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SYNCHRONOUS REFERENCE SCHEME TO IMPROVE THE ACTIVE POWER FILTER PERFORMANCE BY USING FUZZY CONTROLLER

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***Abstract*— This paper proposes an active power filter implemented with a four leg voltage-source inverter to reduce the harmonics in three phase four wire system. The use of a four-leg voltage-source inverter allows the compensation of current harmonic components, as well as unbalanced current generated by single- phase non-linear loads. A detailed analysis of DQ (Synchronous Reference Frame) based Current Reference Generator scheme for extracting reference current of shunt active power filter by using fuzzy logic controller is presented. Fuzzy logic technique reduces computational efforts. Proposed control scheme offers an efficient method for reduction of total harmonic distortion. Simulation results of proposed active power filter using fuzzy logic controller has been carried out in MATLAB/SIMULINK.**

***Index Terms*— Active Power Filter, Current Control, Four-leg Converters, Fuzzy Controller.**

I. INTRODUCTION

The widespread use of non-linear loads is leading to a variety of undesirable phenomena in the operation of power systems. The harmonic components in current and voltage waveforms are the most important among these. Conventionally, passive filters have been used to eliminate line current harmonics. However, they introduce resonance in the power system and tend to be bulky. So active power line conditioners have become more popular than passive filters as it compensates the harmonics and reactive power simultaneously. The active power filter topology can be connected in series or shunt and combinations of both. Shunt active filter is more popular than series active filter because most of the industrial applications require current harmonic compensation. Different types of active filters have been proposed to increase the electric system quality; a generalized block diagram of active power filter is presented in Fig 1. The classification is based on following criteria. - Power rating and speed of response required in compensated system. - System parameters to be compensated (e.g. current harmonics, power factor voltage harmonics). - Technique used for estimating the reference current/voltage. Current controlled voltage source inverters can be utilized with an appropriate control strategy to perform an active filter functionality. One of the most common problems when connecting small renewable energy systems to the electric grid concerns the interface unit between the power sources and the grid, because it can inject harmonic components that may deteriorate the power quality [1], [2]. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality power. In [3] an inverter operates as active inductor at a certain frequency to absorb the harmonic current. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in the distribution network is proposed in [4],[5].

II. FOUR LEG CONVERTER MODEL

The proposed system consist of RES connected to the dc link of grid interfacing inverter as shown in Fig 1.VSI interfaces RES to the grid and delivers generated power. The RES may be DC source or an AC source with rectifier connected to DC link.

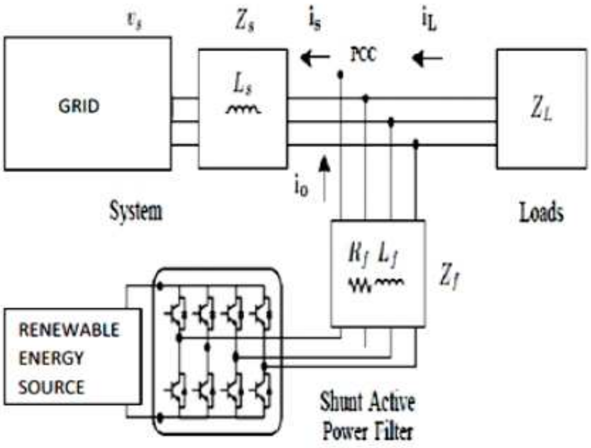

Fig. 1 Schematic diagram of renewable based distributed generation system.

Power generated from these RES needs power conditioning before connecting on dc-link [6]-[8].

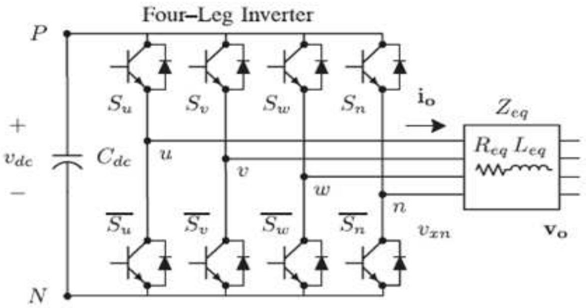

Fig. 2 Two-level four-leg VSI topology

The four-leg PWM converter topology is shown in Fig 2. This converter topology is similar to the conventional three phase converter with the fourth leg connected to the neutral bus of the system. The voltage in any leg x of the converter, measured from the negative point of the dc-voltage (N), can be expressed in terms of switching terms as follows,

$$V_{xn} = S_x - S_n V_{dc} \qquad x=u, v, w, n \qquad (1)$$

The mathematical model of the filter derived from equivalent circuit as shown in Fig 1 is,

$$V_0 = V_{xn} - R_{eq} i_0 - L_{eq}\frac{di_0}{dt} \qquad (2)$$

Where, Req and Leq are the VSI output parameters expressed as Thevenin impedances at the converter output terminals Z_{eq} .Therefore, the Thevenin equivalent impedance is determined by a series connection of the ripple filter impedance Z_f and a parallel arrangement between the system equivalent impedance Z_s and the load impedance.

$$Z_{eq} = \frac{Z_S\, Z_L}{Z_S + Z_L} + Z_f \qquad (3)$$

For this model, it is assumed that $Z_L >> Z_s$, that the resistive part of the system’s equivalent impedance is neglected, and that the series reactance is in the range of 3-7% percent p.u., which is an acceptable approximation of the real system. Finally, in Equation (3) $R_{eq} = R_f$ and $L_{eq} = L_s + L_f$.

III. CURRENT REFERENCE GENERATION

A dq-based current reference generator scheme [9]-[14] is used to obtain the active power filter current reference signals. This scheme presents a fast and accurate signal tracking capability. This characteristic avoids voltage fluctuations that deteriorate the current reference signal affecting compensation performance. The current reference signals are obtained from the corresponding load currents as shown in Fig 3. This module calculates the reference signal currents required by the converter to compensate reactive power, current harmonic, and current imbalance.

The displacement power factor and maximum total harmonic distortion of the load defines the relationship between apparent powers required by the active power filter, with respect to the load as shown:

$$\frac{S_{APF}}{S_L} = \frac{\sqrt{\sin\emptyset\,(L) + THD(L)^2}}{\sqrt{1 + THD(L)^2}} \qquad (4)$$

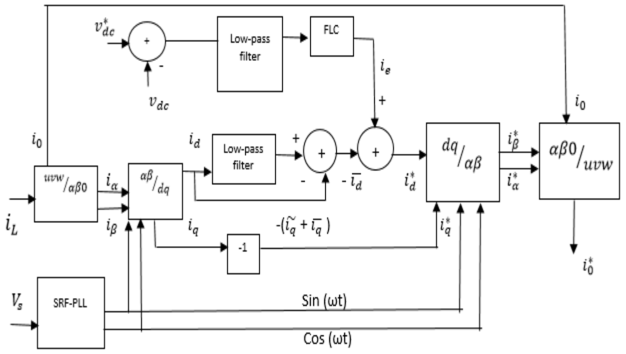

Fig. 3 dq-based current reference generator block diagram

where the value of $THD_{(L)}$ includes the maximum compensable harmonic current, defined as double the sampling frequency f_s .The frequency of the maximum current harmonic component that can be compensated is equal to one half of the converter switching frequency. The dq-based scheme operates in a rotating reference frame [15]-[17]; therefore, the measured currents must be multiplied by the sin (ωt) and cos (ωt) signals. By using dq-transformation, the d current component is synchronized with the corresponding phase-to- neutral system voltage, and the q current component is phase- shifted by 90 degree. The sin (ωt) and cos (ωt) synchronized reference signals are obtained from a synchronous reference frame (SRF) PLL. The SRF-PLL generates a pure sinusoidal waveform even when the system voltage is severely distorted. Tracking errors are eliminated, since SRF-PLLs are designed to avoid phase voltage unbalancing, harmonics (i.e., less than 5 and 3% in fifth and seventh, respectively), and offset caused by the nonlinear load conditions and measurement errors. Equation (5) shows the relationship between the real currents i_{Lx}(t) and the associated dq components.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} \sin\omega t & \cos\omega t \\ -\cos\omega t & \sin\omega t \end{bmatrix}\begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} \qquad (5)$$

A low-pass filter (LFP) extracts the dc component of the phase currents id to generate the harmonic reference components i_d the reactive reference components of the phase-currents are obtained by phase-shifting the corresponding ac and dc components of i_q by 180° . In order to keep the dc-voltage constant, the amplitude of the converter reference current must be modified by adding an active power reference signal i.e. with the d-component. The resulting signals i_d^* and i_q^* are transformed back to a three-phase system by applying the inverse park &Clark transformation. The cutoff frequency of the LPF used in this paper is 20 Hz. The current that flows through the neutral of the load is compensated by injecting the same instantaneous value obtained from the phase-currents, phase-shifted by 180° as shown in equation 7.

$$\begin{bmatrix} i^*_{ou} \\ i^*_{ov} \\ i^*_{ow} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin\omega t & -\cos\omega t \\ 0 & \cos\omega t & \sin\omega t \end{bmatrix} \begin{bmatrix} i_0 \\ i^*_d \\ i^*_q \end{bmatrix} \tag{6}$$

$$i^*_{on} = -(i_{Lu} + i_{Lv} + i_{Lw}) \tag{7}$$

One of the major advantage of dq based current reference generation scheme is that allow the implementation of a linear controller in a dc voltage control loop. One important disad- vantage of the dq based current reference frame algorithm used to generate current reference is that second order harmonic is generated under unbalanced operating conditions. The dc voltage converter is controlled by traditional fuzzy controller [20]. This is an important issue in the evaluation, since the cost function is designed using only current reference in order to avoid the weighing factors. The weighing factors are obtained experimentally and they are not well defined when different operating conditions are required. Additionally the slow dynamic response of the voltage across electrolytic capacitor does not affect the transient response. For this reason the fuzzy controller represents a simple and effective alternative for dc voltage control.

IV. FUZZY CONTROLLER

The disadvantage of PI controller is its inability to react to abrupt changes in the error signal ε because it is only capable of determining the instantaneous value of error signal without considering the change of rise and fall of error that is Δε. The fuzzy logic control [18]-[20] is shown in Fig 4.

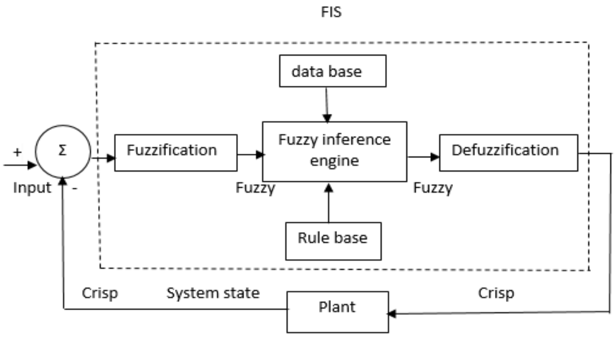

Fig.4 Basic representation of FLC.

In fuzzification crisp values are converted into fuzzy values. The fuzzy inference system used here is mamdani system. The determination of output control signal is done with inference engine with a rule base having if then rules in the form of ”if ε is .... And Δε is.... then output is.... ”.

The value of output is changed according to error signal ε and rate of error signal Δε. The structure and determination of rule base is using trial and error method. All the variable fuzzy subsets for the input ε and Δε are defined as (NB, NM, NS, Z, PS, PM, PB). The membership functions are illustrated in Fig 5, 6 and 7. The fuzzy control rule is illustrated in Table 1.

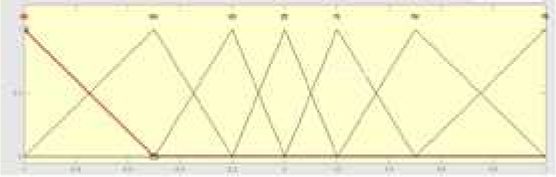

Fig.5 Input membership function ε

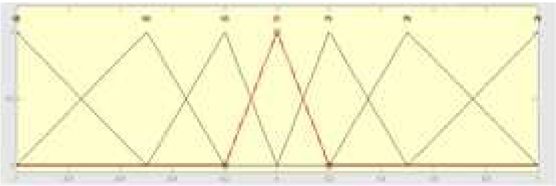

Fig.6 Input membership function Δε

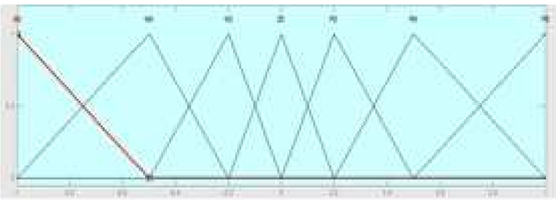

Fig.7 Output membership function

TABLE I: IF-THEN rules for fuzzy logic controller

ε	Δε						
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PM
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

V.SIMULATION RESULT

A simulation model for three phase four leg PWM converter with the parameters shown in Table 2 has been developed using MATLAB- Simulink.

TABLE II: Specification parameters

Variable	Description	Value
V_s	Source voltage	50[Hz]
v_{dc}	dc-voltage	162[V]
C_{dc}	dc capacitor	2200[μF]
L_f	Filter inductor	5.0[mH]

R_f	Internal resistance L_f	0.6[Ω]
T_s	Sampling time	20[μs]
T_s	Execution time	16[μs]

The objective is to verify the current harmonic compensation effectiveness of the proposed control scheme. A six pulse rectifier was used as a non-linear load. In simulated result shown in Fig 8, phase to neutral source voltage at t = 0 to t = 0.8 and Fig 9 shows source currents at t = 0 to t = 0.8.

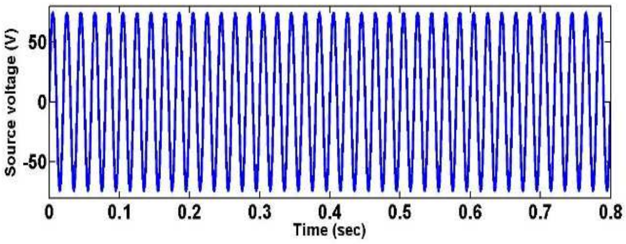

Fig.8 Phase to neutral voltage

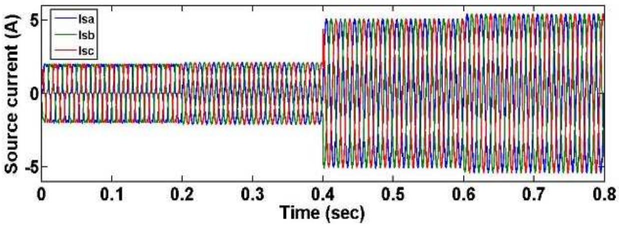

Fig.9 Source currents

As load is non-linear it draws non sinusoidal current, without active power filter compensation shown in Fig 11 and the load current t = 0 to t = 0.4 is shown in Fig 10.

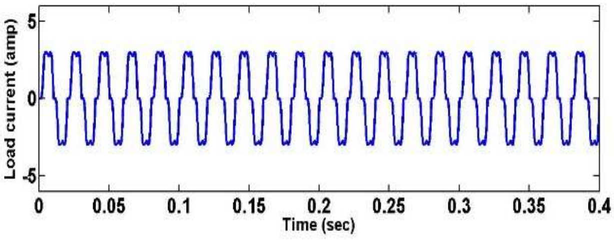

Fig.10 Load current at 0 < t < 0.4

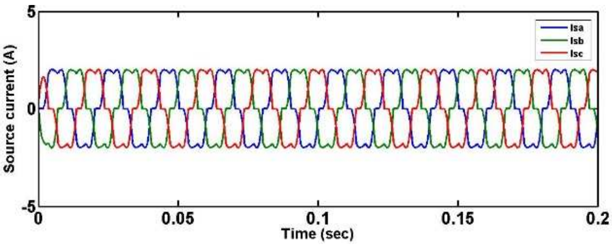

Fig 11 Source current at 0 < t < 0.2

The active filter starts to compensate at t = 0.2. At this time the active power filter injects an output current i_{ou} to compensate current harmonic components, current unbalanced and neutral current simultaneously. During compensation the system current (i_s) is shown in Fig 12 is sinusoidal waveform, with low total harmonic distortion.

At t = 0.4, a three phase balanced load step change is generated shown in Fig 13. The compensated system currents shown in Fig 14 remain sinusoidal despite the change in load current magnitude. Finally at t = 0.6, a single phase load step change is introduced in phase u which is equivalent to 11% current imbalance shown in Fig 15. As expected on the load side, a neutral current flows through a neutral conductor as shown in Fig 16, but on source side no neutral current is observed (i_{sn}) as shown in Fig 17.

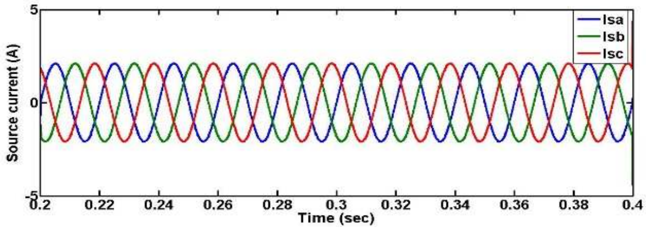

Fig.12 Source currents 0.2 < t < 0.4

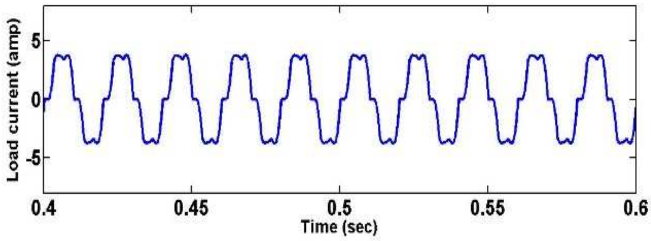

Fig.13 Load currents at 0 < t < 0.4

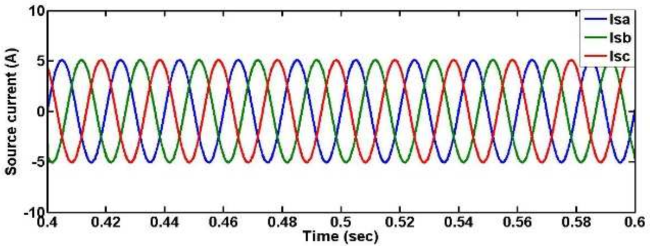

Fig.14 Source currents at 0.4 < t < 0.6

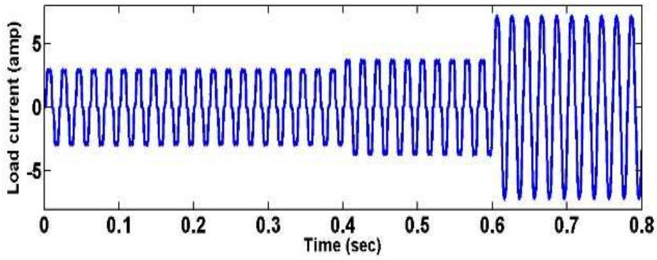

Fig.15 Load current

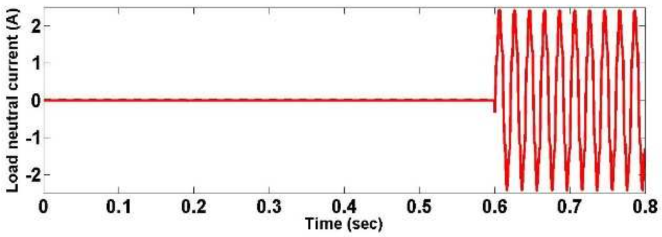

Fig.16 Load neutral current

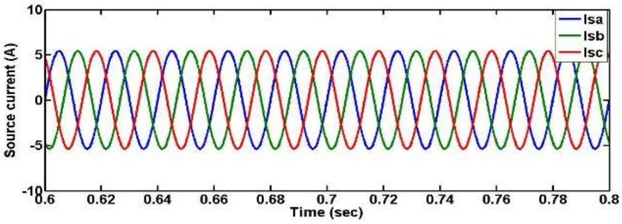

Fig.17 Source current at 0.6 < t < 0.8

The total harmonic distortion values of source current using PI and FUZZY controllers is shown in Table 3.

TABLE III. Performance comparison

SR.NO	Controller	THD (%)
1	with PI	5.83
2	With FLC	0.44

VI. CONCLUSION

Improved dynamics current harmonics and a reactive power compensation scheme for power distribution system with generation from renewable sources has been proposed to improve current quality of distribution system. Advantages of proposed scheme are related to its simplicity, modeling and implementation. Simulated results and THD values of source currents results have been proven that the proposed fuzzy logic control scheme is a good alternative to a classical linear control methods. Simulated results have shown the compensation effectiveness of the proposed active power filter.

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