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FUZZY LOGIC BASED CONTROL OF SHUNT CONNECTED COMPENSATOR FOR POWER QUALITY IN UTILITY CONNECTED GRID SYSTEM

K.Naresh[1], S.Ravindra[2], K.V.Thulasiram[3]
[1]P.G.Student, EEE, QISCET, Ongole, A.P., (India)
[2]EEE, QISCET, Ongole, A.P., (India)
[3]EEE, N.B.K.R.I.T, vidyanagar, A.P., (India)

ABSTRACT

Today everyone is aiming at a reduction in greenhouse gas emissions, the requirements for adding new generation capacity can no longer be met by traditional power generation methods of burning the primary fossil fuels such as coal, oil, natural gas, etc. This is why distributed generators (DG) have significant opportunity in the evolving power system network. This paper concentrates on power quality improvement in the utility grid connected system using Fuzzy Logic controller, The unbalance in the system is compensated using compensating device such as D-statcom, The problem in the single phase system cause due to Non-Linear loads and un-balanced loads and due to source like PV (Photo voltaic cells) and FC(Fuel Cells). In this the D-statcom only supplies reactive power and no real power. In the another Scheme a large 3phase converter controlled DG is placed that only supplies reactive power, and fuzzy logic controller is used for controlling of dc Voltage The effectiveness of controllers has be tested using Matlab/Simulink software.

Keywords: Micro Grid, Fuzzy, D-Statcom, Power Quality, Harmonics.

I. INTRODUCTION

Nowadays, the utilisation of renewable energy sources (RES) for matching the increasing electric energy demand is determined by environmental concerns, economic and social. Nowadays the RES can efficiently improve the micro potential utilisation whereas in the past decades the hydroelectric power plants larger than 10 MW were of interest. Their development will lead to an increase in the green energy percentage and to control pollution. Meanwhile, the actual structure of the electric energy distribution networks begins to suffer modifications related to the interconnection of distributed generation units (DG) based on RES [1]. System stability decline in its terminal zones, the wearing out of the actual control and measurement equipments, the predominant unidirectional energy flow are the drawbacks of the classical energy production and distribution systems. Thus, the DG unit’s development dictates the need for modernizing of the distribution networks. On the other hand, the integration of those units within the existing networks must be accomplished by ensuring the power quality of the energy which is produced, the capacity of fast response to the demands and a minimum perturbing influence on the utility grid. For doing this, the DG units must contain modern measurement, communication and control equipments, protection, making the transition towards Smart Grids [2]. Another possible operating situation in islanded mode is the one in which the micro-grid contains only induction generators [5, 8]. A voltage regulator is necessary besides, the frequency regulator in this case and also a reactive power source that must provide the excitation needs, possible control solutions being detailed in [6,8]. This paper presents the fuzzy logic based control of control of single phase micro-sources (DG) in a utility connected grid. While the DGs supply their maximum generated power, rest of the power demand of each phase is supplied by the utility and three phase DG connected at the PCC, if any. To overcome this problem, we have proposed two different schemes. In the first scheme, a distribution static compensator (DSTATCOM) is connected at the point of common coupling (PCC) to compensate current harmonics and reactive power. . In the second scheme, a three phase DG, connected at the PCC, in place of the DSTATCOM to share both real and reactive power with the utility. The DG also compensates the system and makes the PCC voltage balanced.

II. SYSTEM STRUCTURE

Fig. 1 shows the structure of the system studied in this paper. Rs and Ls represent the source impedance. The three single phase DGs and a three phase compensator is connected to the source side. The three phases DG or DSTATCOM is also connected through secondary feeders to the PCC.

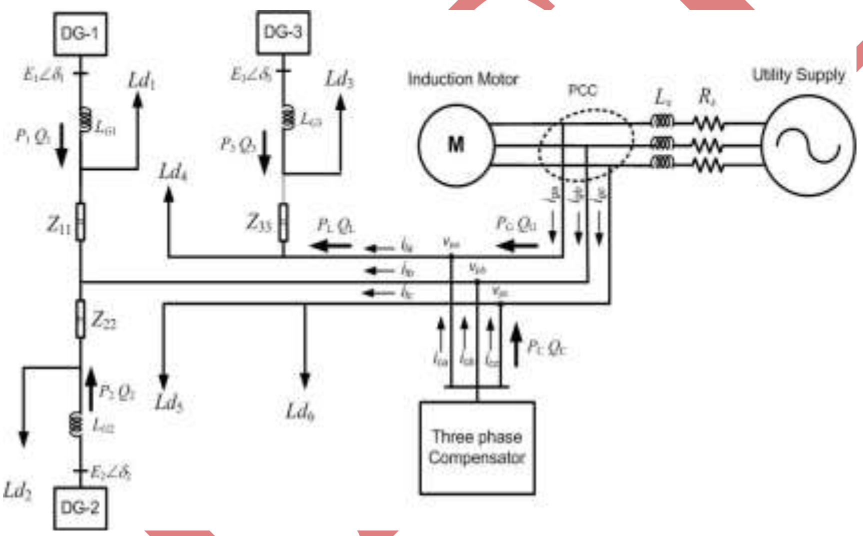


Fig. 1. Structure Of The Grid System Under Consideration.

TABLE-I: GRID SYSTEM PARAMETERS

System Quantities	Values
Systems frequency	50 Hz
Feeder impedance $Z_{12} = Z_{23} = Z_{34} = Z_{45} = Z_{45} = Z_{56} = Z_{67} = Z_{78} = Z_{89}$	1.03 + j 4.71 Ω
Load ratings	
Ld_1	4.2 kW and 3.2 kVAr
Ld_2	4.2 kW and 3.2 kVAr
Ld_3	8.4 kW and 6.4 kVAr
Ld_4	4.2 kW and 3.2 kVAr
Ld_5	8.4 kW and 6.4 kVAr
Ld_6	8.4 kW and 6.4 kVAr
Ld_7	4.2 kW and 3.2 kVAr
DG ratings (nominal)	
DG-1	5.2 kW
DG-2	7.5 kW
DG-3	3.0 kW
Output inductances $L_{G1} = L_{G2} = L_{G3} = L_{G4}$	75 mH
DGs and VSCs	
DC voltages (V_{dc1} to V_{dc4})	0.5kV
Transformer rating	0.350kV/0.350 kV, 0.25 MVA, 2.5% L_f
VSC losses (R_f)	1.5 Ω
Filter capacitance (C_f)	50 µF
Hysteresis constant (h)	10^{-5}

Here power quality can be improved with both of the compensators. It is assumed that all the DG are inertia less and VSC-interfaced. Ld1 to Ld6 indicated the loads. The secondary feeder impedances are denoted by Z. The DG output voltages are denoted by Ei∠δi, i = 1... 3. Each single phase DG is connected to the grid through external inductors as shown in fig. 1. In order to see the power quality an Induction motor is used as a load in the Grid side. Table 1 shows the system parameters

III. CONVERTER STRUCTURE AND CONTROL

In fig2 indicates the single phase converter circuit. Vdc is the dc voltage produced by the ideal DC source to the VSC. The converter is connected the cascaded form. The cascaded output is connected the primary winding of the transformer. The resistance and capacitor filter and inductor is placed in order to eliminate the switching harmonics. The line inductance Lg is physically connected to represent the output inductance of the converter-DG source combination. For all the single phase DG sources the same converter structure is used. The three phase compensator contains three such H-bridges. However, it is connected to the PCC without any output inductance. The schematic diagram is shown in Fig. 3. It is to be noted that for a DSTACOM, the dc bus contains a dc capacitor, whereas for a DG-compensator, the dc bus is supplied by an ideal voltage source.

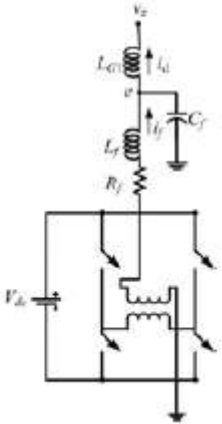


Fig. 2 Single Phase Converter Structure

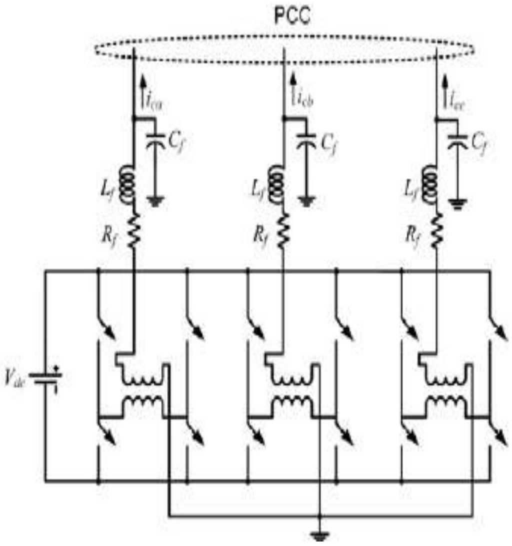


Fig.3 Three Phase Converter Structure For The Compensator

3.1 Control Of Single-Phase VSCS:

The single-phase VSCs are controlled under closed-loop feedback. Figure 4 shows the equivalent circuit of the converter. In this, u·Vdc represents the converter output voltage, where u is the switching function that can take on values ±1the converter is operated in such a s way the compensated voltage is developed. From the circuit of fig. 4, the state space analysis is given as:

$$\dot{x} = Ax + B_{1U_c} + B_2 v_{PCC} \qquad (1)$$

Where U_c is the continuous time control input, based on which the switching function u is determined. The discrete-time equivalent of (1) is

$$x(k+1) = Fx(k) + G_{1u_c}(k) + G_2 v_{PCC}(k) \qquad (2)$$

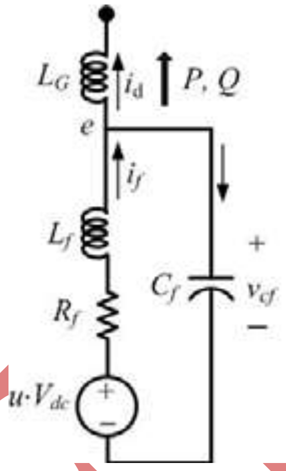


Fig. 4. Equivalent Circuit Of The Converter

v_{PCC} Represents the Voltage across the PCC and is neglected or eliminated assuming it to be a disturbance input, the input-output relationship of the system in (2) can be written in the following two forms

$$\frac{v_{cf}(z)}{u_c(z)} = \frac{M_1(Z^{-1})}{N(Z^{-1})}$$

$$\frac{i_1(z)}{u_c(z)} = \frac{M_2(Z^{-1})}{N(Z^{-1})} \qquad (3),(4)$$

The feedback control laws of the converters are generated as discussed below. The single phases DGs are controlled in a sinusoidal current limiting mode in which the output current is required to produce the maximum power. Let the Reference current for maximum available power be denoted as i_1^*. This is then tracked using a pole placement method to compute $u_c(k)$ from (4) [5].

III.II. Feedback Control of the Compensator

In the three phase compensator structure shown in Fig. 3, each of the cascaded -bridges are controlled in state feedback. For this, a state vector can be defined as $x^T = [v_{cf}\, i_{cf}\, i_1]$. The state feedback control law is

$$u_c(k) = K[x^*(k) - x(k)] \qquad (5)$$

Where K indicated the feedback gain matrix and x^* is the reference state vector. In this paper, this gain matrix is obtained using LQR method.

III.III. Switching Control

Once the reference signal ($u_c(k)$) is generated feedback loop the signal is send in the switching circuit Hysteresis current controller is the technique used to generate the pulses to the compensator. When the hysteresis loop is on 1 pulse is produced and when it is off 0 pulse is produced.

$$\text{If } u_c > h \; then \; u = +1$$

$$\text{Else if } u_c < -h \; then \; u = -1 \qquad (6)$$

Where h is a small number.

IV. REFERENCE GENERATION

In this session as stated earlier we come across the modes of operation, they are: Current feedback mode and state feedback mode. The reference signal generation of the two modes is discussed in this session.

IV.I Current Feedback

As discussed earlier when the power output of the DG suddenly reduces or the loads demands more than the rated output power from the DG, it is switched to a sinusoidal current limiting mode. The powers of the DG can be denoted as P rated and Q rated The magnitude and angle of the reference current is calculated from the voltage magnitude (V_z,) of the adjacent bus voltage as

$$I_1 = \sqrt{P_{rated}{}^2 + Q_{rated}{}^2} \Big/ V_z$$

$$\beta = \delta_2 - tan^{-1}(Q_{rated} \Big/ P_{rated}) \qquad (7)$$

Where δ_z is the angle of the bus voltage (V_z). The instantaneous quantities are then generated from these phasor quantities.

IV-II Three Phase DG-Compensator Reference Generation:

Current harmonics and the reactive power is compensated using the Compensator using D-statcom. If proper compensation is achieved, the currents i_g and i_2 will be balanced and so will be the voltage v_p provided that v_s is balanced. In addition, the DG-compensator can also supply a part of the real and reactive power required, whereas the DSTATCOM only supplies reactive power. Let us assume the three phases as a, b and c. Consider the circuit of Fig. 1 in which the current entering the distribution system from PCC is denoted by i_g and the current supplied to the distribution system is denoted by i_l. The compensator current is denoted by i_c such that the Kirchoff's current law (KCL) at the compensator coupling point is given by

$$i_{ck} + i_{gk} = i_{lk}, \; k = a, b, c \qquad (8)$$

Since, it is desired that the supplied currents are balanced, we have

$$i_{ga} + i_{gb} + i_{gc} = 0 \qquad (9)$$

Therefore combining (8) and (9) by adding the currents of the all three phases together, we get

$$i_{ca} + i_{cb} + i_{cc} = i_{la} + i_{lb} + i_{lc}$$

(10)

Since i_g is balanced due to the action of the compensator, the voltage v_p will also become balanced provided that the supply voltage is balanced. Hence, the instantaneous real powers P_G will be equal to its average components. Therefore it can be writen as

$$v_{pa}i_{ga} + v_{pb}i_{gb} + v_{pc}i_{gc} = P_G \tag{11}$$

From the KCL of (8), (11) can be written as

$$v_{pa}\left(i_{la} - i_{ca}\right) + v_{pb}\left(i_{lb} - i_{cb}\right) + v_{pc}\left(i_{lc} - i_{cc}\right) = P_G \tag{12}$$

Similarly the reactive powers Q_G and Q_C will be equal to their instantaneous components. Therefore we can write

$$\left(v_{pb} - v_{pc}\right)i_{ga} + \left(v_{pc} - v_{pa}\right)i_{gb} + \left(v_{pa} - v_{pb}\right)i_{gc} = \sqrt{3} \times Q_G \tag{13}$$

Using the KCL of (8), (13) can be written as

$$\left(v_{pb} - v_{pc}\right)\left(i_{la} - i_{ca}\right) + \left(v_{pc} - v_{pa}\right)\left(i_{lb} - i_{cb}\right) + \left(v_{pa} - v_{pb}\right)\left(i_{lc} - i_{cc}\right) = \sqrt{3}Q_G \tag{14}$$

Equations (10), (12) and (14) form the basis of the algorithm. From these three, the following can be written

$$A\begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = A\begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} + \begin{bmatrix} 0 \\ -P_G \\ -\sqrt{3}Q_G \end{bmatrix}$$

Where

$$A = \begin{bmatrix} 1 & 1 & 1 \\ v_{pa} & v_{pb} & v_{pc} \\ v_{pb} - v_{pc} & v_{pc} - v_{pa} & v_{pa} - v_{pb} \end{bmatrix} \tag{15}$$

The determinant of the matrix A is given by

$$|A| = v_{pa}\left(v_{pc} + v_{pb} - 2v_{pa}\right) + v_{pb}\left(v_{pa} + v_{pc} - 2v_{pb}\right) + v_{pc}\left(v_{pb} + v_{pa} - 2v_{pc}\right) \tag{16}$$

If v_p is balanced, then the following is true

$$v_{pa} + v_{pb} + v_{pc} = 0 \tag{17}$$

Substituting (17) in (16), the determinant of A is given as

$$|A| = -3\left(v_{pa}^2 + v_{pb}^2 + v_{pc}^2\right) \tag{18}$$

Computing the inverse of the matrix A, the solution of (15) is given as

$$\begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} + \frac{1}{|\Delta|} \begin{bmatrix} 3P_G v_{pa} + \sqrt{3} Q_G (v_{pb} - v_{pc}) \\ 3P_G v_{pb} + \sqrt{3} Q_G (v_{pc} - v_{pa}) \\ 3P_G v_{pc} + \sqrt{3} Q_G (v_{pa} - v_{pb}) \end{bmatrix} \tag{19}$$

Now let us stipulate that the utility supplies P_G that is λ_p times the average power P_{Lav} supplied to the distribution system and Q_G which is λ_q times the average reactive power Q_{Lav} supplied to the distribution system. This is given by the following two relations

$$P_G = \lambda_p \times P_{Lav}$$

$$Q_G = \lambda_q \times Q_{Lav}$$

(20)

V. FUZZY LOGIC CONTROLLER

The Fuzzy Logic Controller (FLC) is used as controller in the proposed model. The Fuzzy Logic tool was introduced in 1965, also by Lotfi Zadeh, and is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership _the important concept of computing with words‘. It provides a technique to deal with imprecision and information granularity. The fuzzy theory provides a mechanism for representing linguistic constructs such as 'many' 'low' 'medium' 'often' 'few'. In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. In fuzzy logic, basic control is determined by a set of linguistic rules which are determined by the system. Since numerical variables are converted into linguistic variables, mathematical modelling of the system is not required. The fuzzy logic control is being proposed for controlling the inverter action. FLC is a new addition to control theory and it incorporates a simple, rule based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically

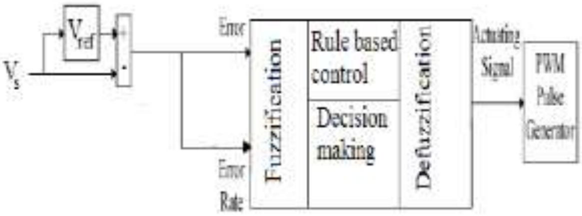


Fig.5 Block diagram of proposed control system

5.1 Error Calculation:

The error is calculated from the difference between supply voltage data and the reference voltage data. The error rate is the rate of change of error.

5.2 Fuzzification:

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy. Thus Fuzzification process may involve assigning membership values for the given crisp quantities. This unit transforms the non-fuzzy (numeric) input variable measurements into the fuzzy set (linguistic) variable that is a clearly defined boundary, without a crisp (answer). In this simulation study, the error and error rate are defined by linguistic variables such as negative big (NB), negative medium (NM), negative small (NM), zero (Z), positive small (PS), positive medium (PM) and positive big (PB) characterized by membership functions given in Fig. 7.

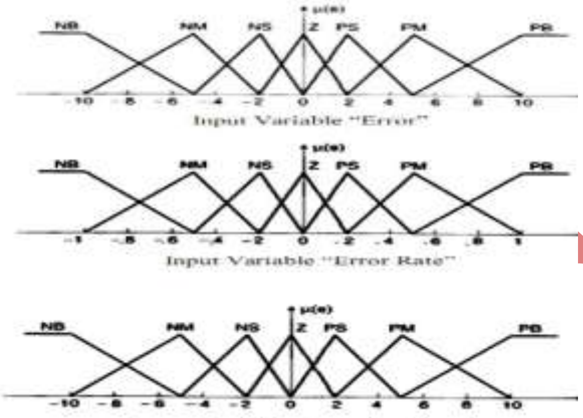


Fig 6 Membership Functions for inputs and output

5.3 Decision Making:

Fuzzy process is realized by Mamdani method. Mamdani inference method has been used because it can easily obtain the relationship between its inputs and output [11]. The set of rules for fuzzy controller are represented in Table II. There are 49 rules for fuzzy controller. The output membership function for each rule is given by the Min (minimum) operator. The Max operator is used to get the combined fuzzy output from the set of outputs of Min operator .The output is produced by the fuzzy sets and fuzzy logic operations by evaluating all the rules. A simple if-then rule is defined as follows: If error is Z and error rate is Z then output is Z

Table II

Ce\e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PM	PB	PB	PB

5.4 Defuzzification:

It is the process of converting the controller outputs in linguistic labels represented by fuzzy set to real control (analog) signals. Defuzzification means the fuzzy to crisp conversions. The fuzzy results generated cannot be used as such to the applications, hence it is necessary to convert the fuzzy quantities into crisp quantities for further processing. This can be achieved by using Defuzzification process. Centroid method is used for Defuzzification in the present studies.

5.5 Signal Processing:

The outputs of FLC process are the control signals that are used in generation of switching signals of the PWM inverter by comparing with a carrier signal.

V. SIMULATION STUDIES

Case-1: Without Compensator:

Table I Indicates the total load demand is more than the total maximum generation. Thus the rest of the power requirement has to be supplied from the utility. Let us assume that the system is operating in without any deviation in which DG-2 is supplying 3 kW and load Ld1 is not connected. Suddenly at 0.45 s, the power output of DG-2 raises to 7 kW. Furthermore, at 0.7 s, the load Ld1 gets connected drawing real and reactive power of 4.2 kW and 3.2 kVAr respectively. It can be seen that the maximum power supply by DG- 2 increase, while the load change has not impact on the maximum power supplied by any of the DGs. The oscillation in the power level is due to the unbalance in the three phases. At 0.45 s the utility power decreases as the power generation in DG-2 is increased, while at 0.7 s the utility supply is increased to supply the load change in phase b. Fig 7 represents the active and reactive power and fig8 represents the utility power. Fig 9 and Fig 10 represents the utility power and currents and the induction motor torque

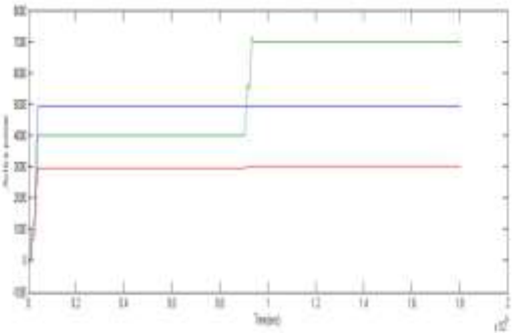


Fig 7: Active and Reactive power

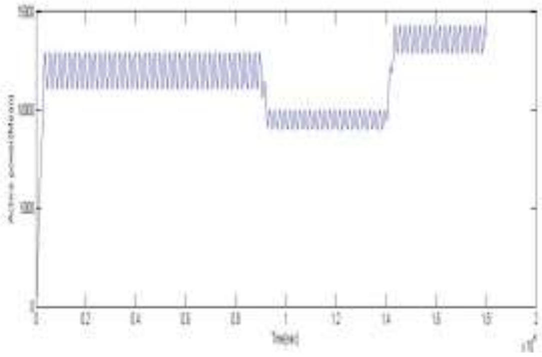


Fig 8: Utility power

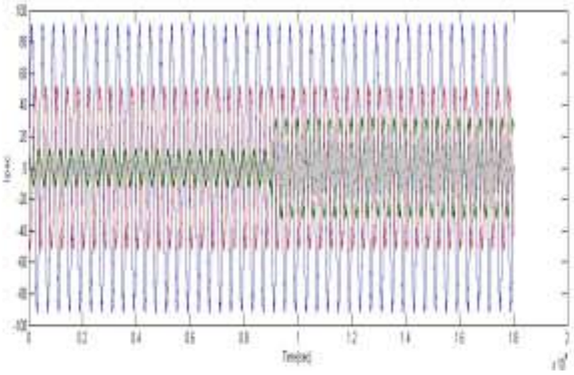
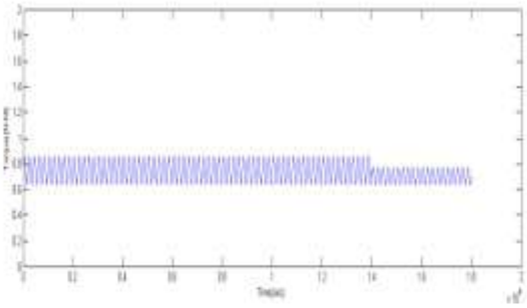


Fig 9: Unbalance utility power and currents



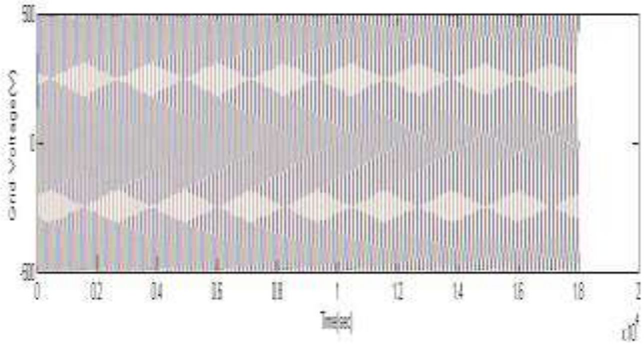


Fig 10: Induction motor torque and Voltage at PCC

Case-2: DSTATCOM Connected at PCC:

In order to compensate the unbalance in the system, a DSTATCOM is connected as a three phase compensator. DSTATCOM can share the reactive power requirement with utility in a pre-specified ratio. The DSTATCOM is connected to the system at 0.2 s and it is desired that DSTATCOM supply the 70% of the reactive power while balancing the utility currents. It can be seen that the utility currents gets balanced after the DSTATCOM connection. However, the DSTATCOM supplies unbalanced currents to compensate for the downstream unbalance. Fig 11a represents the Pcc currents and voltages and we can absorb that 0.2 sec d-statcom is connected and the pcc is compensated and the d-statcom currents can be seen in the fig 11b. And fig 11(c, d) indicates the reactive power of utility and the induction motor torque which is used as load.

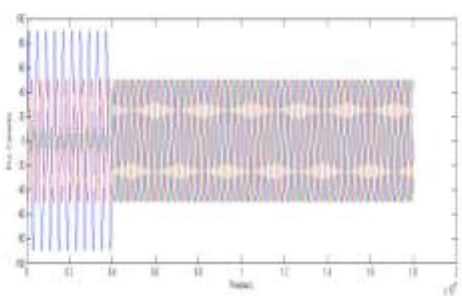


Fig (11a): Pcc Currents

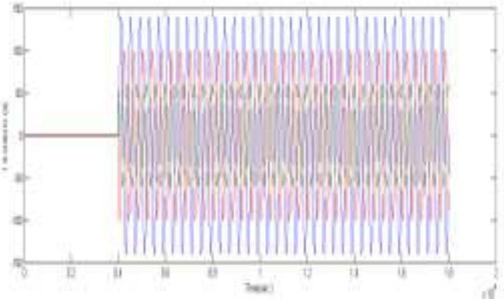


Fig (11b) Compensator current

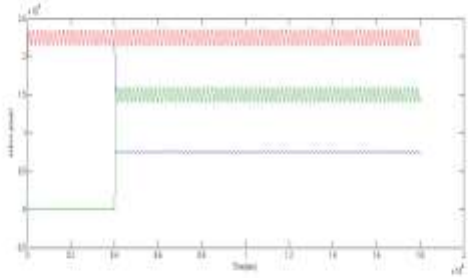


Fig (11c): active power from utility grid

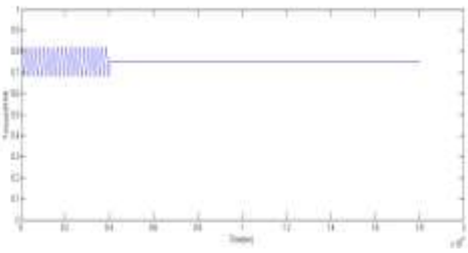


Fig (11d): Induction motor torque

Case-3:

DG-Compensator Connected at PCC While the DSTATCOM can only provide the required reactive power, a compensator connected with DG can also share the real power burden of the utility. Let us assume that the DG-compensator supplies 30% of the real and reactive power demand (PL, QL), when it gets connected to the system at 0.45 s. The system responses are shown in Figs.12 Fig. 12a, 12b shows the three phases current from utility and DG compensator. The real and reactive power sharing are shown in Fig. 12c, 12d. While utility provides balanced real and reactive power, the DG supplies the oscillating component alone in the desired ratio. The induction motor torque is shown in Fig. 12d.

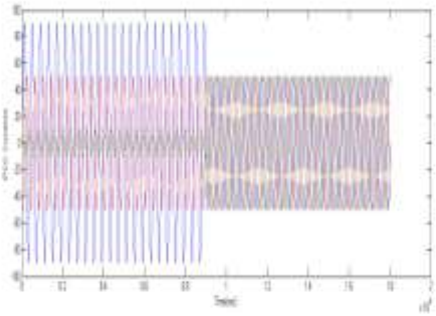


Fig 12a: PCC Current

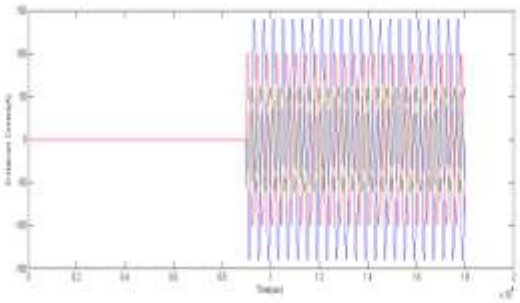


Fig 12b: Compensator current

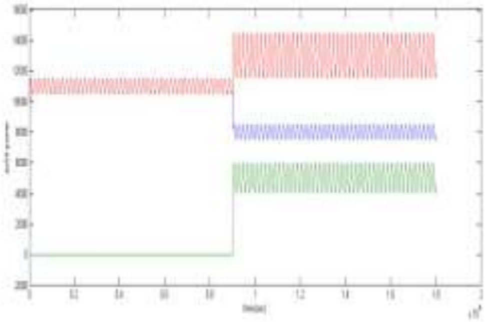


Fig 12c: Active power from Grid

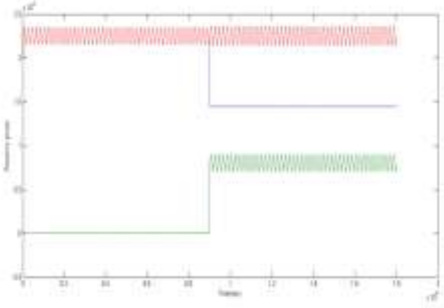


Fig 12c: Reactive power from Grid

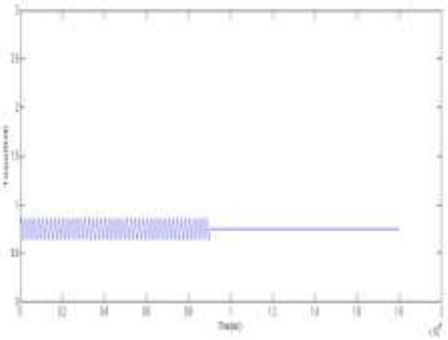


Fig 12d: Torque

Case 4: Nonlinear Loads:

In order to know whether DG is efficiently or not further a nonlinear loads are added to the linear loads Ld1, Ld4 and Ld5. It is assumed that the power consumed by these nonlinear loads is 20% of their linear counterparts. The results are shown in Fig. 13 where is DG-compensator is connected at 0.45 s. It can be seen from Fig. 13 (a) that the utility currents get balanced as soon as the DG-compensator is connected. The induction motor torque pulsation also ceases due to the DG-compensator connection as can be seen from Fig. 13 (b). The total harmonic distortion (THD) has been computed for this case. The THD of the grid voltage is about 10 % and the negative and zero sequence components are around 5 % of the positive sequence component before DG-compensation connection. These are then reduced such that the THD becomes less than 0.5 %, whereas, negative and zero sequence components of the voltages remain below 0.02 % once the DG compensator is connected.

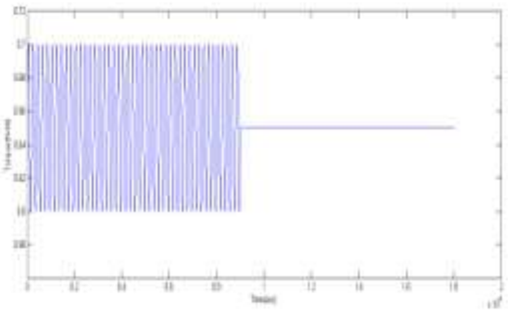


Fig 13a: Torque

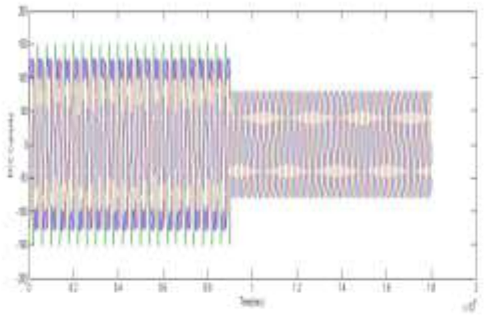


Fig 13b: PCC Voltage

VI. CONCLUSIONS

In this paper, Fuzzy logic based control of single phase DG sources are considered in a three-phase utility connected grid. The single phase sources are operated to deliver available maximum power generated while the rest of the power demands in each of the phases are supplied by utility (and if available, three phase DG sources). The imbalance in three phase power is compensated two ways –either through a DSTATCOM or through a DG-compensator. A DSTATCOM can compensate for unbalances and nonlinearities, while providing reactive power support. The size of the dc capacitor determines how much reactive power support the DSTATCOM can provide without any drop in voltage. The choice of this capacitor is thus a trade-off between the reactive support and system response [6]. Alternatively a three phase DG-compensator can be connected at the PCC to share the real and reactive power with utility and to compensate for the unbalance and nonlinearities in the system. The efficiency of the compensation is validated through extensive simulations with fuzzy logic controller it is possible to operate single phase DG sources in a utility connected grid and this might become a useful tool as their penetration in distribution systems increases.

REFERENCES

[1] B. K. Bose, “Energy, environment, and advances in power electronics,” IEEE Trans. on Power Electronics, vol. 15, pp. 688–701, July 2000.

[2] X. Yoasuo, C. Liuchen, B. K. Soren, B. Josep and S. Toshihisa, “Topologies of single-phase inverters for small distributed power generators: an overview”, IEEE Trans. on Power Electronics, vol. 19, pp. 1305-1314, Sep 2004

[3] T. E. McDermott, R. C. Dugan, “Distributed generation impact on reliability and power quality indices” Rural Electric Power Conference, 2002, pp D3-D3_7.

[4] Y. W. Li, D. M. Vilathgamuwa and P. C. Loh, “A grid-interfacing power quality compensator for three-phase three-wire microgrid applications,” IEEE Trans on Power Electronics, Vol. 21, Issue 4, pp. 1021-1031, July 2006

[5] A. Ghosh, A. K. Jindal and A. Joshi, “Inverter control using output feedback for power compensating devices,” Proc. IEEE Asia-Pacific Region-10 Conference TENCON, Bangalore, pp. 49-52, October 2003.

[6] A. Ghosh and G. Ledwich, "Load compensating DSTATCOM is weak ac systems," IEEE Trans. Power Delivery, Vol. 18, No. 4, pp. 1302- 1309, 2003.

[7] W. Freitas, A. Morelato, X. Wilsun and F. Sato, “Impacts of ac generators and DSTATCOM devices on the dynamic performance of distribution systems,” IEEE Trans. On Power Delivery, Vol. 20, No. 2, pp. 1493-1501, 2005.