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Performance Evaluation of STATCOM Connected to Renewable Energy Source

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Abstract: *A Power quality problem is an occurrence of nonstandard voltage, current or frequency that results in a failure or a misoperation 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 novel control strategy for achieving maximum benefits from these grid-interfacing inverters using the closed loop fuzzy logic control, when installed in 3-phase 4-wire distribution systems. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. This new control concept is demonstrated with extensive MATLAB/Simulink.*
Keywords—*Active power filter (APF), distributed generation (DG), distribution system, grid interconnection, power quality (PQ), renewable energy, Photo Voltaic (PV) System.*

I. Introduction

Renewable energy systems such as PV, solar thermal electricity such as dish-stirling systems, and WT are appropriate solar and wind technologies that can be considered for electric power generation at the distribution system level. Other renewable energy technologies, such as the solar central receiver, hydro-electric generation, geothermal, and large wind farms are normally connected to the grid at the sub-transmission or transmission level because of the higher power capacities of these types of systems. Due to increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards Renewable Energy Sources (RES) as a future energy solution. Renewable Energy Sources are increasingly integrated at the distribution level due to increase in load demand which utilize power electronic converters. Due to the extensive use of power electronic devices, disturbances occur on the electrical supply network. These disturbances are due to the use of non-linear devices. These will introduce harmonics in the power system thereby causing equipment overheating, damage devices, EMI related problems etc. Active Power Filters (APF) is extensively used to compensate the current harmonics and load unbalance. Power quality is one of the most important topics that electrical engineers have been noticed in recent years. Voltage sag is one of the problems related to power quality. This phenomenon happens continuously in transmission and distribution systems. During a voltage sag event, amplitude of the effective load voltage decrease from 0.9 of the nominal load voltage to 0.1 in very short time (less than one minute). Short circuit, transformer energizing, capacitor bank charging etc are causes of voltage sag. Voltage sag has been classified in 7 groups of A-G [1].

II. System Description

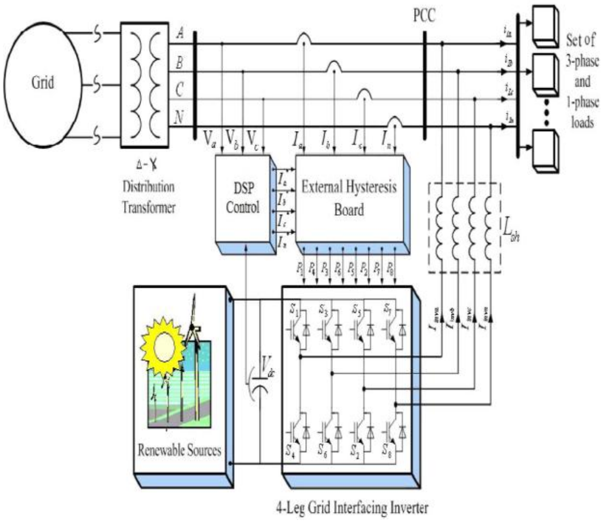

Fig. 1. Schematic of proposed renewable based distributed generation system.

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.

2.1 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.

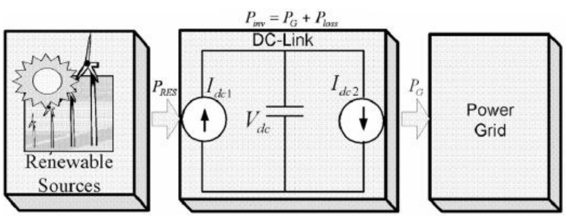

Fig. 2. DC-Link equivalent diagram.

The current flow on the other side of dc-link can be represented as,

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

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 $P_{RES}= P_G$.

2.2 Control of Grid Interfacing Inverter

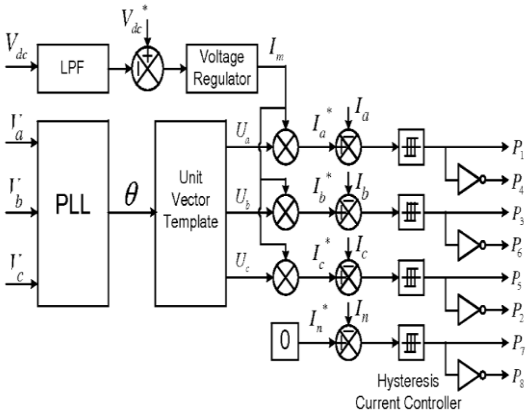

Fig. 3. Block diagram representation of grid-interfacing inverter control.

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:

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$(I_a^*, I_b^*, \text{ and } I_c^*)$. 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

$$I_{\text{aerr}} = I_a^* - I_a \quad (12)$$
$$I_{\text{berr}} = I_b^* - I_b \quad (13)$$
$$I_{\text{cerr}} = I_c^* - I_c \quad (14)$$
$$I_{\text{nerr}} = I_n^* - I_n. \quad (15)$$

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

$$\frac{dI_{\text{Inva}}}{dt} = \frac{(V_{\text{Inva}} - V_a)}{L_{\text{sh}}} \quad (16)$$
$$\frac{dI_{\text{Invb}}}{dt} = \frac{(V_{\text{Invb}} - V_b)}{L_{\text{sh}}} \quad (17)$$
$$\frac{dI_{\text{Invc}}}{dt} = \frac{(V_{\text{Invc}} - V_c)}{L_{\text{sh}}} \quad (18)$$
$$\frac{dI_{\text{Invn}}}{dt} = \frac{(V_{\text{Invn}} - V_n)}{L_{\text{sh}}} \quad (19)$$
$$\frac{dV_{\text{dc}}}{dt} = \frac{(I_{\text{Invad}} + I_{\text{Invbd}} + I_{\text{Invcd}} + I_{\text{Invnd}})}{C_{\text{dc}}} \quad (20)$$

Where V_{Inva}, V_{Invb}, V_{Invc} and V_{Invn} are the three-phase ac switching voltages generated on the output terminal of inverter.

These inverter output voltages can be modeled in terms of instantaneous dc bus voltage and switching pulses of the inverter as

$$V_{\text{Inva}} = \frac{(P_1 - P_4)}{2} V_{\text{dc}} \quad (21)$$
$$V_{\text{Inva}} = \frac{(P_3 - P_6)}{2} V_{\text{dc}} \quad (22)$$
$$V_{\text{Inva}} = \frac{(P_5 - P_2)}{2} V_{\text{dc}} \quad (23)$$
$$V_{\text{Inva}} = \frac{(P_7 - P_8)}{2} V_{\text{dc}} \quad (24)$$

Similarly the charging currents VInvad, VInvbd, VInvcd and Vinvnd on dc bus due to the each leg of inverter can be expressed as

$$I_{\text{Invad}} = I_{\text{Inva}}(P_1 - P_4) \quad (25)$$
$$I_{\text{Invbd}} = I_{\text{Invb}}(P_3 - P_6) \quad (26)$$
$$I_{\text{Invcd}} = I_{\text{Invc}}(P_5 - P_2) \quad (27)$$
$$I_{\text{Invad}} = I_{\text{Inva}}(P_7 - P_8) \quad (28)$$

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 $I_{\text{Inva}} < (I^*_{\text{Inva}} - h_b)$, 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.

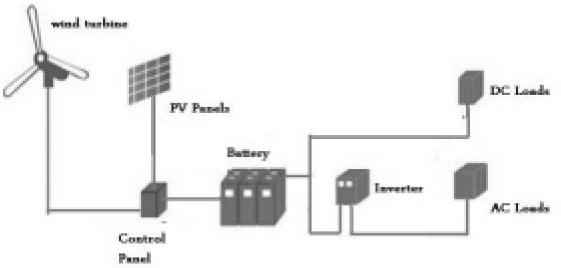

Fig. 4. Hybrid system

Control unit decides which source to use for charging the battery with respect to condition of the incoming energy as seen in Figure 6.

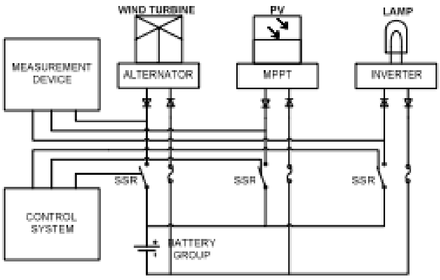

Fig. 5. System block diagram

Wind turbine first converts the kinetic energy to mechanical energy and then converts it to the electricity. The wind turbine in the system consists of tower, alternator, and speed converters (gear box), and propeller. And a picture of the constructed hybrid system is The kinetic energy of the wind is converted to the mechanical energy in the rotor. The rotor shaft speed, 1/18, is accelerated in the reduction gear and then transmitted to alternator. The electricity that comes from the alternator can be directly transmitted to DC receivers as well as it can be stored in the batteries.

III. ABOUT FUZZY CONTROLLER

A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, input voltage *Vdc* and the input reference voltage *Vdc-ref* have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current *I*max. 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.8.

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.

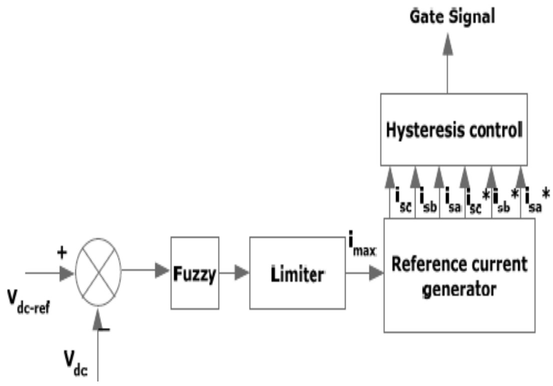

Fig.6.Conventional fuzzy controller

Fuzzification: the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.

IV. MATLAB MODELEING AND SIMULATION RESULTS

Here the simulation is carried out in two cases 1.Implementation of proposed converter using conventional PI controller. 2. Implementation of proposed converter using fuzzy logic controller 3. Implementation of proposed converter using hybrid fuzzy logic controller.

Case 1: Implementation of proposed converter using conventional PI controller with PV model.

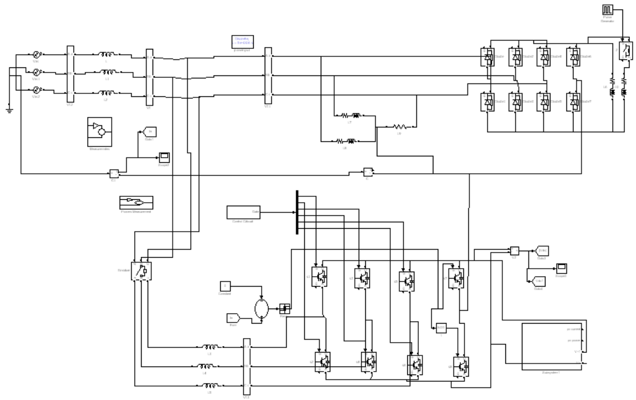

Fig.. 7 Matlab/Simulink Model of Proposed Power Circuit

The power circuit as well as control system are modeled using Power System Block set and Simulink. Performance of proposed converter connected to a weak supply system is shown in

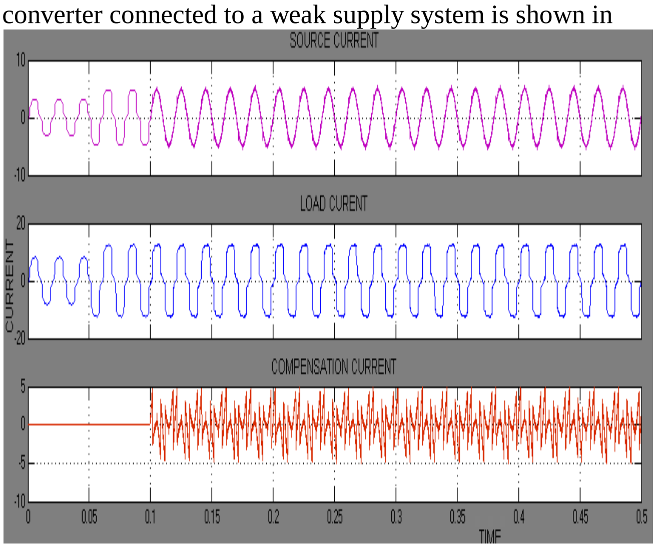

Fig.8. Simulation results for Un Balanced Non Linear Load using PI controller (a) Source current. (b) Load current. (c) Inverter injected current.

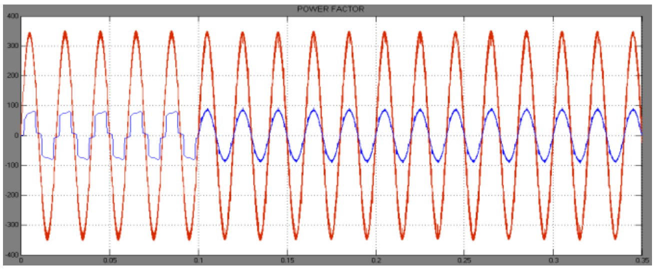

Fig.9. Simulation results power factor for Un balanced Non linear Load

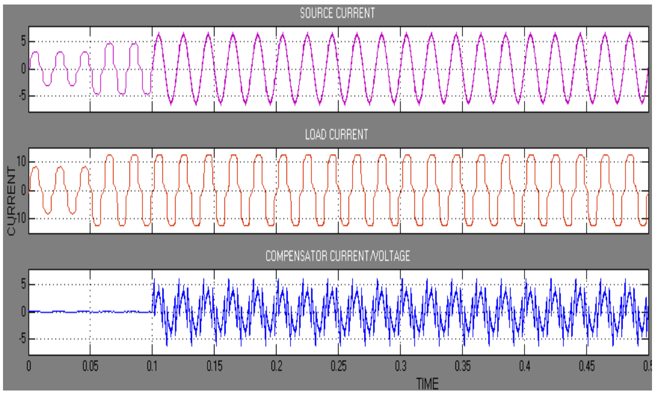

Fig:10 Simulation results for Un Balanced Non Linear Load using fuzzy controller (a) Source current. (b) Load current. (c) Inverter injected current

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. Both PI controllers based and fuzzy logic controller VSI based shunt active power filter are implemented for harmonic and reactive power compensation of the non-linear load. A circuit has been developed to simulate the fuzzy logic based and PI controller based shunt active power filter in MATLAB. It is found from simulation results that shunt active power filter improves power quality of the power system by eliminating harmonics and reactive current of the load current, which makes the load current sinusoidal and in phase with the source voltage. The performance of both the controllers has been studied and compared. A model has been developed in MATLAB SIMULINK and simulated to verify the results. The THD of the source current is below 5%, the harmonics limit imposed by IEEE standard. The simulation results show that the performance of converter system has been found to be satisfactory for improving the power quality at the consumer premises. By using conventional controller we get THD value is 3.05%, but using the fuzzy logic controller THD value is 2.35% and using the hybrid fuzzy logic controller THD value is 1.72%. Finally Matlab/Simulink based model is developed and simulation results are presented.

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]. Satyanarayana, K.Lakshmi Ganesh , CH. Narendra Kumar, N. Srinivasa Rao "Realization of Hybrid Active Power Filter Applied to BLDC Motor Drive Using Dual Instantaneous Power Theory", International Journal of Engineering Associates, Vol-1, Issue 3, p.p. 32-37, Feb, 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.