Enhancement of Power Quality for Renewable Energy System Based Multilevel Inverter

Subbi Naidu Bora
Assistant Professor, Department of EEE,Rajiv Gandhi University of Knowledge and Technology, Nuzvid,Andhra Pradesh-521202,India

Abstract—**A Power quality problem is an occurrence of nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. With the increase in load demand, the Renewable Energy Sources (RES) are increasingly connected in the distribution systems which utilizes power electronic Converters/Inverters. This paper presents a single-stage, three-phase grid connected solar photovoltaic (SPV) system. The proposed system is dual purpose, as it not only feeds extracted solar energy into the grid but it also helps in improving power quality in the distribution system. The presented system serves the purpose of maximum power point tracking (MPPT), feeding SPV energy to the grid, harmonics mitigation of loads connected at point of common coupling (PCC) and balancing the grid currents. The SPV system uses a three-phase voltage source converter (VSC) for performing all these functions. An improved linear sinusoidal tracer (ILST)-based control algorithm is proposed for control of VSC. In the proposed system, a variable dc link voltage is used for MPPT. An instantaneous compensation technique is used incorporating changes in PV power for fast dynamic response. The SPV system is first simulated in MATLAB along with Simulink and simpower system toolboxes.**

Index Terms—**power quality (PQ), renewable energy, Photo Voltaic (PV) System**

I. INTRODUCTION

Power electronics devices are widely used in different fields and for different practical applications. The expansion of their field of applications is related to the knowledge of the device behaviour and of their performances [2]. One of the most interesting fields of application is load compensation, i.e. active filtering of load harmonics, load unbalance and / or load power factor compensation. Both items require a proper drive of power electronics apparatus. The harmonic components in current and voltage waveforms are the most important among these. Conventionally [4]-[6], 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 popular than passive filters as it compensates the harmonics and reactive power simultaneously [1]. The active power filter topology can be connected in series or shunt and combinations of both [8]. Shunt active filter is more popular than series active filter because most of the industrial applications require current harmonics compensation. Different types of active filters have been proposed [10] to increase the electric system quality; a generalized block diagram of active power filter is presented. Active power filter continues to attract considerable attention Because of sensitivity of consumers on power quality and advancement in power electronics.

Generally, current controlled voltage source inverters are used to interface the intermittent RES in distributed system. Recently, a few control strategies for grid connected inverters incorporating PQ solution have been proposed. In [3] an inverter operates as active inductor at a certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in [4]. In [5], a control strategy for renewable interfacing inverter based on – theory is proposed. In this strategy both load and inverter current sensing is required to compensate the load current harmonics. Among these events, harmonics are the most dominant one. The effects of harmonics on PQ are specially described in [4]. According to the IEEE standard, harmonics in th epower system should be limited by two different methods; one is the limit of harmonic current that a user can inject into the utility system at the point of common coupling (PCC) and the other is the limit of harmonic voltage that the can supply to any customer at the PCC. DG interconnection standards are to be followed considering PQ, protection and stability issues [6].

II. SYSTEM DESCRIPTION

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Fig. 1. The voltage source inverter is a key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. The RES may be a DC source or an A source with rectifier coupled to dc-link. Usually, the fuel cell and photovoltaic energy sources generate power at variable low dc voltage, while the variable speed wind turbines generate power at variable ac voltage. Thus, the power generated from these renewable 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.

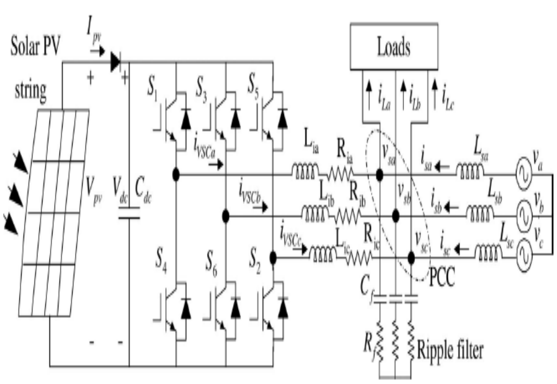

Fig. 1. Schematic of proposed renewable based distributed generation system

A. DC-Link Voltage and Power Control Operation

Due to the intermittent nature of RES, the generated power is of variable nature. The dc-link plays an important role in transferring this variable power from renewable energy source to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. Fig. 2 shows the systematic representation of power transfer from the renewable energy resources to the grid via the dc-link. The current injected by renewable into dc-link at voltage level Vdc can be given as

$$I_{\mathrm{dc1}} = \frac{P_{\mathrm{RES}}}{V_{\mathrm{dc}}} \quad (1)$$

Where PRES is the power generated from RES.

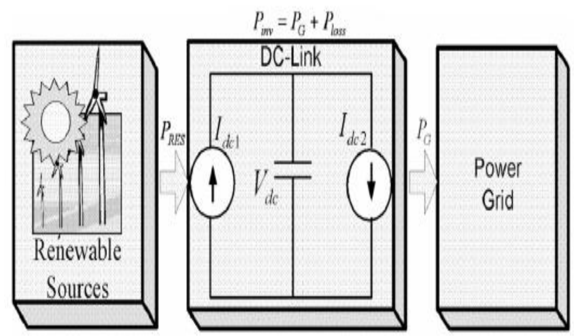

Fig. 2.DC-Link equivalent diagram

The current flow on the other side of dc-link can be represented as,as used as a dc/dc converter to step up the low dc voltage to a medium- voltage level, which effectively reduces the cable losses at the collection system.

$$I_{\mathrm{dc2}} = \frac{P_{\mathrm{inv}}}{V_{\mathrm{dc}}} = \frac{P_G + P_{\mathrm{Loss}}}{V_{\mathrm{dc}}} \quad (2)$$

Where P_{inv}, P_G and P_{Loss} are total power available at grid-interfacing inverter side, active power supplied to the grid and inverter losses, respectively. If inverter losses are negligible then $P_{RES} = P_G$.

B. Control of Grid Interfacing Inverter

The control diagram of grid- interfacing inverter for a 3-phase 4-wire system is shown in Fig. 3. The fourth leg of inverter is used to compensate the neutral current of load. The main aim of proposed approach is to regulate the power at PCC during:

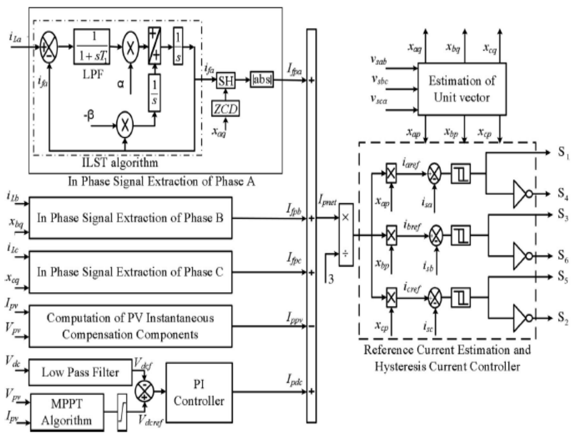

Fig. 3. Block diagram representation of grid-interfacing inverter control.

1) $P_{RES} = 0$; 2) $P_{RES} <$ Total load power (P_L) ; and 3) $P_{RES} > P_L$. While performing the power management operation, the inverter is actively controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid. If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance, and neutral current. The duty ratio of inverter switches are varied in a power cycle such that the combination of load and inverter injected power appears as balanced resistive load to the grid. The regulation of dc-link voltage carries the information regarding the exchange of active power in between renewable source and grid. Thus the output of dc-link voltage regulator results in an active current (Im). The multiplication of active current component (Im). With unity grid voltage vector templates (U_a,U_b, and U_c) generates the reference grid currents (I_a^*, I_b^*, and I_c^*) . The reference grid neutral current (I^*n) is set to zero, being the instantaneous sum of balanced grid currents. The grid synchronizing angle (θ) obtained from phase locked loop (PLL) is used to generate unity vector template as [9]–[11]

$$U_a = \mathrm{Sin}(\theta) \quad (3)$$

$$U_b = \mathrm{Sin}(\theta - \frac{2\pi}{3}) \quad (4)$$

$$U_c = \mathrm{Sin}(\theta + \frac{2\pi}{3}) \quad (5)$$

The actual dc-link voltage (V_{dc}) is sensed and passed through a first-order *low pass filter* (LPF) to eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage (V^*_{dc}) is given to a discrete- PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error V_{dceer}(n) at nth sampling instant is given as:

$$V_{\mathrm{dcerr}(n)} = V^*_{\mathrm{dc}(n)} - V_{\mathrm{dc}(n)}. \quad (6)$$

The output of discrete-PI regulator at th sampling instant is expressed as

$$I_{m(n)} = I_{m(n-1)} + K_{PV_{\mathrm{dc}}}(V_{\mathrm{dcerr}(n)} - V_{\mathrm{dcerr}(n-1)}) + K_{IV_{\mathrm{dc}}} V_{\mathrm{dcerr}(n)} \quad (7)$$

Where $K_{PVdc} = 10$ and $K_{IVdc} = 0.05$ are proportional and integral gains of dc-voltage regulator. The instantaneous values of reference three phase grid currents are computed as

$$I_a^* = I_m \cdot U_a \quad (8)$$

$$I_b^* = I_m \cdot U_b \quad (9)$$

$$I_c^* = I_m \cdot U_c. \quad (10)$$

The neutral current, present if any, due to the loads connected to the neutral conductor should be compensated by forth leg of grid-interfacing inverter and thus should not be drawn from the grid. In other words, the reference current for the grid neutral current is considered as zero and can be expressed as

$$I_n^* = 0. \quad (11)$$

The reference grid currents (I^*a, I^*b,I^*c and I^*n) are compared with actual grid currents (Ia, Ib,Ic and In) to compute the current errors as

$$I_{\mathrm{aerr}} = I_a^* - I_a \quad (12)$$

$$I_{\mathrm{berr}} = I_b^* - I_b \quad (13)$$

$$I_{\mathrm{cerr}} = I_c^* - I_c \quad (14)$$

$$I_{\mathrm{nerr}} = I_n^* - I_n. \quad (15)$$

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P_1 *to* P_8) for the gate drives of grid-interfacing inverter. The average model of 4-leg inverter can be obtained by the following state space equations

$$\frac{dI_{\mathrm{Inva}}}{dt} = \frac{(V_{\mathrm{Inva}} - V_a)}{L_{\mathrm{sh}}} \quad (16)$$

$$\frac{dI_{\mathrm{Invb}}}{dt} = \frac{(V_{\mathrm{Invb}} - V_b)}{L_{\mathrm{sh}}} \quad (17)$$

$$\frac{dI_{\mathrm{Invc}}}{dt} = \frac{(V_{\mathrm{Invc}} - V_c)}{L_{\mathrm{sh}}} \quad (18)$$

The switching pattern of each IGBT inside inverter can be formulated on the basis of error between actual and reference current of inverter, which can be explained as:

If $I_{Inva} < (I^*_{Inva}-h_b)$, then upper switch S_1will be OFF (P_1 =0) and lower switch S_4 will be ON (P_4=1) in the phase "a" leg of inverter.

If $I_{Inva} > (I^*_{Inva}-h_b)$, then upper switch S_1 will be ON (P_1 =1) and lower switch S_4 will be OFF (P_4=0) in the phase "a" leg of inverter Where hb is the width of hysteresis band. On the same principle, the switching pulses for the other remaining three legs can be derived.

III.RENEWABLE ENERGY RESOURCES

Renewable energy resources are the ones that are persistently available and renewing itself with the time. Industrialization and increasing world population has remarked the use of renewable energy resources. Solar power, wind power, biomass, tide power, wave power, geothermal power is known ones.

A) Solar Power: Solar panels are the medium to convert solar power into the electrical power. Solar panels can convert the energy directly or heat the water with the induced energy. PV (Photo-voltaic) cells are made up from semiconductor structures as in the computer technologies. Sun beam is absorbed with this material and electrons are emitted from the atoms that they are bounded. This release activates a current. Photovoltaic is known as the process between beam absorbed and the electricity induced. With a common principle and individual components, solar power is converted into the electric power. Solar batteries are produced by waffling p-n semiconductors. A current-volt characteristic of the PV in the darkness is very similar to that of diot. Under beam, electron flow and current occurs. In closed-loop, PV current passes through the external load. While in open-loop, the current completes the circuit through the p-n diode structure [4]. Solar batteries can be represented with an equivalent circuit of a current source, a resistor and a diot in parallel, and an external load-resistor [5], as seen in Figure 4.

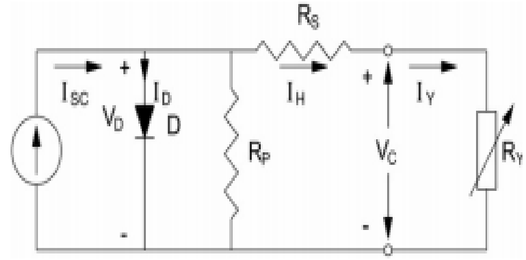

Fig. 4. Equivalent circuit of solar battery

IV. MATLAB MODELEING AND SIMULATION RESULTS

To verify the proposed control approach to achieve the multi function of four leg inverter simulation study is carried out using MATLAB/Simulink.Here simulation is carried out in different cases 1). Implementation of 4-Leg VSI with Balanced Linear Load Condition 2). Implementation of 4-Leg VSI with Un-Balanced Linear Load Condition 3). Implementation of 4-Leg VSI with Balanced Non-Linear Load Condition 4). Implementation of 4-Leg VSI with Un-Balanced Non-Linear Load Condition

Case 1: Implementation of 4-Leg VSI with Balanced Linear Load Condition

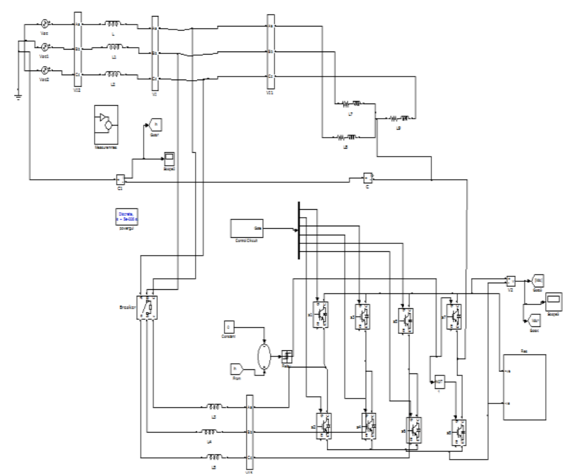

Fig.6 Matlab/Simulink Model of Proposed 4-Leg VSI with Balanced Linear Load Condition

Fig.6 shows the Matlab/Simulink Model of Proposed 4-Leg VSI with Balanced Linear Load Condition using Matlab/Simulink Platform.

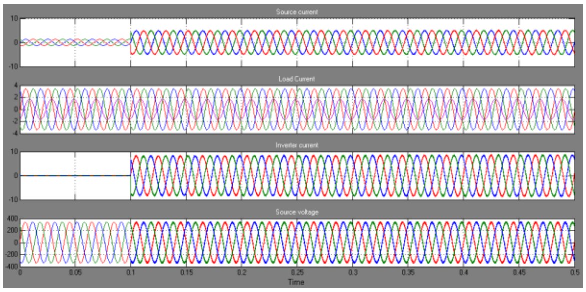

Fig. 7 Source Current, Load Current, Inverter Injecting Current, Grid Voltage

Fig.7 shows the Source Current, Load Current, Inverter Injecting Current, and Grid Voltage of Proposed 4-Leg VSI with Balanced Linear Load Condition. At t=0.1s, the grid interfacing inverter is now connected to network. Fig.7 shows the grid current starts changing to sinusoidal balanced from balanced nonlinear current. At this instant, active power injected by the inverter from RES is shown in Fig.6. The load power demand is less than the generated power and the additional power in fed back to the grid.

Case 2: Implementation of 4-Leg VSI with Un-Balanced Linear Load Condition

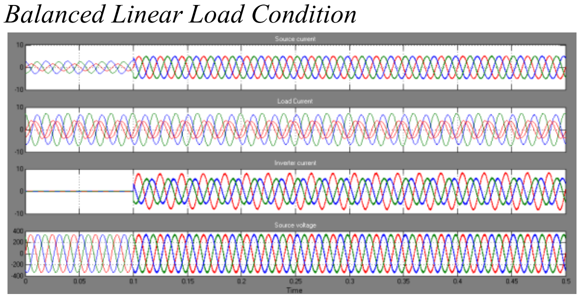

Fig. 8 Source Current, Load Current, Inverter Injecting Current, Grid Voltage

Fig.9 shows the Matlab/Simulink Model of Proposed 4-Leg VSI with Balanced Non-Linear Load Condition using Matlab/Simulink Platform.

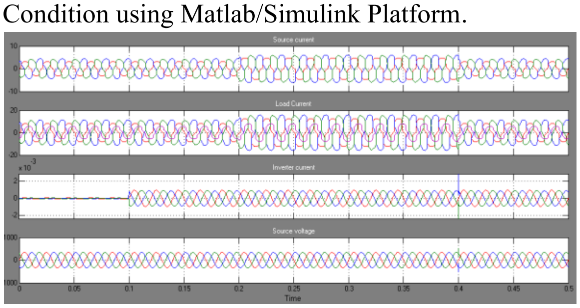

Fig. 10 Source Current, Load Current, Inverter Injecting Current, Grid Voltage

Fig.10 shows the Source Current, Load Current, Inverter Injecting Current, and Grid Voltage of Proposed 4-Leg without VSI with Balanced Non-Linear Load Condition, due to non linear load our source parameters distort. At t=0.1s, the grid interfacing inverter is now connected to network. Fig.10 shows the grid current starts changing to sinusoidal balanced from balanced nonlinear current.

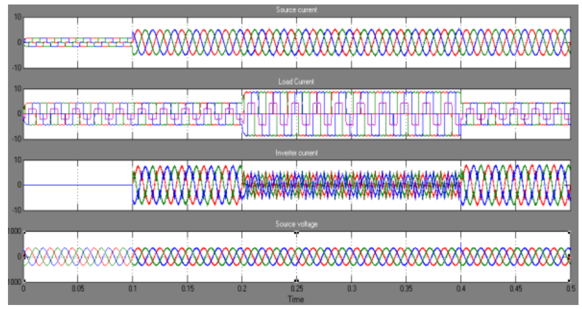

Fig. 11 Source Current, Load Current, Inverter Injecting Current, Grid Voltage

Fig.11 shows the Source Current, Load Current, Inverter Injecting Current, and Grid Voltage of Proposed 4-Leg VSI with Balanced Non-Linear Load Condition, due to non linear load our source parameters distort, but compensator compensates the harmonics and maintain sinusoidal nature. At t=0.1s, the grid interfacing inverter is now connected to network and the compensation is done from t=0.2s to t=0.4s.

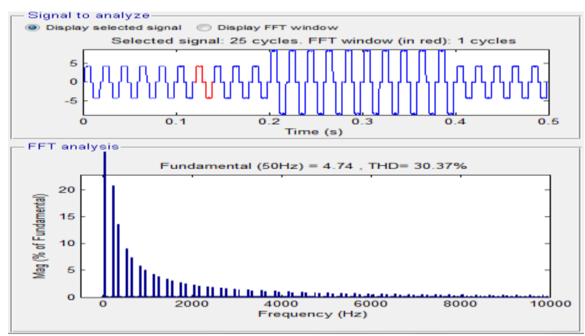

Fig.12 FFT Analysis of Source Current of Proposed 4-Leg without VSI with Balanced Non-Linear Load Condition

Fig.12 shows the FFT Analysis of Source Current of Proposed 4-Leg without VSI with Balanced Non-Linear Load Condition, we get 30.37%.

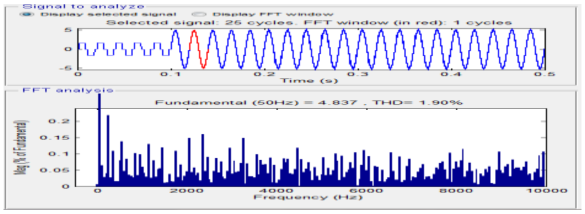
Fig.13 FFT Analysis of Source Current of Proposed 4-Leg with VSI with Balanced Non-Linear Load Condition

V. CONCLUSION

As conventional fossil-fuel energy sources diminish and the world's environmental concern about acid deposition and global warming increases, renewable energy sources (solar, wind, tidal, and geothermal, etc.) are attracting more attention as alternative energy sources. This paper presented a control of Three phase Four leg grid interfacing inverter improve the quality of power at PCC for a 3 phase 4 wire system applied to various load conditions, here we preferred balanced as well as unbalanced load conditions with linear & non-linear load. It has been shown that the grid interfacing inverter can simultaneously be utilized to inject power generated from RES to PCC and to improve the quality of power at PCC. Thus, the proposed controller precisely manages any variation in real power at dc link and effectively feeds it to the main grid. The current harmonics caused by non linear load connected at PCC are compensated effectively such that the grid currents are always maintained sinusoidal at unity power factor. This approach thus eliminates the need for additional power conditioning equipment to improve the quality of power at PCC. Thus, the load neutral current is prevented from flowing into the grid side by compensating it locally from the fourth leg of the inverter. The performance of proposed single stage grid interfaced SPV system along with harmonics compensation, power factor correction, and grid currents balancing has been found satisfactory and meeting IEEE standards.

REFERENCES

[1] J. M. Guerrero, L. G. de Vicuna, J. Matas, M. Castilla, and J. Miret, "A wireless controller to enhance dynamic performance of parallel inverters in distributed generation systems," IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1205–1213, Sep. 2004.

[2] J. H. R. Enslin and P. J. M. Heskes, "Harmonic interaction between a large number of distributed power inverters and the distribution network," IEEE Trans. Power Electron. vol. 19, no. 6, pp. 1586–1593, Nov. 2004.

[3] U. Borup, F. Blaabjerg, and P. N. Enjeti, "Sharing of nonlinear load in parallel-connected three-phase converters," IEEE Trans. Ind. Appl., vol. 37, no. 6, pp. 1817–1823, Nov./Dec. 2001.

[4] P. Jintakosonwit, H. Fujita, H. Akagi, and S. Ogasawara, "Implementation and performance of cooperative control of shunt active filters for harmonic damping throughout a power distribution system," IEEE Trans. Ind. Appl., vol. 39, no. 2, pp. 556–564, Mar./Apr. 2003.

[5] G.Satyanarayana., K.N. V Prasad, G.Ranjith Kumar, K. Lakshmi Ganesh, "Improvement of power quality by using hybrid fuzzy controlled based IPQC at various load conditions," Energy Efficient Technologies for Sustainability (ICEETS), 2013 International Conference on, vol., no., pp.1243,1250, 10-12 April 2013.

[6] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems," IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1398–1409, Oct. 2006.

[7] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galván, R. C. P. Guisado, M. Á. M. Prats, J. I. León, and N. M. Alfonso, "Powerelectronic systems for the grid integration of renewable energy sources: A survey," IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002–1016, Aug. 2006.

[8] G.Satyanarayana., K.N. V Prasad, G.Ranjith Kumar, K. Lakshmi Ganesh, "Improvement of power quality by using hybrid fuzzy controlled based IPQC at various load conditions," Energy Efficient Technologies for Sustainability (ICEETS), 2013 International Conference on, vol., no., pp.1243,1250, 10-12 April 2013.

[9] V. Khadkikar, A. Chandra, A. O. Barry, and T. D. Nguyen, "Application of UPQC to protect a sensitive load on a polluted distribution network," in Proc. Annu. Conf. IEEE Power Eng. Soc. Gen. Meeting, 2006, pp. 867–872.

[10] G. Satya Narayana, Ch. Narendra Kumar, Ch. Rambabu "A Comparative Analysis of PI Controller and Fuzzy Logic Controller for Hybrid Active Power Filter Using Dual Instantaneous Power Theory" International Journal of Engineering Research & Development, Vol-4, Issue-6, p.p. 29-39,
Oct, 2012.

[11] P. Rodríguez, J. Pou, J. Bergas, J. I. Candela, R. P. Burgos, and D. Boroyevich, "Decoupled double synchronous reference frame PLL for power converters control," IEEE Trans. Power Electron, vol. 22, no. 2, pp.584–592, Mar. 007.