Power Enhancement by Adopting Active Power Filter Scheme with Fuzzy Based One Cycle controller under Grid Distortions

R. Divya
M. Tech Student
Dept. of Electrical and Electronics Engineering
GVR & S College of Engineering & Technology
Guntur, Andra Pradesh. India

Vanama Rajesh
Assistant Professor
Dept. of Electrical and Electronics Engineering
GVR & S College of Engineering & Technology
Guntur, Andra Pradesh. India

Abstract- When a three phase supply is connected to a non linear load, current harmonics developed at the source which results in various problems such as detrimental disturbances, aging effect, poor power factor, and lower efficiency These harmonics are eliminated by using active power filters scheme with efficient control strategies. hence results in reactive power compensation and system stability The final test system outcomes with three control strategies are demonstrated by using MATLAB/SIMULINK.

Key words: A three phase three wire power system,l shunt active power filters, , one cycle controller, DOF control .

I. INTRODUCTION

The distributed generation systems with the collective combination, which should accomplish the required necessities as per the operators, regarding grid support under nonlinear load conditions and other distortions or grid faults, has exhilarated many researchers with their innovative solutions to advance the existing conventional control schemes for grid connected active power filters. Usually, the behavior of an electrical network depends upon numerous factors, like constructions of power generation systems, grid faults occurrence, resonance effects or the loads that are nonlinear in nature. Nonlinear characteristics depend upon various application that is connected and active in commercials, industrials and other domestic loads, etc., are in frequent, affecting entire main grid system. Due to rapid technology growth throughout the globe, resulted in accumulative of nonlinear loads. The concept of nonlinear arises when the voltage and current associations are when not in phase. Harmonics of multiple frequencies due to nonlinear loads producing negative sequence voltages getting overlapped with positive sequence voltages coming from the source of fundamental, making sequence overlapping complications. Therefore, to safeguard from these types of catastrophe conditions like threats to humans or other beings, permanent blackouts, apparatus damage & so on, resulted employment of active power filters and passive or hybrid filters with effective controlling techniques for satisfaction of consumer's demands made the priority, at the same time to keep operation in continuous. The extraction of fuel through conventional principles, fever resource availability, etc., gave a foremost shift to new renewable energy sources. It includes other profits like pollution free energy, low EMI (Electro Magnetic Interference), & inexpensive consistency, etc. Therefore employing of additional alternative sources to the existing distribution generation networks became a common practice. The most effectual Distribution Energy Resources (DER)for power production sustain are, solar, the wind, tidal and geothermal energy.

A three phase three wire power system is employed to which a locally generated network in the shunt is connected such that real power can be substituted to the main grid and the load. This is a micro grid or APF main and may facilitate as supplementary voltage source inverter (VSI) with external DC source to support power quality. The micro grid or three phase three wire APF has two main tasks such as i) injection of real power to grid ii) to mitigate harmonic currents and reactive power compensation.

II. ACTIVE POWER FILTERS OR (APF)

At the time of fault occurrences, the APF controller will be activated as a backup to maintain grid in the desired condition. In most industries, three phase four wire power distribution systems are executed. Whenever these power systems connected to non-linear loads, the pure sinusoidal source will get distorted. Here 4^{th} wire does not pass any source current but will carry excess lower order harmonic currents. So it is suggested to filter out surplus neutral currents that are possible using three phase four wire APFs.

Shunt Connected Active Power Filters(APFs):

Active power filters connected in shunt of power distribution systems, for proper compensation of harmonic currents by injecting equal amount but opposite of system harmonic currents. Therefore the load carrying harmonic current will be canceled out. These APFs are used in many applications for harmonic currents mitigation, including compensation of reactive power.

III. CONTROLLINGSTRATEGIES

A. ONE-CYCLE CONTROLLER FOR APF

For the unity-power-factor of three-phase APF, the main control goal is to force the grid line current in each phase so to follow the corresponding sinusoidal phase voltage, i.e.,

$$V_a = R_e * i_a$$
$$V_b = R_e * i_b$$
$$V_c = R_e * i_c \quad ....\ (1)$$

Where Re is the emulated resistance that reflects the real power of the load. This control goal can be realized by controlling the equivalent currents in and i_p to follow the voltages V_n^{*} and V_p^{*} The control goal of three-phase APF can be rewritten.

$$V_p^* = R_e * i_p$$
$$V_n^* = R_e * i_p \quad \text{------------}\ (2)$$

The switch is ON for the entire 60 regions it is obtained that

$$\begin{bmatrix}(1-d_p)\\(1-d_n)\end{bmatrix} = \frac{R_e}{ER_s} \cdot R_s . \begin{bmatrix}2 & 1\\1 & 2\end{bmatrix} . \begin{bmatrix}i_p\\i_n\end{bmatrix} \quad \text{----------(3)}$$

$$d_t = 1$$

Define

$$V_m = \frac{ER_s}{R_e} \quad \text{--------(4)}$$

Where the signal V_m can be generated from the output voltage feedback compensator which is used to regulate the output capacitor voltage E of the voltage source converter according to the load level Rs is equivalent current sensing resistance and is fixed constant.

$$V_m \begin{bmatrix}(1-d_p)\\(1-d_n)\end{bmatrix} = R_s . \begin{bmatrix}2 & 1\\1 & 2\end{bmatrix} . \begin{bmatrix}i_p\\i_n\end{bmatrix} \quad \text{-------------(5)}$$

The above equation indicates that three-phase power factor can be achieved by controlling the duty ratios of switches, so the first-order polynomial equation is satisfied. This can be realized by the one-cycle control core as shown in Fig.[1]. The operation waveforms are shown in Fig [2]

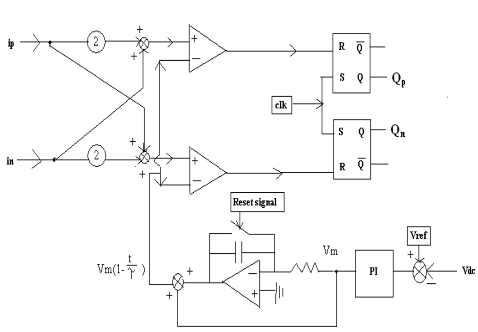

Fig .1 One- cycle control logic

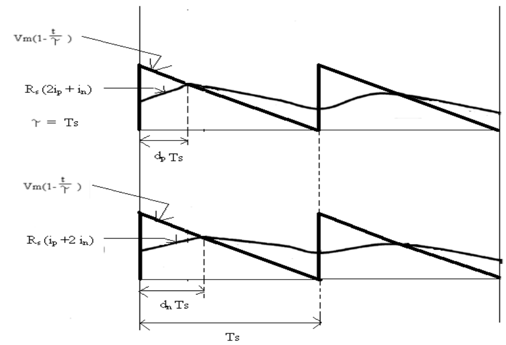

Fig.2 Operation waveforms of one-cycle controlled APF controller

IV. PROPOSED MODEL SCHEME

With the help of instantaneous symmetrical component theory (ISCT), the function of grid connected Dual Active Power Filter (APF) is analyzed and developed[10], with control algorithms. At PCC the positive sequence extraction of voltage is done byabc-dq0 transformation as shown in fig(2) of active power filters independently. As in *fig.1*, a three phase four wire power system with active power filters in shunt of three phase three wire(APF)and micro grid is implemented. Instantaneous symmetrical component theory ISCT is as, three phase distorted ac source will be "sum of components in the positive, negative and zero sequence." It is therefore simple in the analysis under non-linear load conditions. Moreover, converts the linear transformation to a new set of components of three phase, called symmetrical components [6].

[**Note:** Micro grid have external DC voltageV_{dc}; in three phase three wire (APF) DC-link capacitor (C $=C_1 + C_2$); $i_{af} = (i_{am} + i_{ax})$,$i_{bf} = (i_{bm} + i_{bx})$, &$i_{cf} = (i_{cm} + i_{cx})$, $L_3 = (L_m + L_x)$, $R_3 = (R_m + R_x)$

The power of micro grid can be obtained from several distributed energy resources (DER), is adjusted and tuned by trial and error method in simulation, adapted from [6].

Therefore distorted three-phase ac source voltage for compensation as [3]:

$$\begin{bmatrix}Va\\Vb\\Vc\end{bmatrix} = V^+\begin{bmatrix}\sin(\omega t + \Phi^+)\\ \sin(\omega t - 120^\circ + \Phi^+)\\ \sin(\omega t + 120^\circ + \Phi^+)\end{bmatrix} + V^-\begin{bmatrix}\sin(\omega t + \Phi^-)\\ \sin(\omega t - 120^\circ + \Phi^-)\\ \sin(\omega t + 120^\circ + \Phi^-)\end{bmatrix} + V^0\begin{bmatrix}\sin(\omega t + \Phi^0)\\ \sin(\omega t + \Phi^0)\\ \sin(\omega t + \Phi^0)\end{bmatrix}$$

...........(6)

Where V^+ , V^- and V^0 are the amplitude of the voltage, Φ^+,Φ^- and Φ^0 as initial phase angles.

ISSN : 0731-6755

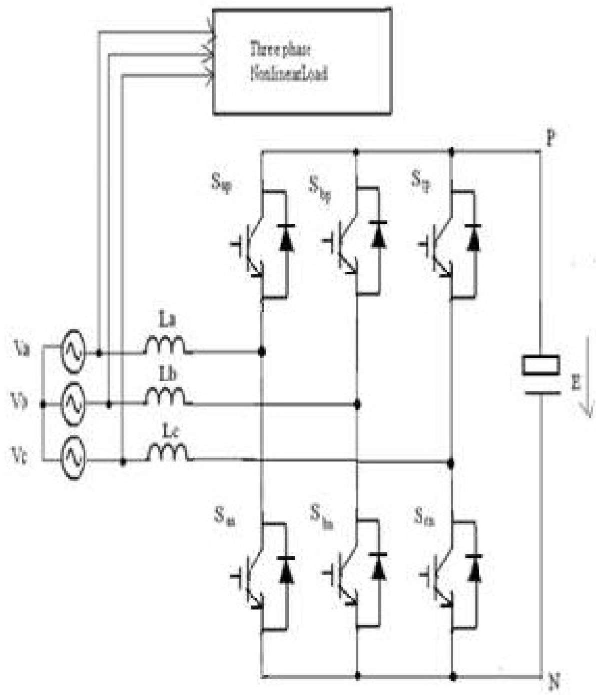

Fig.7 Proposed Active Power Filter Scheme

A APF is reflected as shown in *fig.6* [6]. Neglecting Lg reactors, 3-phase circuit equations connecting APF and APF main independently as [1],

$$\frac{L_3\, d}{dt} i_{af} = V_{sa} - R_3 i_{af} - V_{af} \text{ ……………………..(7)}$$

$$\frac{L_3 d}{dt} i_{bf} = V_{sb} - R_3 i_{bf} - V_{bf} \text{ ……………………….(8)}$$

$$\frac{L_3 d}{dt} i_{cf} = V_{sc} - R_3 i_{cf} - V_{cf} \text{ …………………….(9)}$$

The abc-dq0Transformation or Synchronous Reference Frame SRF for each APFs separately, given as:

$$\begin{bmatrix} Vd \\ Vq \\ 0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin\omega t & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos\omega t & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} vsa \\ vsb \\ vsc \end{bmatrix} \quad (10)$$

Factor 2/3 by power invariance method also called time invariant. And added as a factor of correction such that scaling errors can be eliminated occurred due to multiplication.

State model analysis of APF1 and APF main (micro grid):

$$\frac{L_3 d}{dt} i_{df} = V_d - R_{3 i_{df}} - V_{df} + \omega_e L_3 i_{qf} \text{……….. (11)}$$

$$\frac{L_3 d}{dt} i_{qf} = V_q - R_3 i_{qf} - V_{qf} - \omega_e L_3 i_{df} \text{……….(12)}$$

Where v_d and v_q for d-q axes of SRF, ωe as power system frequency. Moreover, DC-link voltage feedback of APF:

$$\frac{C_3 d}{dt} V_{dc} = f_a(i_{af}) + f_b(i_{bf}) + f_c(i_{cf}) \text{…………(13)}$$

Where f_b , fc are switching functions, C3 as the capacitance of DC-link APF1.

Whereas from equation (8) in d-q axes frame of APF

$$\frac{C_3 d}{dt} V_{dc3} = \frac{3}{2} (f_d i_{df} + f_q i_{qf}) \text{……………………..(14)}$$

Assuming three phase voltages as balanced, hence

$$V_d = V_m \text{ ……………………..(15)}$$

$$V_q = 0 \text{ ………………………..(16)}$$

WhereV_m is input peak value of phase voltage.

The instantaneous real and reactive power given as P_L and q_L on the load side at three phase balanced load condition can be expressed as [1],

$$P_L = \frac{3}{2} V_m i_{dl} \text{ ……………………..(17)}$$

$$q_L = -\frac{3}{2} V_m i_{ql} \text{ ………………..(18)}$$

The above equations (17) and (18) are valid for both unbalanced and balanced loading conditions, in whichP_L and q_L are dependent oni_{dl} and i_{ql} only. If assuming, both active power filters having harmonic current as fully compensated then equations (17) and (18) can be further expressed as [1],

$$P_s = \frac{3}{2} V_m i_1 \text{ ……………………(19)}$$

$$q_s = 0 \text{……………………..(20)}$$

P_s and q_s are instantaneous real and reactive power respectively. Here "i1" in equation (19) is labeled through d- axis current i_{dl}.

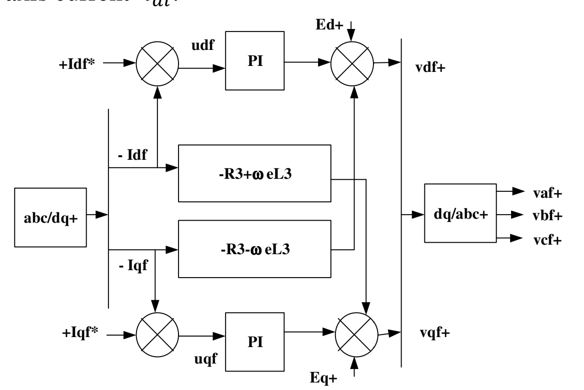

Fig.8 Control Structure using Park Transformation

And i_{df} * and i_{qf} * as reference currents obtained using feedback of load and low pass filter, [1] i.e.,

$$I_{df} *= i_1 - i_{dl} \text{ ……………………….(21)}$$

$$I_{qf} *= -i_{ql} \text{ ……………………………………(22)}$$

Control of an Active Power Filter can be obtained by compensating voltage fluctuation across DC-link of APF1 & APF main. Final d-axis reference current of both may result [1],

$$I_{df} *= I_{dc} + I_1 - I_{dl} \text{………………………(23)}$$

$$I_{dc} = G_{dc}(s)(V_{dc} * - V_{dc}) \text{…………….(24)}$$

Where, I_{dc} is the DC-link voltage regulator, current command. While V_{dc}* is DC-link voltage command and V_{dc} is feedback of DC-link voltage. Therefore,

$V_{df} *= V_m - R_3 I_{df} - U_{df} + \omega_e L_3 I_{qf}$……………….(25)

$V_{qf} *= -R_3 I_{qf} - U_{qf} - \omega_e L_3 I_{df}$…………………..(26)

Where active power filter's current regulators as voltage commands are U_{df} and U_{qf}.

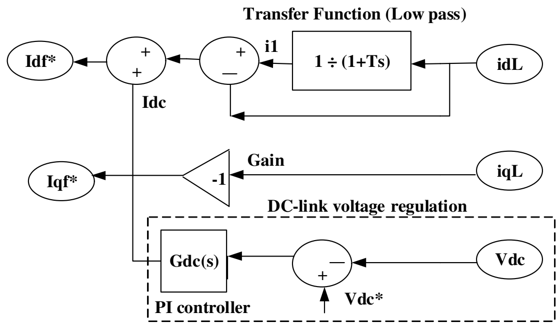

Fig.9 DC-link voltage regulator & low pass filter block

From equations (25) and (26), the termsw_eωeL3Iqf & –ωeL3Idf is due to cross-coupling in d-q current control loops [1], [3]. This is generally possible when the main source voltage sinusoidal balanced waveform consists of the only positive sequence. Moreover, non-linear loads with negative sequence currents flowing in three phase power system may result overlapping of both sequences. Hence there is a need for decoupling of these effects that may possible using PI controllers as $G_{df}(s)$ and $G_{qf}(s)$ controller's gain of dq-axes respectively. Therefore, [1]

$U_{df} = G_{df}(s)(I_{df} * - I_{df})$……………………(27)

$U_{qf} = G_{qf}(s)(I_{qf} * - I_{qf})$…………………(28)

The Inverse Park Transformation or (dq0 to abc) is represented as,

$$\begin{bmatrix} Vaf^* \\ Vbf^* \\ Vcf^* \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin\omega t & \cos\omega t & 1 \\ \sin\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t - \frac{2\pi}{3}\right) & 1 \\ \sin\left(\omega t + \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} Vdf^* \\ Vqf^* \\ 0 \end{bmatrix} \quad \ldots(29)$$

From equations (22) and (23),

$G_{dc}(s) = (K_P d_f + \frac{K_i d_f}{s})$……………………..(30)

$G_{qf}(s) = (K_q q_f + \frac{K_i q_f}{s})$...............................(31)

Here [1], [13] G_{df}(s) and G_{qf}(s) are for control response time delay as PI controllers, to reduce overshoot complications. & feedback DC-link voltage time delay as:

$G_{dc}(s) = (K_P d_c + \frac{K_i d_c}{s})$…………………..(32)

Low pass filter transfer function (current controller) as,

1 / (1+sT) ………………..(33)

Here T = 1/ω, the delay time between the load current and reference current of APF. ω, as cut-off frequency will compensate harmonic current and keep the stability of the system.

While low pass filter attenuates signals of higher than cut-off frequency. Moreover, first order delay improves current regulators tracking capability with simplified model analysis.

V. Simulation Results

4.1. Without APF

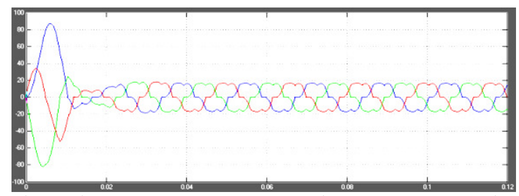

Fig 10 Three Phase AC Source Current under Non-Linear Load

The fig 9 and fig 10 shows the basic 3-phase 4-wire system is considered without using any shunt connected APFs and is having 16.2% of THD when connected to a non-linear load

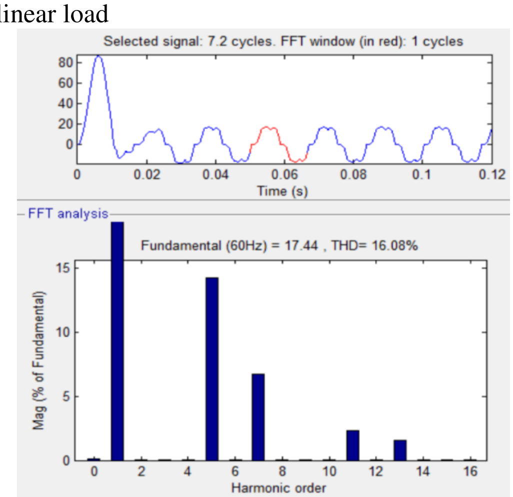

Fig.11 THD Analysis

4.2. With APF (One cycle PI Control)

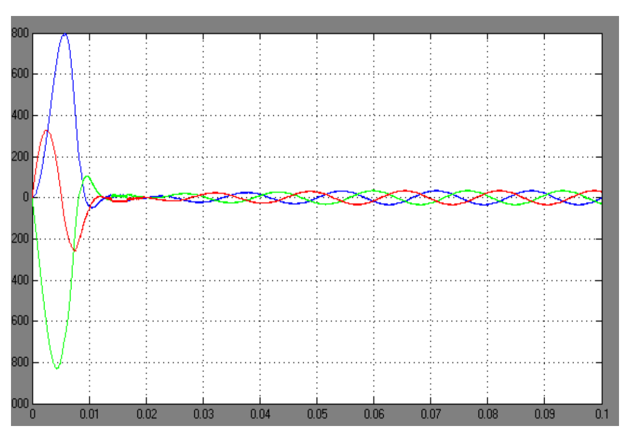

Fig.14Source current with pi one cycle control

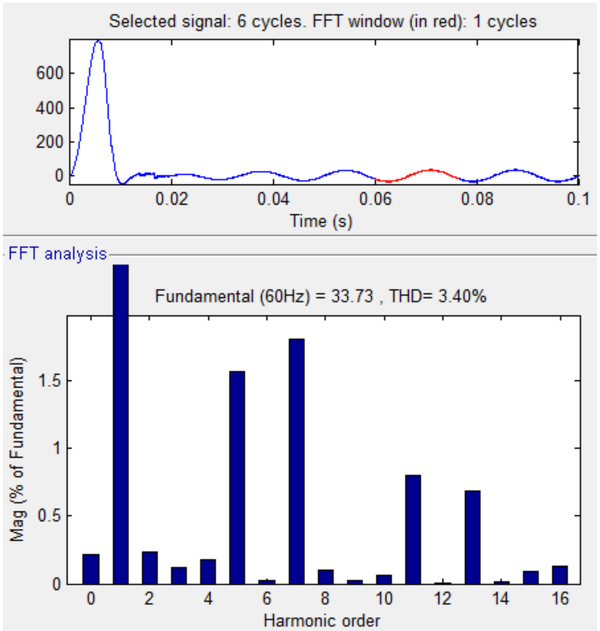

Fig.15 Total Harmonic Distortion with pi one cycle controller

4.3. With APF (One cycle Fuzzy Control)

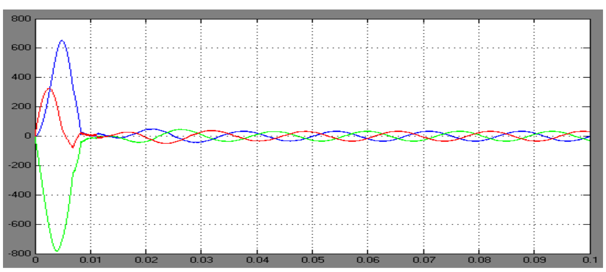

Fig.16 Source current with fuzzy one cycle control

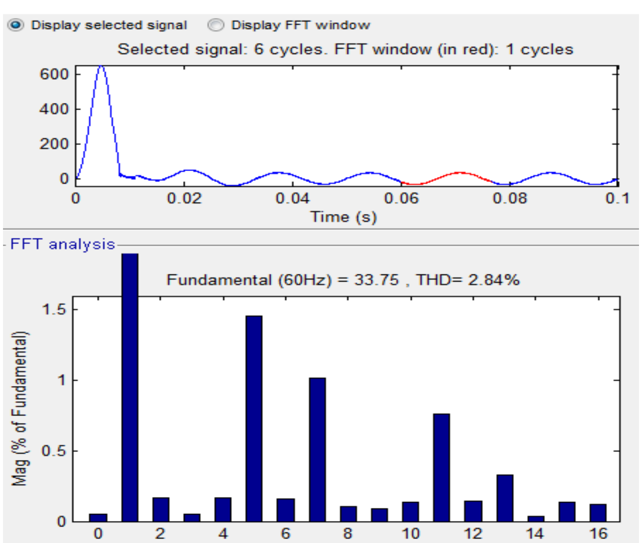

Fig.17 THD with fuzzy one cycle controller

FINAL RESULTS& COMPARISONS

Three Phase Four Wire Distribution System with & without Dual Shunt (DAPF) Active Power Filter		
	Total Harmonic Distortion (THD) at phase-A source current (ias)	***Power factor (cos Φ)***
Without APF	16.08 %	0.8773
One cycle PI controlled APF	3.40%	0.8336
One cycle Fuzzy controlled APF	2.84%	0.8564

VI. CONCLUSION

After the thorough analysis of the proposed scheme, harmonic currents and the power oscillations are seem feasible to cancel out. With the help of Sliding mode control including PI- controllers, the feedback currents, and the reference currents can be simplified to a first order delay time. Further, the Active Power Filters are rectified by regulating DC-link voltage. In this APF model scheme, an additional micro grid is implemented for real power injection. By introducing this model, the necessity of additional dc-link voltage is excluded. If micro grid system fails or stopped working will not be get affected to the main system continuity operation, since APF of three phase three wire inverter will be in operating condition as alternate. The system model using sinusoidal Pulse Width Modulation technique with additional an effective passive filter is connected such that to cancel out third order odd harmonics. Although total harmonic distortion got reduced but by using modified scheme i.e., hysteresis current controller, total harmonic distortion got reduced to the maximum extent as per IEEE standard limits. It includes fast and dynamic response with much simpler circuitry design. In order to maintain power factor constant near to unity, capacitors bank as power factor correction is added. Hence the desired maximum power is successfully delivered to the required loads and stabilization of system is achieved.

REFERENCES

[1] H.H.Kuo, S.N.Yeh and J.C.Hwang, "Novel analytical model for design and implementation of three-phase active power filter controller," IEE Proceedings, Vol.148, No. 4, July 2001.

[2] Yantao Song and Bingsen Wang, "Survey on Reliability of Power Electronic Systems," IEEE Transaction on Power electronics, vol.28, No.1,January 2013.

[3] A Joun Wiley and Sons, Ltd, "Grid converters for photovoltaic and wind power systems," IEEE, Publication 2011.

[4] Maur´ıcio Aredes, "Three-Phase Four-Wire Shunt Active Filter Control Strategies," IEEE Transactions On Power Electronics, Vol. 12, No. 2, March 1997.

[5] Pedro Rodriguez, Adrian V. Timbus, Remus Teodorescu, Marco Liserre, and Frede Blaabjerg, "Flexible Active Power Control of Distributed Power Generation Systems During Grid Faults," IEEE Transactions On Industrial Electronics, Vol. 54, No. 5, October 2007.

[6] M. V. Manoj Kumar, Mahesh K. Mishra,and Chandan Kumar, "A Grid-Connected Dual Voltage Source Inverter With Power Quality Improvement Features," IEEE Transactions On Sustainable Energy, Vol. 6, No. 2, April 2015.

[7] Mukhtiar Singh, Vinod Khadkikar, Ambrish Chandra, and Rajiv K. Varma, "Grid Interconnection of Renewable Energy Sources at the Distribution Level With Power-Quality Improvement Features,"

IEEE Transactions On Power Delivery, Vol. 26, No. 1, January 2011.
[8] Poh Chiang Loh, Lei Zhang, and Feng Gao, "Compact Integrated Energy Systems for Distributed Generation" IEEE Transactions On Industrial Electronics, Vol. 60, No. 4, April 2013.
[9] E.ON Netz GmbH, Bayreuth, "Grid Code: High and Extra high voltage" April 2006.
[10] Dhanpat Rai Publications (P) Ltd, "Electrical Circuit's Analysis".
[11] Muhammad H. Rashid, "Power Electronics Handbook", Editor-In-Chief.
[12] Muhammad H. Rashid, "Power Electronics Circuits, Devices, And Applications", Pearson, Third Edition.
[13] A. Nagoor Kani, "Control Systems", RBA Publications, First Edition.