} \\ i_{c\beta^*} \end{bmatrix} \quad (3)$$

$$i_{cn^*} = -(i_{ca^*} + i_{cb^*} + i_{cc^*}) \quad (4)$$

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The calculations presented so far are synthesized in Fig. 5 and correspond to a shunt active filter control strategy for constant instantaneous supply power.

1) The phase supply currents become sinusoidal, balanced, and in phase with the voltages. (in other words, the power supply "sees" the load as a purely resistive symmetrical load);
2) The neutral current is made equal to zero (even 3rd order current harmonics are compensated);
3) The total instantaneous power supplied,

$$p_{3s}(t) = v_a.i_{sa} + v_b.i_{sb} + v_c.i_{sc} \quad (5)$$

is made constant.

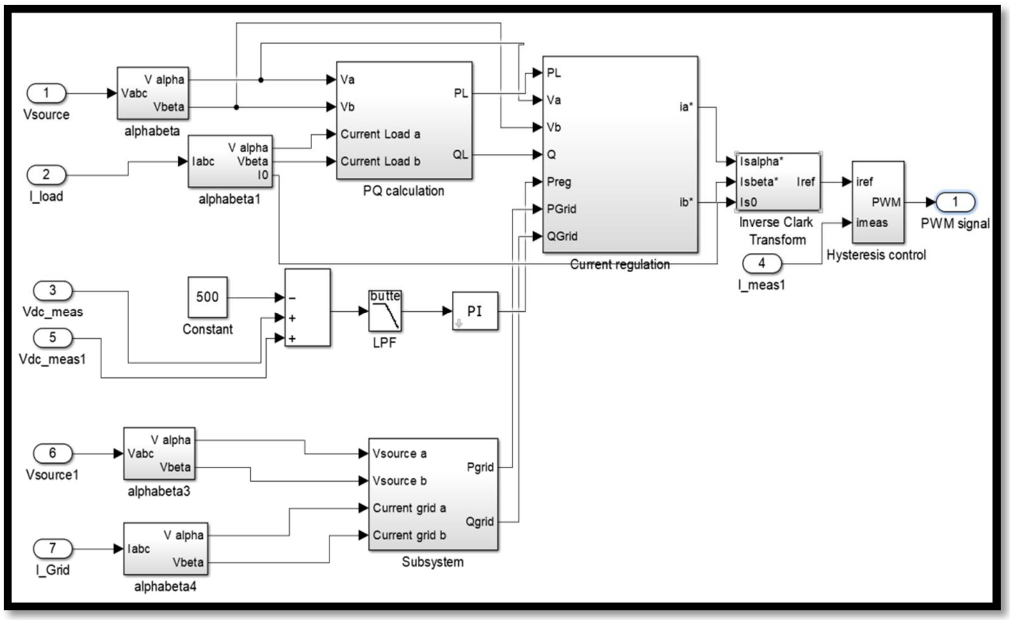

Fig.5 Calculation for the Constant Supply Power Control Strategy.

Above Fig.5 is the calculation for the constant instantaneous supply power control strategy by PQ theory which implement for the active power filter, and the diagram given below Fig.6 is the simulation part of the above Fig.5 calculation.

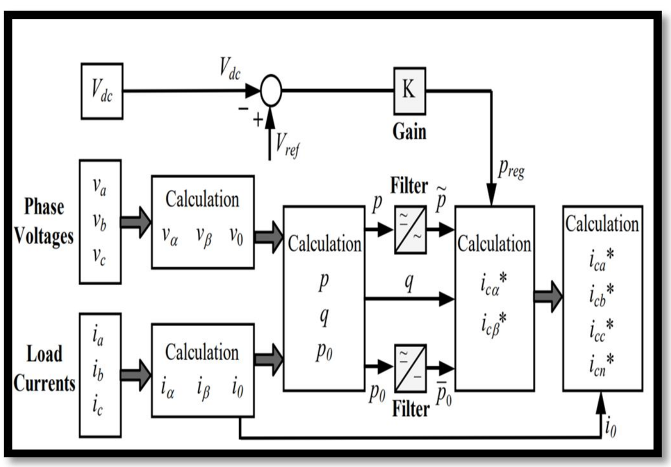

Fig.6 Simulation of the Calculation of Constant Supply Power Control Strategy.

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D. PV Array

DC bus is powered by a RES, in this case with a PV source; due the DC bus has to maintain a constant DC voltage of 400V the dc voltage out of PV has to be increased. A boost DC-DC converted is used to perform the voltage level increment. The IGBT acts as a switch, pulses can be obtained comparing a triangular signal with constant magnitude and a control signal. Due the varying nature of the RES as PV constant duty cycle is not suitable for the system, for this reason various control switching techniques are present in the literature in [7-8] techniques of maximum power point tracking are described, including perturb and observe algorithm, in [9] Hill climbing method is perform. In this simulation a simple MPPT with Perturb and Observe method is developed for his simplicity and effectiveness as seen in [10].

IV. SIMULATION RESULT

The performance of the whole system was modeled and run under Matlab/Simulink with SimPowerSystems toolbox. The model and tools of SimPowerSystems runs in discrete mode with Ts of 5us, and the Low pass filters runs in continuous mode. From 0.0s to 0.1s APF is not connected. Current signals from non-lineal loads can be observed.

An FFT analysis is perform to obtain the THD for the fundamental F = 50Hz. Table 2.

From 0.1s to 0.3s only APF function is activated, from 0.3s to 0.5s APF with PV support is activated, and, from 0.5s to 0.7s the system is enabling to feed the load. Fig. 7 shows this simulation.

Current at PCC

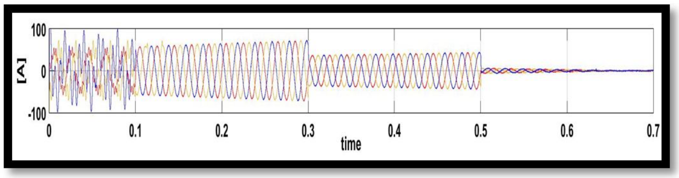

Fig.7 Current Waveform at PCC.

Table 3, Shows the THD levels in the system with APF activated. Notice that PF is completely fixed, and THD levels are reduced considerably.

Fig. 5 shows the power flow from the grid under the three different modes. Form 0s to 0.1s the APF is disconnected, from 0.1s to 0.3 the action of the APF could be observed, the instantaneous power stabilizes due the filter action. From 0.3s to 0.5s the APF + PV provokes a power reduction, because the power from the PV system insertion. Finally, from 0.5s to 0.7s the active power becomes negative; this is because the system allows the PV system to inject power to the grid.

Active Power from the Grid

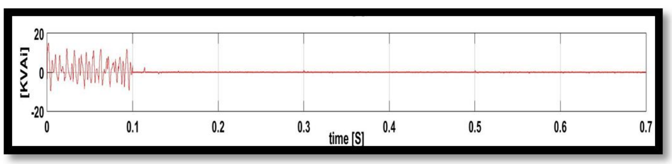

Fig.8 Instantaneous active power at PCC.

Fig.9 shows the imaginary power flowing between the grid and the system, is evident after the 0.1s, that the imaginary power interchange is reduced to near zero, this is due the action of the APF.

Imaginary Power from the Grid

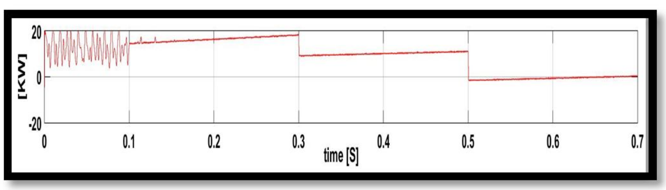

Fig.9 Imaginary active power at PCC.

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V. CONCLUSION

This work shows the use of a Shunt Active Filters as an interface between renewable energy source and the electric grid. The shunt Active filter has the capability of injecting sinusoidal currents with low THD. Active filters are a solution to power quality problems. Shunt active filters allows the compensation of current harmonics and balanced phases, together with power factor correction, and can be a much better solution than the conventional approach (capacitors for power factor correction and passive filters to compensate for current harmonics).

Phase	DPF	PF	THD (%)
Phase *a*	0.96	0.94	13.97
Phase *b*	0.94	0.99	51.43
Phase *c*	0.92	0.96	41.86

Table.2 Currents THD Values at Load before APF Connection.

This work has shown that active filters can be implemented in the same installation of the load. Different scenarios of harmonics are injected into the network to demonstrate the robustness of the filter. APF consume power from the grid, renewable resources like solar PV could be used to supply that power need. In this propose, the algorithm allows the power generated from PV to feed the total active and reactive power demand and export the surplus energy to the grid.

Phase	DPF	PF	THD (%)
Phase *a*	1	1	1.33
Phase *b*	1	1	1.15
Phase *c*	1	1	1.76

Table.3 Currents THD Values at Load after APF Connection.

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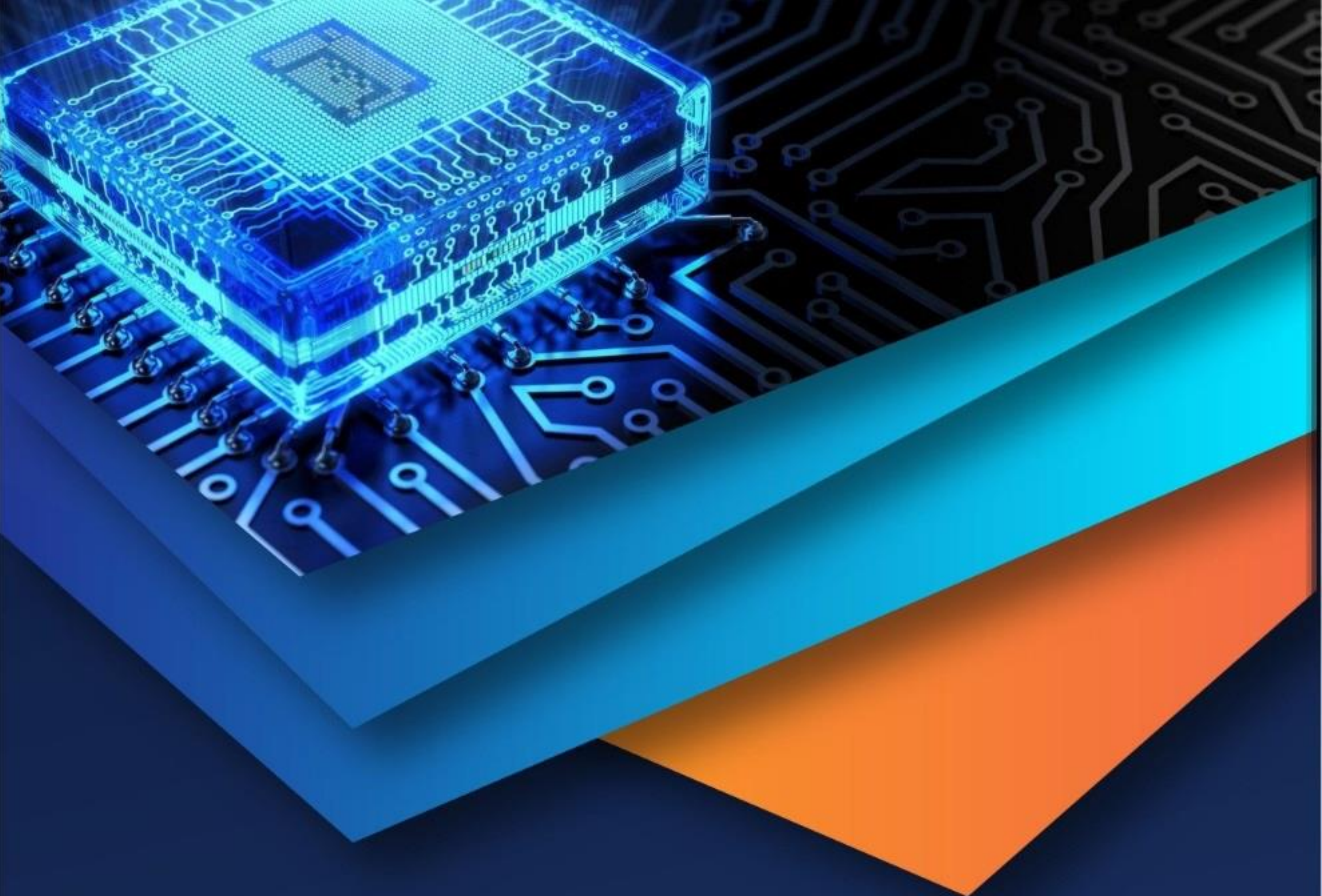

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