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A Comparative Study for Alleviation of Current Harmonics using PI/Fuzzy Controller based PV-APF System

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Abstract

Background/Objectives: The main ideology behind this paper is to design a Fuzzy Controller based Photo Voltaic-Active Power Filter (PV-APF) combinational system for alleviation of Current Harmonics. **Methods/Statistical Analysis:** The efficiency of PV module can be elevated by operating at Maximum Power Point (MPP) to achieve utmost power output. Hence, Maximum Power Point Methods (MPPT) methods. Here the Voltage Source Converter would act as active power filter compensating the current harmonics that are produced in 3-Φ 3-wire system there by the system power quality can be improved. Also, in this paper comparison is performed among fuzzy and PI controllers. **Findings:** The unified system is simulated in MATLAB/SIMULINK software based on simulation results obtained, we can able to conclude that compared to PI the total harmonic distortion of Fuzzy Controller is reduced to 3.68%. **Application/Improvement:** The THD value obtained from Fuzzy Controller is accurate. Hence Fuzzy Controller based PV-APF System is used for Alleviation of Current Harmonics.

Keywords: Current Harmonics, Energy Demand, Harmonic Distortion, Power Quality, Renewable Energy Reserves

1. Introduction

Due to rising energy requirement drastically against reduced fossil resources, PV energy is accepted as an infinite, uncontaminated alternative resource. So, the usage of PV Generator (PVG) becomes more feasible, practical. The direct conversion of available energy to DC voltage is made through PV cell without any resonance and interruption. The cost effectiveness of PV modeling[1] made the PV energy more economical. The effectiveness of PV model can be enhanced by operating at Maximum Power Point to achieve utmost power output. Depending on solar radiation and PV cell temperature, the peak power point is varied. Hence, Maximum Power Point Tracking Techniques (MPPT)[2,3] are employed for effective system operation. Since 1960's several MPPT techniques have been developed. These MPPT techniques are classified into two methods they are:

- Direct.
- Indirect.

Indirect tracking mechanisms such as Open circuit and Short circuit are not accurate for all meteorological conditions. To rectify this condition direct mechanisms are used. Some of the frequently used direct mechanisms are:

- P&O (Perturb and Observe) mechanism.
- INC (Incremental Conductance) mechanism.
- MPPT based on Fuzzy logic mechanism.

The enormous usage of power electronic drives create nonlinearity in power system network, there by harmonics are induced affecting its overall performance. To overcome these consequences caused by harmonics, filters are equipped inside the system.

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Passive filtering[4] is one of the simplest techniques incorporated to reduce harmonics. But they are mainly responsible for resonance criterion problems in grid. To eradicate these problems active filtering is used. The size and weight of active filters is radically reduced compared to passive and also not effected with resonance. So, the usage of APF[5–7] is rapidly improved.

Here, the PV-Active Power Filter system[8] is employed which is responsible for supply unity power factor to the utility and sinusoidal currents to the nonlinear loads.

The paper is segregated as:

- Section-2 describes the combined topology of PV-APF.
- Section 3 deals with PV array modeling and maximum power extraction through usage of Incremental conductance.
- Section 4 analyses the generation of reference currents by P-Q theory.
- Prominence of current controllers such as PI and fuzzy, the rule formation, operation of fuzzy controllers are explained in Section-5.
- The simulation results and conclusion obtained under MATLAB/SIMULINK environment are explained in Section 6.

2. Description of PV-APF Combined Topology

Figure 1 narrates the configurational ideology of PV-APF combination. The PV array used here is Sun power 305-type composed of 5 series-66 parallel Solar cells, delivering 100 KW maximum power at 1000 W/m^2 solar radiation. The output from this PV-array is DC voltage which is coupled to a 5-KHz DC-DC boost converter adopting MPPT by integral regulator incremental conductance technique that adjusts duty cycle to extract maximum power thereby enhancing the energy production. For grid incorporated systems DC voltage is transformed to AC voltage by placing DC/AC Voltage Source Converter (VSC) which converts 500 V DC to 260 V AC. Various techniques are tested in DC/AC Voltage Source Converter consequently such as dq-Current technique, PV-Active Power Filter technique and Active Power Filter technique. This VSC would act like an active power filter. In order to filter out switching harmonics induced by VSC 10-KVAR capacitor bank is used.

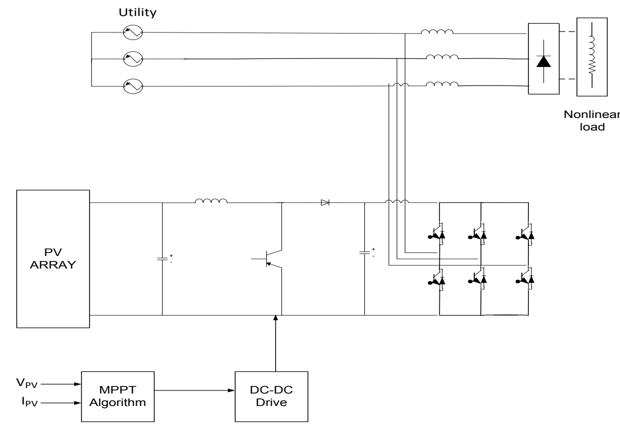


Figure 1. PV-active power filter system configuration.

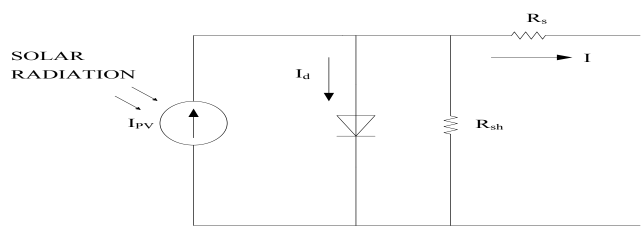


Figure 2. Diagramatical representation of PV module.

3. Photovoltaic Array Modeling

Photovoltaic cell is used to change light energy into electrical energy. A collection of photovoltaic cells is named as photovoltaic module. For voltage and current improvement photovoltaic cells in photovoltaic module are assembled in series and shunt.

Figure 2 represents Solar cell model[9] which involves a PV cell, driven by photo current. This PV cell is connected anti-parallel with diode and resistors.

Current output of PV cell is specified as follows:

$$I = I_{PV} - I_d \tag{1}$$

Where I_{PV} means photovoltaic current and I_d is current in the diode.

Diode current equation given by:

$$I_d = I_s\{\exp(\frac{q}{AK_bT_c})\text{-}1\} \tag{2}$$

Where, I_s is diode saturation current, q is equal to charge of e^- (1.60_*10^{-19} C), A and K_b are ideality and Boltzmann constants and T_C is operating temperature.

From Figure 2 current equation can be written as:

$$I = I_{PV} - I_d - I_{R_{sh}} \tag{3}$$

$$I = I_{pv} - I_s\{\exp(\frac{q}{AKT_cN_s}V + IR_s) - 1\} - \frac{V + IR_s}{R_{sh}} \tag{4}$$

Here, N_S stands for number of series connected solar cells, R_s and R_{Sh} are series and shunt resistances.

Variations of maximum power in PV array are mainly due to solar irradiance to overcome this situation the PV array must trace the point at which peak power is attained. To fulfill this criterion MPPT technique[10] is used.

3.1 Maximum Power Point Tracking

A normal photovoltaic panel converts nearly 40% of incidental light energy into electrical energy. The efficiency of the photovoltaic panel is improved by MPPT. Methodology involved in MPPT is the source and load impedances should match to attain maximum power point. Among various methods to realize MPPT, incremental conductance is simple.

3.2 Incremental Conductance MPPT

By changing terminal voltage of PV array w.r.t to Maximum Power Point voltage peak power can be achieved.

From Figure 3,

$\frac{dI}{dV}$ and $\frac{I}{V}$ specifies incremental and instantaneous conductances of the PV module.

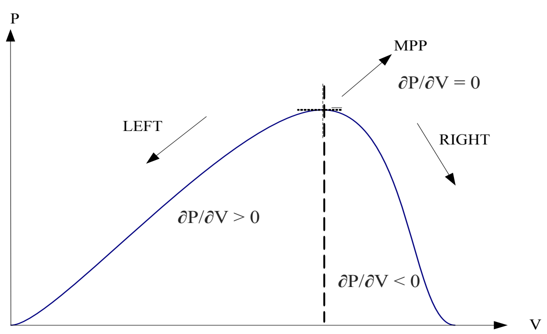


Figure 3. PV power curve specifing fundamental ideology of incremental conductance.

Relation among incremental and instantaneous conductances:

Case 1:

Zero at MPP,

$$\frac{dI}{dV} + \frac{I}{V} = 0$$

Case 2:

Greater at left of MPP,

$$\frac{dI}{dV} + \frac{I}{V} > 0$$

Case 3:

Lesser at right of MPP,

$$\frac{dI}{dV} + \frac{I}{V} < 0$$

3.3 Incremental Conductance MPPT Algorithm

From fundamental power equation,

$$P = V * I \tag{5}$$

By derivating the above equation w.r.t. voltage we get,

$$\frac{\partial P}{\partial V} = \frac{\partial(VI)}{\partial V} \tag{6}$$

At MPP, $\frac{\partial P}{\partial V} = 0$

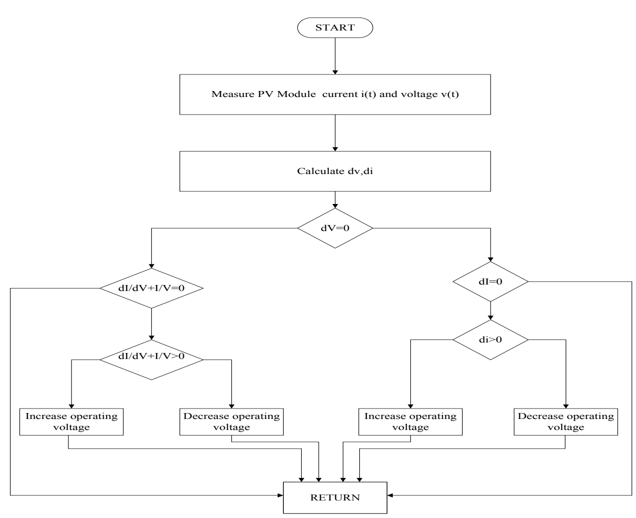


Figure 4. INC mechanism flow chart.

Rewriting Equation (6) in terms of array current and voltage:

$$\frac{\partial I}{\partial V} = -\frac{I}{V} \tag{7}$$

Boost converter's pulse width modulation signal is regulated by MPPT until (dI/dV)+(I/V) = 0 is achieved. In this mechanism peak power of array is greater than its incremental conductance i.e above 98%. A DC-DC boost converter is employed to implement this algorithm. Here DC/DC converter is switched, in order to vary the duty cycle to match the change in input resistance of the panel with the load resistance to attain maximum power of PV module. The flow chart for incremental conductance algorithm is as shown Figure 4.

4. Reference Current Generation using P-Q Theory

Important criterion emphasized to inject PV maximum power into grid is to produce proper reference current signal. As mentioned earlier, Instantaneous power theory is used for reference current generation. Using this theory, the 3-Φ voltages and currents in abc stationary phase are converted into the α-β phase as shown in Equations (8) and (9):

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{9}$$

The reference current in abc phase shown in Equation (10) is obtained by applying inverse to equation:

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{10}$$

5. Fuzzy Logic Controller

Figure 5 specifies the Fuzzy Logic Controller (FLC) incorporated in PV system. The behavior of the MPPT system in steady and dynamic state can be improved by adopting fuzzy. The proposed concept of Fuzzy Logic Controller is more beneficial than conventional PI controller by eliminating the problems caused by PI.

Fuzzy logic is one of the new concept given by Zadeh which uses linguistic variables rather than numericals. The FLC structure is represented by Figure 5, principle mechanisms in Fuzzy Controller are:

- Fuzzification.
- Knowledge base.
- Inference Engine.
- Defuzzification.

Inputs for FLC are Error and Change in Error respectively. Error (e) specifies capacitor voltage (V_{dc}), its derivative (V^*_{dc}) corresponds to Change in Error (ce) and output for the controller is considered as maximum current (I_{max}) is shown in Figure 6. Mamdani's fuzzy method is used for implementing proposed controller. To specify fuzzy input/output variables triangular membership function having the linguistic variables VL, L, Z, H, VH are considered. Both the inputs have 5 subsets. So, 25 rules are formed by if-then statements. Table 1 specifies the rule base formulated for the proposed topology.

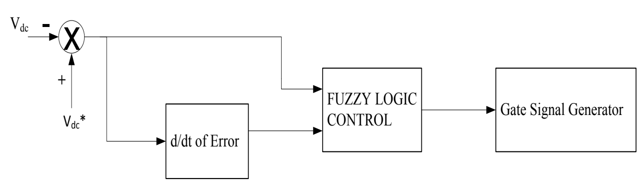


Figure 5. Fuzzy logic control scheme.

Table 1. Fuzzy rule base formation

Error→ Change in error ↓	VL	L	Z	H	VH
VL	VL	VL	VL	H	VH
L	VL	L	Z	H	VH
Z	VL	Z	Z	H	VH
H	VL	H	H	H	H
VH	VL	VH	VH	VH	VH

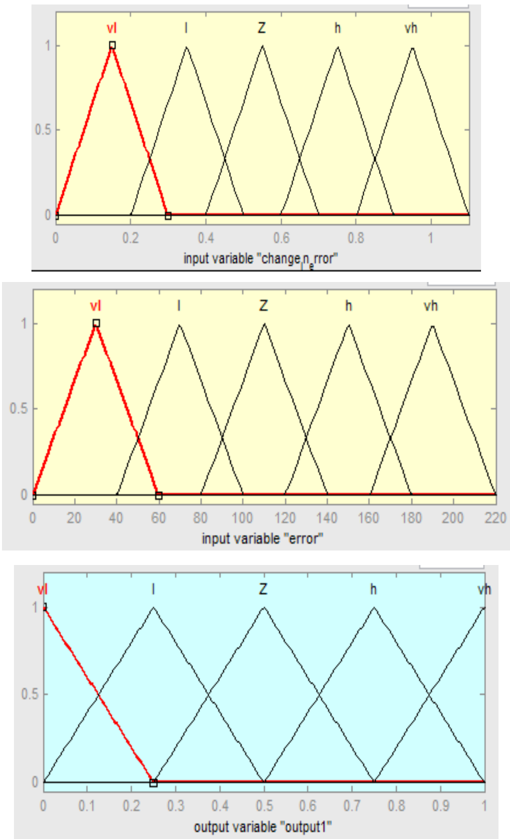


Figure 6. Input and output variable.

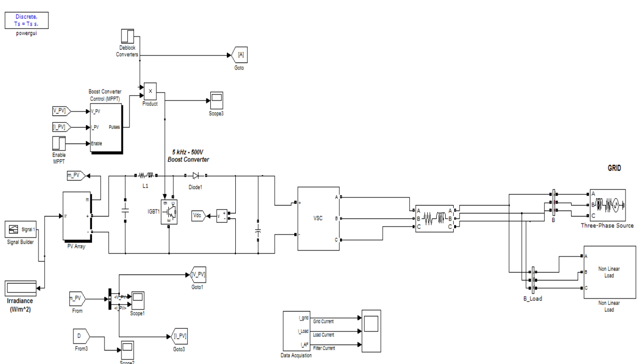


Figure 7. MATLAB design of PV-APF system with PI controller.

6. Simulation Diagram and Results

The simulation diagram of PV-APF combination is shown in Figure 7.

The overall simulation for the entire system is performed in a total time period of 0.75 sec which is divided into following operational techniques. The period from 0.05 to 0.35 sec corresponds to VSC dq-current controller without MPPT, 0.35 to 0.5 sec corresponds to VSC dq-current controller with MPPT, 0.5 to 0.6 sec corresponds to PV-APF mode and 0.6 to 0.7 sec is APF mode and rest all i.e 0.7 to 0.75 sec is considered as utility.

Case 1: Proposed PV-APF combination with Conventional PI Controller.

Through proper evaluation from Figure 8 we can conclude that among all techniques when PV-APF is turned on at 0.5 seconds, the harmonics coming from nonlinear load are distorted out effectively thereby grid current waveforms become sinusoidal.

The detailed analysis of currents in various operating techniques with PI Controller is evaluated by FFT as shown in Figure 9.

After thorough analysis we can conclude that among four techniques, the PI based PV-APF technique is ultimate with reduced THD of 4.37%.

Case 2: Proposed PV-APF combination with Fuzzy Controller.

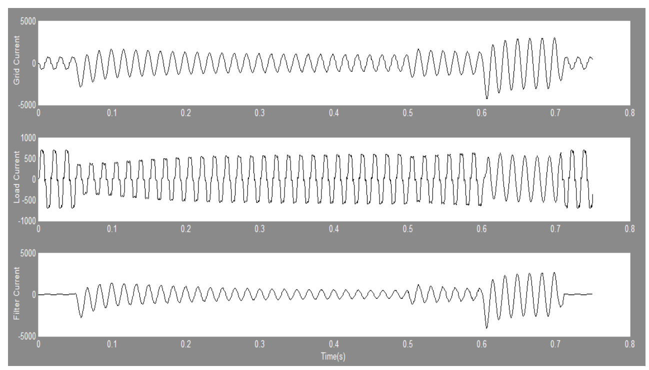
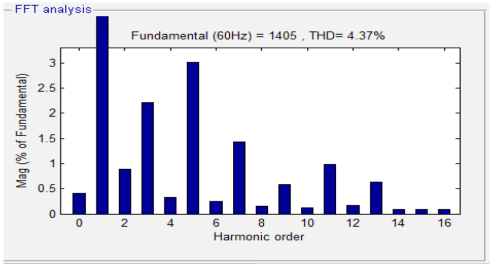


Figure 8. Simulation results for APF with PI Controller (a) Grid current. (b) Load current. (c) Filter current.

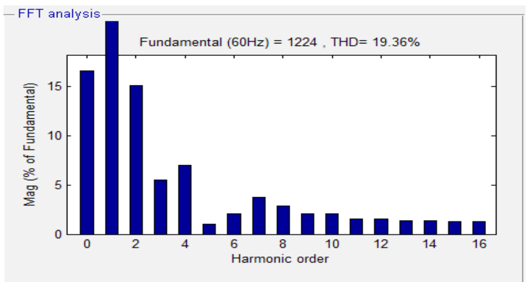
After proper evaluation from Figure 10 we can conclude that among all the modes the PV-APF technique at 0.5 seconds compensate the harmonics coming from nonlinear load there by grid current waveforms become sinusoidal.

The complete study of currents among different operating techniques with Fuzzy Controller are examined through FFT as shown in Figure 11.

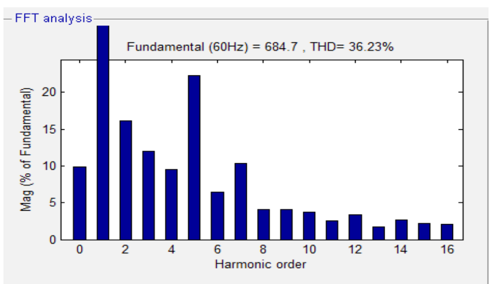
After detailed analysis we can conclude that among all techniques, the fuzzy based PV-APF mode is considered as best with minimum of 3.68%.



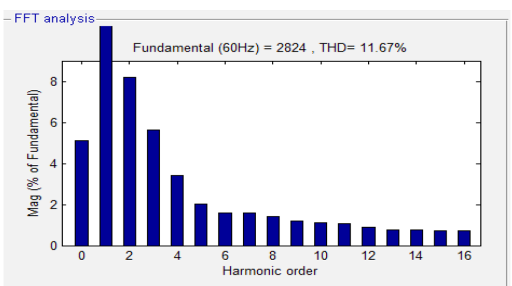
1) dq- current technique



2) PV- APF technique



3) APF technique



4) Considering utility

Figure 9. FFT analysis of grid current in various modes with PI controller.

Table 2. Evaluation of %THDs

Modes→ Type↓	d-q Current (0.49sec)	PV-APF (0.56sec)	APF (0.69sec)	Utility (0.71sec)
PI	19.36	4.37	11.67	36.23
FUZZY	16.03	3.68	11.04	30.60

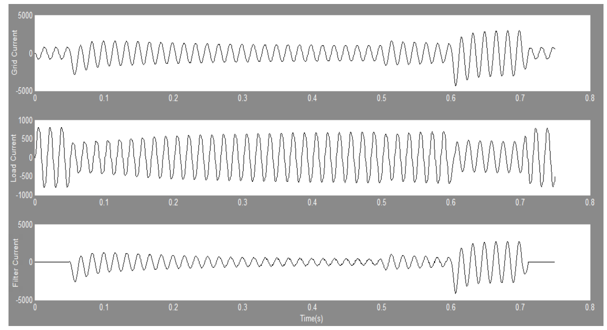
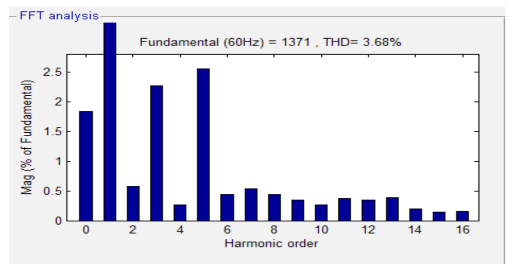
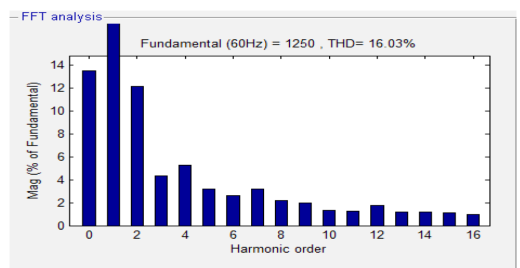


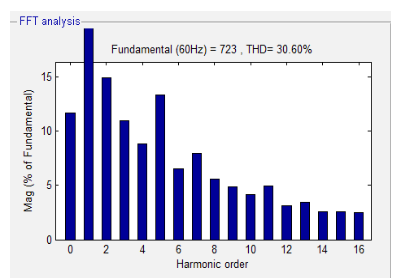
Figure 10. Simulation results for APF with Fuzzy Controller (a) Grid current. (b) Load current.(c) Filter current.



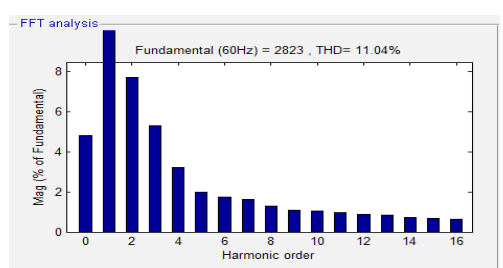
1) dq- current technique



2) PV- APF technique



3) APF technique



4) Considering utility

The comparison of THD for various operating techniques of VSC with both PI and fuzzy based controller are illustrated in the following Table 2.

From the table compared to PI the THD of fuzzy based PV-APF combination is reduced to 3.68% hence it is effective.

7. Conclusion

The proposed system includes a PV array with active power filter. Based on observations made, we can conclude that proposed system is competent for maximum power extraction by Incremental conductance method, because in this method the panel terminal voltage is varied in accordance with the MPP voltage there by offering effective performance under varying meteorological conditions. To regulate the DC voltage here PI, Fuzzy Controllers are developed and verified. From the analysis of both the controllers for current harmonic compensation it is observed that FLC shows better performance over PI controller. Additionally the control approach by p-q theory is useful for generation of reference currents in the system due to its advantage that here the "θ" angle is derived directly from main voltage, hence it is frequency independent thus avoiding large number of problems related to synchronization. Thus with p-q theory and fuzzy logic an ideal APF can be developed which can be used effectively for current harmonic reduction.

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