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FUZZY LOGIC CONTROLLER BASED THREE PHASE SHUNT ACTIVE POWER FILTER FOR HARMONICS REDUCTION WITH ID-IQ CONTROL STRATEGY

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Abstract: For the elimination of current harmonic in power system, Shunt active power filter is a complete current source. Its performance depends on the topology of inverter used in the design, control technique, and strategy employed in reference current generation. In this study, fuzzy logic current control technique is used for generation of pulses of the three phase inverter. A band pass filter is mainly required in synchronous reference frame algorithm (SRF) or Id-Iq theory for harmonics extraction. Under balanced voltage condition the shunt active power filter performance is evaluated with MATLAB/SIMULINK. The result are good and gives satisfactory response in elimination of the harmonics.

Keywords—PI controller, Shunt active power filter, synchronous reference frame, voltage source converters, Pulse with modulation, fuzzy logic controller, linear and nonlinear loads.

I. INTRODUCTION

Power quality is greatly influenced by nonlinear loads i.e. power electronic equipment, electrical drives, welders, energy saving lamps, ovens etc., leads to injection of harmonics in distribution system. Disturbed power quality results improper function of devices, which leads in spurious tripping of protective devices, overheating of rotating machinery, etc. This problem can be solved by installation of power quality improvement devices [1-3]. For the mitigation of this power quality issue, passive power filter is a traditional harmonic mitigation method. But it has certain disdavantage as it fails to eliminate all of the harmonics.

and has many drawbacks including heavy weight, and bulky sizes , problem of series or parallel resonance with the system impedance, sensitivity against system parameter variation [3-6]. The important components while designing of any shunt active power filter is control strategy, inverter topology and current control method used in the generation of pulse for the inverter [7]. synchronous reference frame (SRF) theory or d-q theory [11-12] widely used in three phase system of extraction of reference current from the load harmonics current, due to its simplicity and easy implementation as compared other many methods. for obtaining good accuracy and dynamics in SRF method numerical filtering method play very important role. Fuzzy logic controller is proposed in this study for current control of the three phase voltage source inverter(VSI). Under balanced voltage condition, the output performance of shunt active power filter is simulated with MATLAB/SIMULINK.

II. SHUNT ACTIVE POWER FILTER

Fig. 1 shows the basic block diagram of the SAPF. Shunt active power filter has the capability for compensating load harmonics currents and reactive power requirement of the nonlinear loads[8]. Shunt active filter is connected in parallel to the power system network at a point of common coupling (PCC) as shown in fig 1.

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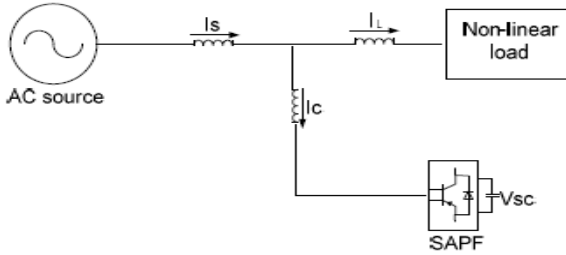29th -30th, Jan. 2016

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Fig. 1 Shunt active power filter(SAPF)

III. SYNCHRONOUS REFERENCE FRAME METHOD

For extraction of reference current, Synchronous reference frame detection method or Id-Iq method is used. Fig. 2 shows its general block diagram.
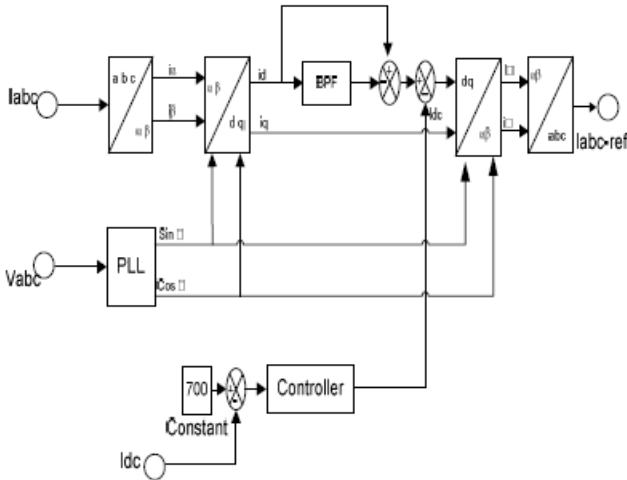

Fig. 2 Block diagram of Id-Iq method

SRF method contains filtering devices such as band pass filter (BPF). In SRF method supply current i_a, i_b, i_c are transformed to two phase ($\alpha - \beta$) stationary reference frame current $i\alpha$ and $i\beta$ as shown in equation 1.

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

PLL is required to generate sine and cosine signals needed to be synchronised with various phase to neutral voltages [9-10].

In d-q reference frame, the current expression is given by;

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \sin(\theta) & -cos(\theta) \\ cos(\theta) & sin(\theta) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad 2$$

Where θ phase angel of voltages.

Band pass filter is used convert harmonics with the DC quantities in to non-DC quantities.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \overline{i_d} & id \\ \overline{i_q} & i_q \end{bmatrix} \qquad 3$$

Thus i_α and i_β are obtained as given below:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \sin(\theta) & -cos(\theta) \\ cos(\theta) & sin(\theta) \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \qquad 4$$

The reference current $i_{\alpha\text{-ref}}$ and $i_{\beta\text{-ref}}$ is given by

$$\begin{bmatrix} i_{\alpha-ref} \\ i_{\beta-ref} \end{bmatrix} = \begin{bmatrix} \sin(\theta) & -cos(\theta) \\ cos(\theta) & sin(\theta) \end{bmatrix} \begin{bmatrix} \tilde{i_d} + i_{dc} \\ \tilde{i_q} \end{bmatrix} \qquad 5$$

Finally in the abc reference frame the current are given as

$$\begin{bmatrix} i_{a-ref} \\ i_{b-ref} \\ i_{c-ref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{\alpha-ref} \\ i_{\beta-ref} \end{bmatrix} \qquad 6$$

IV. PI CONTROLLER

The control circuit with PI controller is shown in Fig 3. As shown in fig 3 the conventional PI controller control strategy includes PI controller with hysteresis limiter, and a three phase sine wave generator for the generation of reference current and switching signal. The peak value of the reference current is estimated by adjusting the DC link voltage. error signal is obtained by comparing The actual capacitor voltage value with the set reference DC voltage value and it is processed through a PI controller which helps to the zero steady state error in tracking the reference current signal.
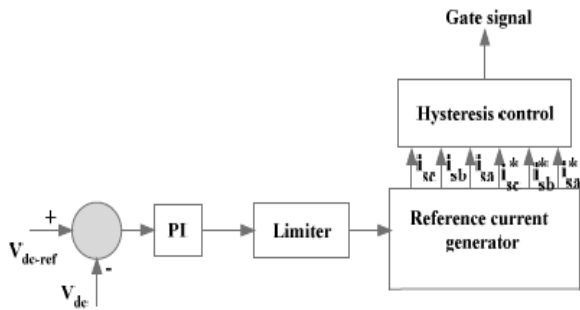
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Fig. 3 conventional PI controller

The average capacitor voltage is maintained at a constant value, by multiplying peak value of the current (Imax) and the unit sine vectors in phase with the respective source voltages to obtain the reference compensating currents. error signal for the modulation technique is evaluted by comparing estimated reference currents and the actual sensed compensating current in a hysteresis limiter.

V. FUZZY LOGIC CONTROLLER

Fuzzy logic technique gives an improved performance of switching pulse for voltage source inverter than PI controller. Fuzzy control depends on logical system that involves the set of simple linguistic rules called fuzzy logic for the determination of control action[8]. The internal control circuit with fuzzy controller is shown in fig 4. It consist of two inputs [11, 12] namely error (e) and change in error (Δe) and one output.
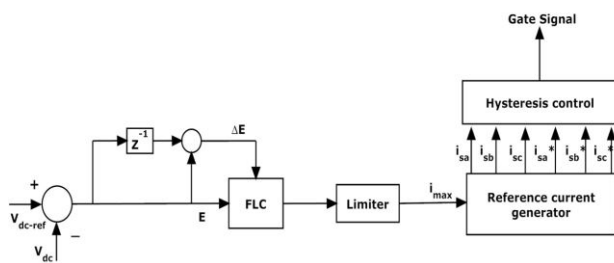

Fig. 4 control circuit with fuzzy controller

The error signal is the difference between current I_{ref} and actual current I_{inv} of VSI for each phase.

$$Error = I_{inv} - I_{ref} \qquad 7$$

The error signal is processed through a Fuzzy controller, which helps to gain zero steady error in tracking the reference current signal. Input voltage V_{dc} which is propotional to actual current of VSI and the input reference voltage $V_{dc\text{-}ref}$ which is propotional to reference current are given to differentiate block as a input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the Current limiter. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as:

NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in fig 5. The fuzzy controller is characterized as follows:

1. Seven fuzzy sets for each input and output;
2. Fuzzification using continuous universe of discourse;
3. Implication using Mamdani's 'min' operator;
4. De-fuzzification using the 'centroid' method.
   Fuzzification: the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.
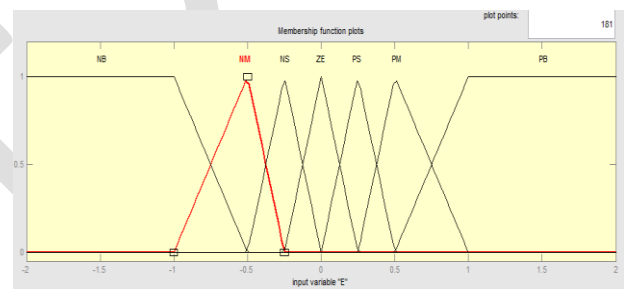

Fig. 5. a) Input Variable Error 'E' Membership Function using Id-Iq Theory
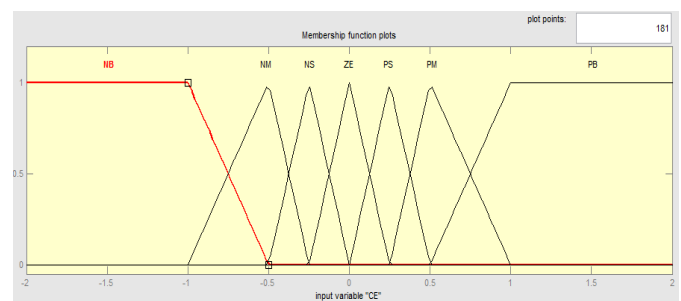

Fig. 5. b) Input Change in Error (ΔE) Normalized MF using Id-Iq Theory
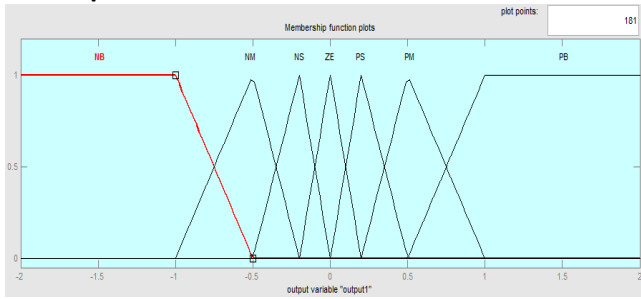
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Fig. 5. c) Output Imax Normalized Membership Function using Id-Iq Theory

Table 1 Rule Table for Fuzzy Logic Controller

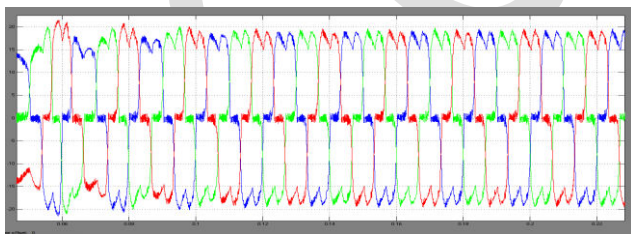| E \ ΔE	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

VI. RESULTS AND DISCUSSION

Fig. 6.1 Simulation result of Load Current using Id-Iq Theory

Fig. 6.1 shows simulation result of nonlinear load which contains harmonics and due to nonlinear load there is harmonics also in source side. Due to that harmonic, distortion in current waveform on source side and system is not stable
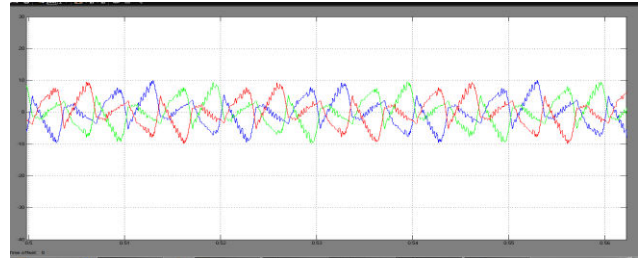

Fig. 6.2 Simulation result of filter Current using Id-Iq Theory

Fig. 6.2 shows simulation result of filter current which is used for compensation of harmonics by using Id-Iq Theory. In this case the shunt active power filter operates as a current source which injects the harmonic components which are phase-shifted by 180° to the load harmonics.
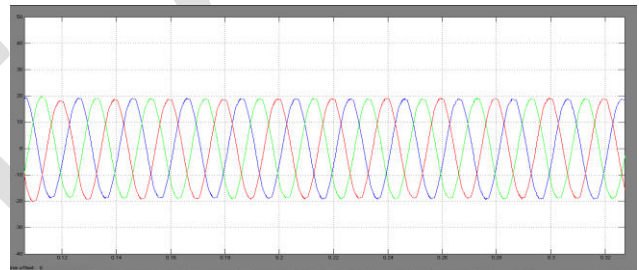

Fig. 6.3 Simulation result of Source Current using Id-Iq Theory with PI Controller

Fig. 6.3 shows simulation result of source current after compensation of harmonics with the help of active filter by using PI controller with Id-Iq Theory. Shunt active power filter is controlled such that it contributes to making the source current in phase with the source voltage. By using PI controller we try to make source current sinusoidal which is shown above.
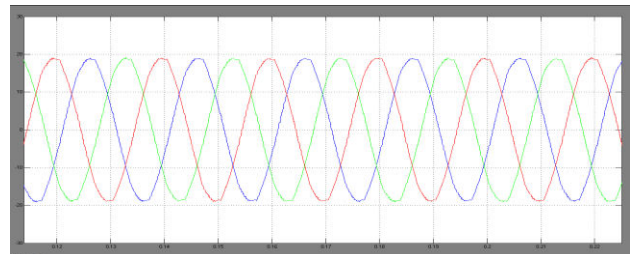

Fig. 6.4 Simulation result of Source Current using Id-Iq Theory with Fuzzy Logic Controller

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Fig. 6.4 shows simulation result of source current after compensation of harmonics with the help of active filter by using fuzzy logic controller with Id-Iq Theory.By using fuzzy logic controller we try to make source current sinusoidal and while we compare with PI controller fuzzy gives better response than PI controller which is shown above
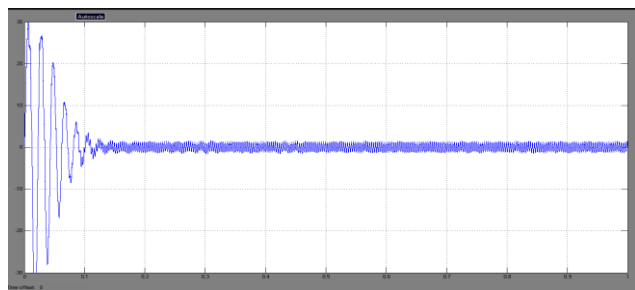

Fig. 6.5 Simulation results of voltage across capacitor by using Id-Iq Theory with PI Controller

Fig. 6.5 shows simulation result of voltage across DC side capacitor during the compensation of harmonics with the help of Shunt active power filter by using PI controller with Id-Iq Theory. In this case, system gives oscillatory behaviour during transient period i.e. at starting and settles down after specific time.
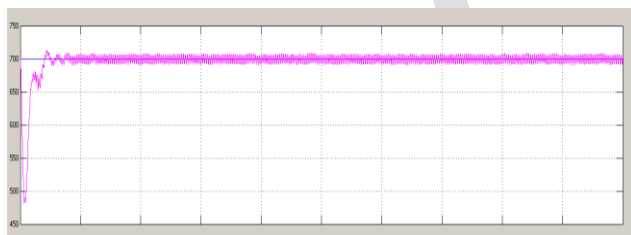

Fig. 6.6 Simulation results of voltage across capacitor by using Id-Iq Theory with Fuzzy Logic Controller

Fig. 6.6 shows simulation result of voltage across DC side capacitor during the compensation of harmonics with the help of Shunt active power active filter by using Fuzzy logic controller with Id-Iq Theory. In this case, system produces less oscillation at starting and settles down within short period as compared to PI controller. Steady state response using Fuzzy logic controller is better as compared to PI controller.
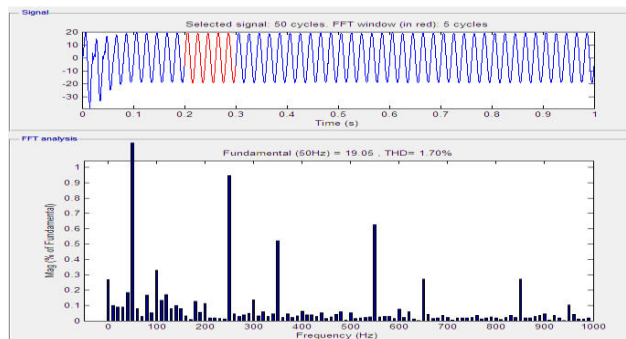

Fig. 6.7 Simulation results of FFT Analysis to show Total Harmonic Distortion by using Id-Iq Theory with PI Controller

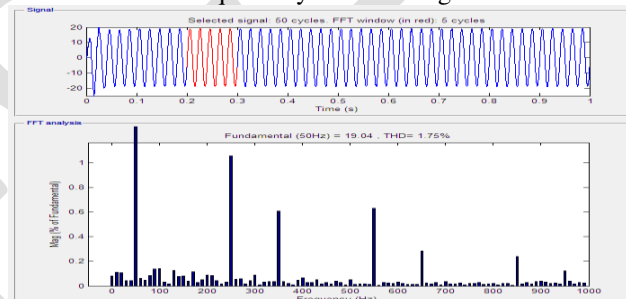Fig. 6.7 shows simulation FFT window by using PI controller with Id-Iq Theory and showing %THD is 1.70.

Fig. 6.8 Simulation results of FFT Analysis to show Total Harmonic Distortion by using Id-Iq Theory with Fuzzy Logic Controller

Fig. 6.8 shows simulation FFT window by using fuzzy logic controller with Id-Iq Theory and showing %THD is 1.75.

Table 2 Comparison of PI and Fuzzy Logic Controller

No.	Parameter	PI Controller	Fuzzy Logic Controller
1	Transient Response	Good	Better
2	Undershoot and overshoot	More	Less
3	Steady State Response	Good	Better
4	% Error	Less	Slightly less than PI Controller
5	Load current	Same	Same
6	Settling time	More	Less

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VII CONCLUSION

This paper presents an overview of Instantaneous Power and Current Strategies for Current Harmonics Cancellation using Shunt Active Power Filter with PI and fuzzy logic controllers. The controllers PI and fuzzy logic under balanced, unbalanced, non-sinusoidal control has to be validated for Shunt Active Power Filter (SAPF).Comparison of controllers with PI and fuzzy logic will be made based on certain performance parameters.

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