Performance improving of active power filter in microgrid system by using fuzzy controller

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Abstract— In the distribution system load has been sudden changes and it is like a non-linear loads the use of nonlinear loads creates the problems in the power system such as load harmonics, reactive power and excessive neutral currents. This paper presents an Active Power Filter implemented with a four leg voltage source inverter using dq (synchronous reference frame) based current reference generator scheme is presented. the use of a four-leg voltage source inverter allows the compensation of current harmonic components and also unbalanced current generated by single phase non-linear loads. the grid interfacing can thus be utilized as i)power converter to inject generated power from rest of the grid, and ii)shunts APF to current unbalance, load current harmonics and load reactive power demand the compensation, performance of the active power filter using an fuzzy controller and the associated control scheme under steady state and transient operating condition is demonstrated through simulation results.

Index terms- Active power filter, Four leg converter, fuzzy controller, RES(renewable energy sources).

I. INTRODUCTION

The lots of use of non-linear loads is leading to a variety of undesirable phenomena in the operation of power systems. The components of harmonic in current and voltage waveforms are the most important among these. For eliminate line current harmonics passive filters have been used. However, In the power system they introduce resonance and tend to be bulky. So active power filter have become more popular than passive filters as it compensates the both harmonics and reactive power simultaneously. The active power filter can be connected in series or shunt and combinations of both. Shunt active filter is more popular than series active filter because in many industrial applications require current harmonic compensation. To increase the electric system quality different types of active power filters have been proposed; a generalized active power filter block diagram is presented in [2].The classification is based on following criteria.

Power rating and speed of response required in compensated system.

parameters of the System 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. The electrical grid will include a very large number of small producers that use renewable energy sources, like wind generators or solar panels. One of the most 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 detoriate the power quality [1],[2]. However, the extensive use of power electronics equipment and non-linear loads at PCC generate harmonic currents, which may detoriate the quality power. In [3] an inverter operates as active inductor at a perticular frequency to absorb the harmonic current. A similar approach in which a shunt active filter acts as active conductance in the distribution network to damp out the harmonics which is proposed in[4],[5].

II. FOUR-LEG CONVERTER MODEL

The proposed system consists of RES connected to the Dc link of a grid-interfacing inverter as shown in Figure 1.

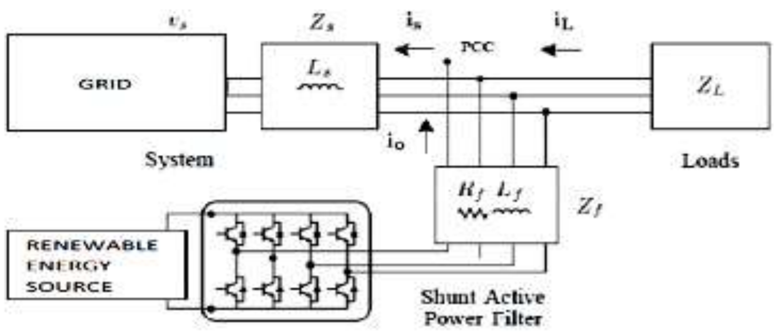

Figure 1. Schematic diagram of renewable based distributed generation system

The key element of a DG system is voltage source inverter as it interfaces the renewable energy sources such as wind and sunlight to the grid and delivers the generated power. The RES may be a AC or an DC source with rectifier coupled to dc-link. Usually, At variable low DC voltages the fuel cell and photovoltaic energy sources generate power, while at variable AC voltage the variable speed wind turbines generate power. The power generated from these renewable energy sources needs power conditioning (i.e., dc/dc or ac/dc) before connecting on dc-link [6]–[8]. The dc-capacitor decouples the RES from grid and also allows independent control of converters on either side of dc-link. The four-leg PWM converter topology is shown in Figure 2.

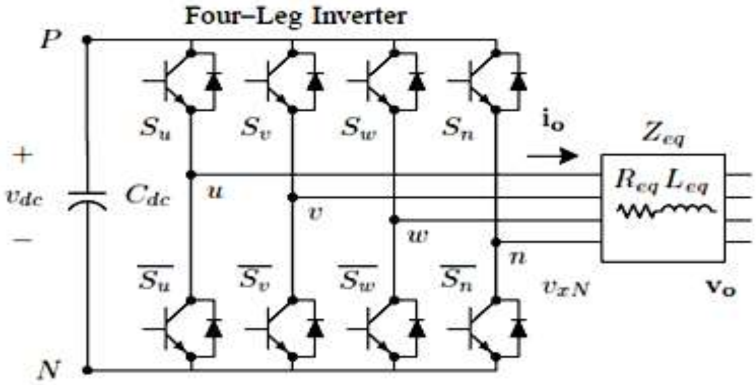

Figure 2. Two-level four-leg PWM-VSI topology

This converter topology is similar to the conventional three converter with the fourth leg connected to the neutral bus of the system. The fourth leg increases switching states from 8 (23) to 16 (24), improving control, flexibility and voltage quality, and is suitable for current unbalanced compensation. The voltage in any leg x of the converter, measured from the negative point of the -voltage (N), can be expressed in terms of switching states, as follows:

$$Vxn = S_x - S_n V_{dc}\,, \qquad x = u, v, w, x \qquad Eq.1$$

The mathematical model of the Active power filter derived from the equivalent circuit which is shown in fig. 2 is

$$v_0 = v_{xn} - R_{eq} i_0 - L_{eq} \frac{di_0}{dt} \qquad Eq.2$$

where $R_{eq}\ and\ L_{eq}$ are the 4L-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 f between the system equivalent impedance Z_s and the load impedance Z_L.

$$Z_{eq} = \frac{Z_s Z_L}{Z_s + Z_L} + Z_f \approx Z_s + Z_f \qquad Eq.3$$

for this model, it is assumed that ZL >> Zs , that is the resistive part of the system's equivalent impedance is neglected, and that the series resistance is in the range of 3-7% p.u., which is an acceptable approximation of the real system. Finally, in equation (2) $R_{eq} = R_f and\ L_{eq} = L_s + L_f$.

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 gives a fast and accurate signal tracking capability. This characteristic avoids the voltage fluctuations from the system that deteriorate the current reference signal affecting compensation performance. The current reference signals are obtained from the corresponding load currents as shown in Figure 3.

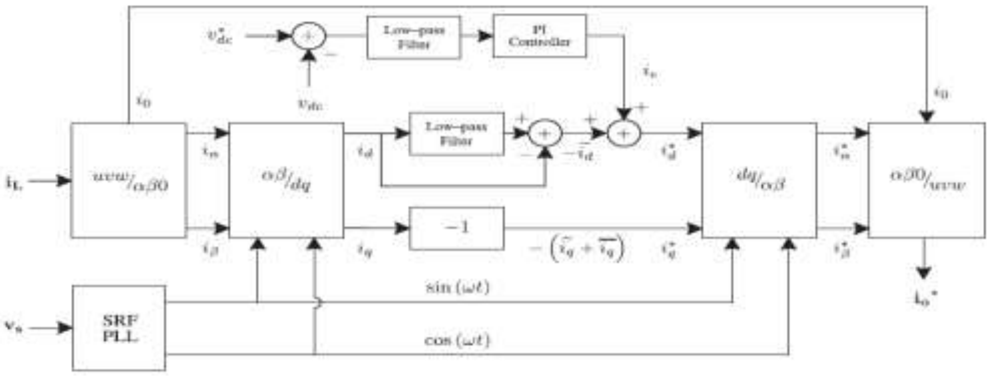

Fig 3. DQ-based Current Reference Generator Block Diagram

This module calculates the reference signal currents required by the converter to compensate reactive power, current harmonic and also current imbalance. The displacement power factor and the maximum total harmonic distortion of the load defines the relationships between the apparent power required by the active power filter, with respect to the load, as shown in below equation.

$$\frac{S_{APF}}{S_L} = \frac{\sqrt{sin\varphi_{(L)}+THD_{(L)}^2}}{\sqrt{1+THD_{(L)}^2}} \qquad \text{Eq. 4}$$

Where the value of $THD_{(L)}$ includes the maximum harmonic current, defined as double the sampling frequency fs. The frequency of the compensated maximum current harmonic component that is equal to two times the converter switching frequency.
The dq-based current reference generator scheme operated in a rotating reference frame[15]-[17]; therefore, the measured currents must be multiplied by the sin(wt) and cos(wt) signals. In a dq transformation, the d current component is synchronized with the corresponding phase-to-neutral system voltage and the q current components are phase-shifted by 90◦. From a Synchronous Reference Frame (SRF) PLL the sin(wt) and cos(wt) synchronized reference signals are obtained. The SRF-PLL generates the pure sinusoidal waveform even when the system voltage is distorted. Tracking errors are eliminated, since SRF-PLLs are designed to avoid unbalancing in the phase voltage, harmonics (i.e. less than 5%th and 3%th in $5^{th} and 7^{th}$respectively), and offset caused by the nonlinear load conditions and measurement errors.

$$\begin{matrix} i_d \\ i_q \end{matrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} sinwt & coswt \\ -coswt & sinwt \end{bmatrix}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix}\begin{matrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{matrix} \qquad \text{Eq. 5}$$

A Low-Pass Filter (LFP) extracts the dc component of the phase-currents i_d to generate the harmonic reference d component i_d. The reactive reference components of the d phase currents are obtained by phase-shifting the corresponding AC and dc components of i_q by 180◦. In q 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 into a three-phase system by applying the inverse Park and 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 below.

One of the major advantages of the dq-based current reference generator scheme is that allows the implementation of a linear controller in the dc-voltage control loop. However, one important disadvantage of the dq-based current reference frame algorithm used to generate the current reference is that a second order harmonic component is generated in i_d and i_q under unbalanced operating conditions. The amplitude of this harmonic depends on the percent of unbalanced load current (expressed as the relationship between the negative sequence current i_L,2 and the positive sequence current i_L,1). The second order harmonic cannot be removed from i_d and i_q , and therefore generates a 3rd harmonic in the reference current when it is converted back to abc frame. Figure shows the percent of system 6rd current imbalance and the percent of 3rd harmonic system current, in function of the percent of load current imbalance [18], [19]. Since the load current does not have a 3rd harmonic, the one generated by the active power filter flows to the power system. By the traditional Fuzzy controller the dc-voltage converter is controlled [20]. This is an important issue in the evaluation, since the cost function is designed using only current references, in order to avoid the use of weighting factors. Generally, these weighting factors are obtained by experimentally, and they are not well defined when different operating conditions are required. Additionally, the slow dynamic response of the voltage across the electrolytic capacitor does not affect the current transient response. For this reason, the Fuzzy controller represents a effective and simple alternative for the dc-voltage control.

IV. FUZZY CONTROLLER

PI controller is only capable of determining the instantaneous value of the error signal without considering the change of the rise and fall of the error The disadvantage of PI controller is its inability to react to abrupt changes in the error signal, ε, in mathematical the term derivative of the error denoted as Δε. PI controller has many disadvantage. To solve this problem Fuzzy logic control is used [21] as it is shown in Figure 4 is proposed.

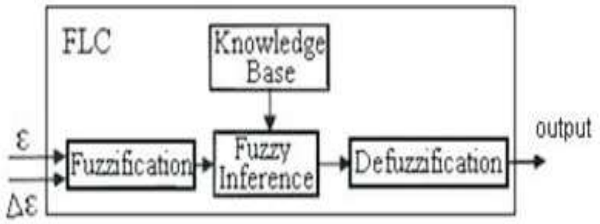

Figure 4. Basic representation of FLC

The determination of the output control signal, is done with an inference engine with a rule base having if-then rules in the form of
"IF ε is .... AND Δε is ...., THEN output is ...."
With the help of rule base, the value of the output is changed according to the value of the error signal ε, and the rate-of-error Δε. The structure determination of the rule base is using trial-and-error methods and also done through experimentation.
All the variable' of fuzzy subsets for the inputs ε and Δε are defined as (NB, NM, NS, Z, PS, PM, PB). The fuzzy control rule base is illustrated in the Table I.

Table.1 FLC Rule Base

ε	$\Delta\varepsilon$						
	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. SIMULATED RESULTS

A simulation model for the three-phase four-leg PWM converter with the parameters shown in Table 2 which has been developed using MATLAB-Simulink. The main objective of this is to verify the current harmonic compensation effectiveness of the proposed control scheme under different operating conditions. A non-linear load was used as a six pulse rectifier.
In the simulated results shown in Figures 8-15, the active power 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 currents show sinusoidal waveform, with low total harmonic distortion. At t =0.4, a three-phase balanced load step change is generated from 0.6 to 1.0 p.u.

Table 2. Specification parameter

Variables	Description	Value
Vs	Source voltage	55[V]
F	System frequency	50[Hz]
Vde	de-voltage	162[V]
Lf	Filter inductor	5.0[mH][0.5 pu]
Rf	Internal resistance within Lf	0.6[x]
Ts	Sampling time	20[Us]
Tc	Execution time	16[Us]

The compensated system currents remain sinusoidal despite the change in the load current magnitude. Finally, at t=0.6, a single-phase load step change is introduced in phase u from 1.0 to 1.3 p.u., which is equivalent to an 11% imbalance of current. As expected on the load side, a neutral current flow through the neutral conductor (iLn), but on the source side,there is no neutral current observed (isn).

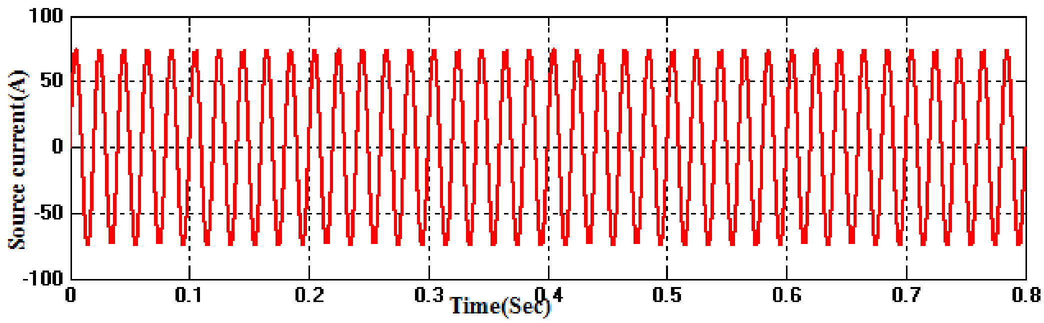

Figure 5. Phase to neutral source voltage

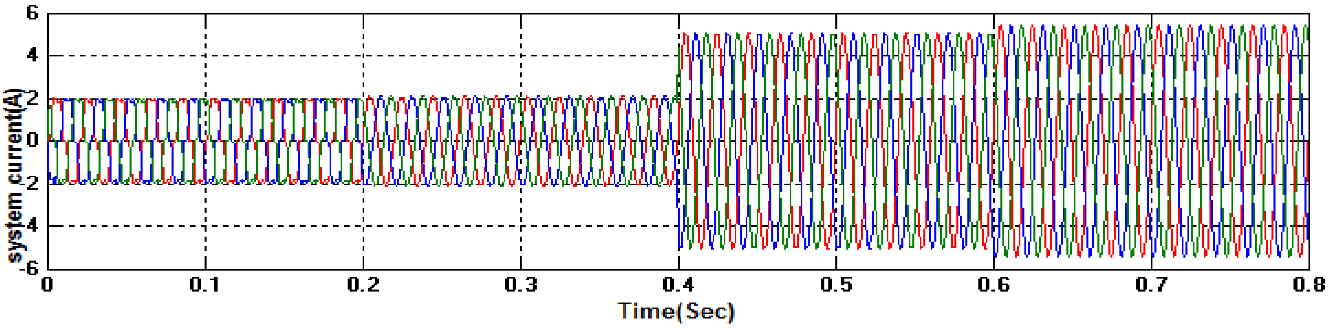

Figure 6. Source current

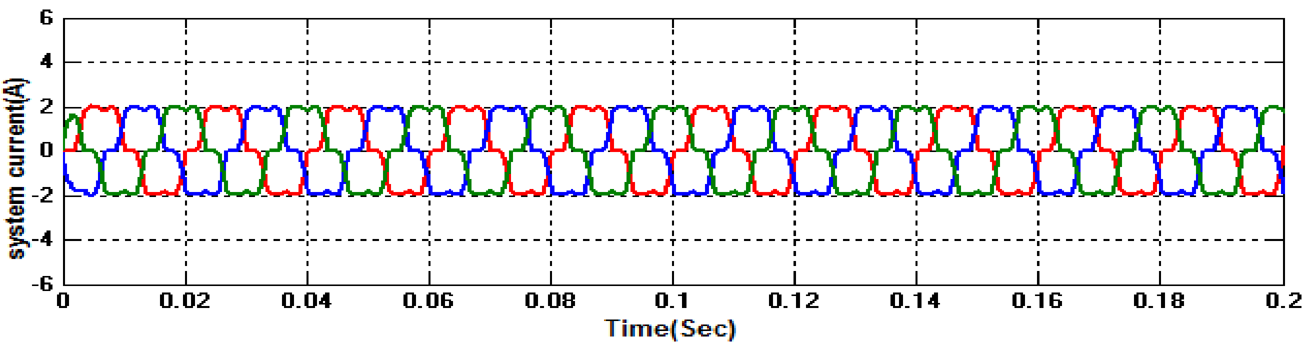

Figure 7. Source current at 0<t<0.2

Simulated results have shown the compensation effectiveness of the proposed active power filter. Above figures show that the proposed control scheme effectively eliminates unbalanced currents. The dc-voltage remains stable throughout the active power filter operation.

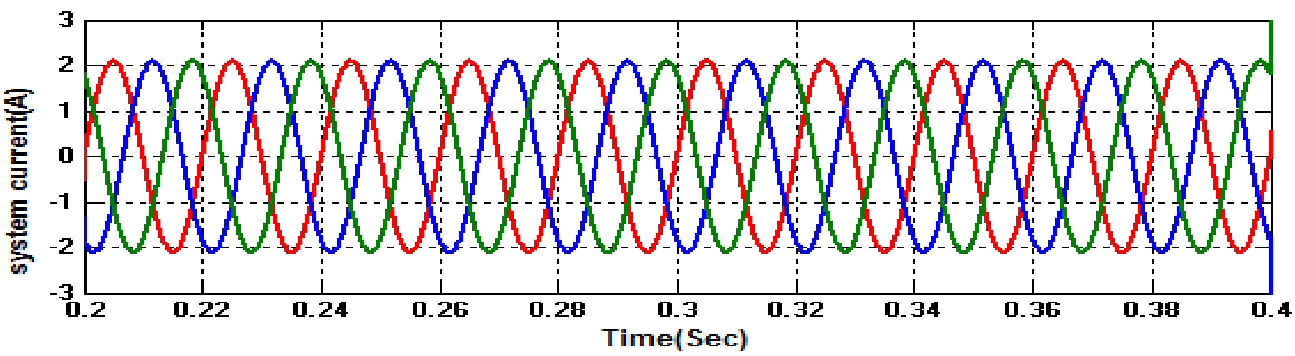

Figure 8. Source current at 0.2< t < 0.4

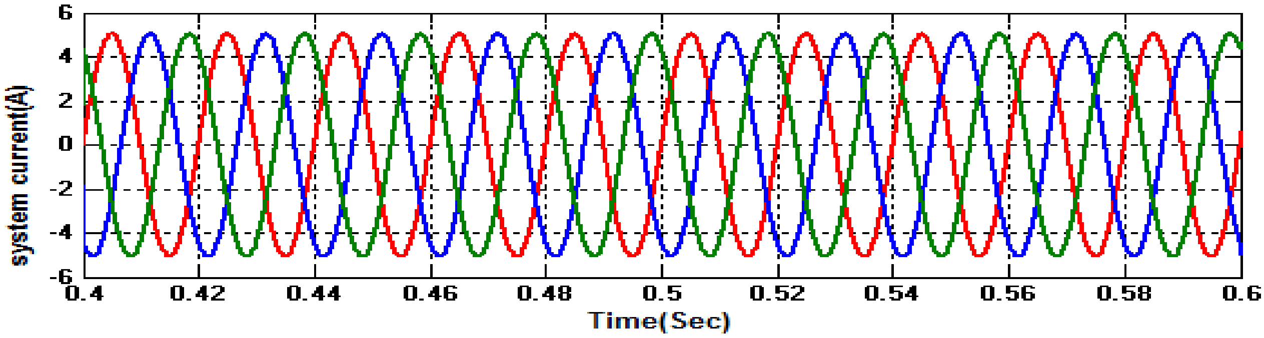

Figure 9. Source current at 0.4 < t < 0.6

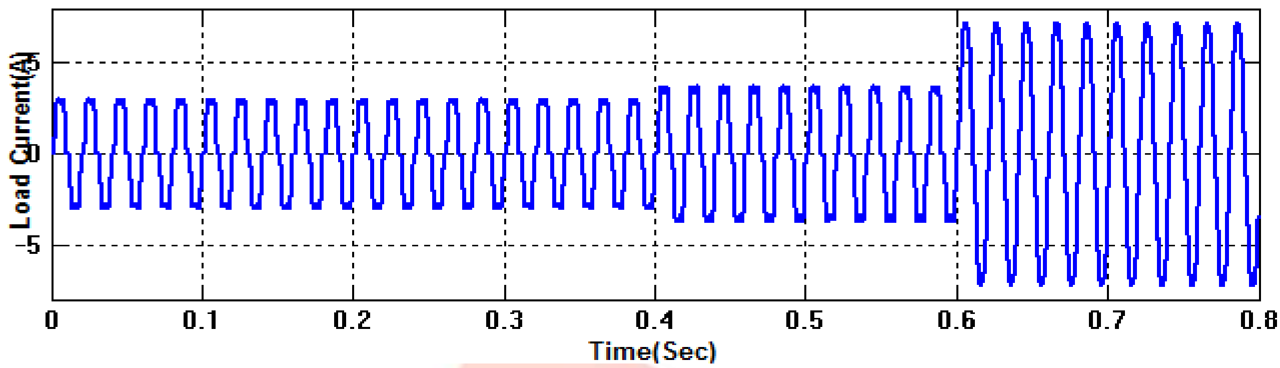

Figure 10. Load current

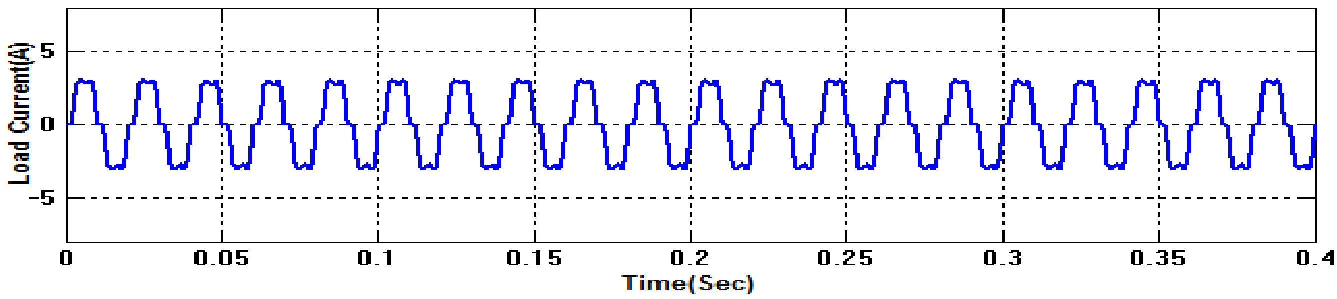

Figure. 11 load current at 0 < t < 0.4

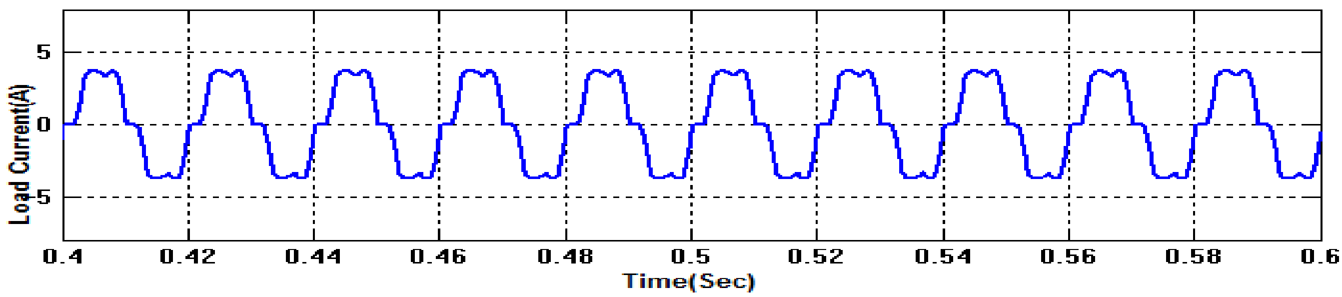

Figure 12. Load current at 0.4 < t <0 .6

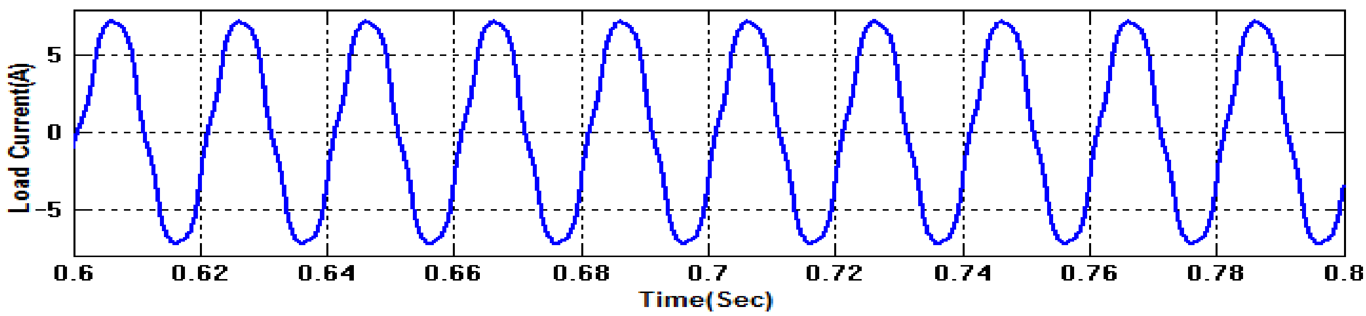

Figure 13.Load current at 0.6< t< 0.8

Conclusion

Improved current harmonics and a reactive power compensation scheme for power distribution systems with generation from renewable sources has been proposed to improve the current quality of the distribution system. Advantages of this proposed scheme is related to its simplicity, modeling and implementation. The MATLAB/SIMULINK simulation model of the proposed system with the connection of renewable energy sources is shown and also validated. The use of a dq-based current reference generation scheme for the converter current loop proved to be an effective solution for active power filter applications, improving capability of current tracking, and transient response. Simulated results have shown that the proposed control method is a good alternative to classical linear control methods. simulated results have shown the compensation effectiveness of the proposed active power filter.

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