

Power Quality Improvement with Renewable Sources for Non-Linear Load with PI and Fuzzy Controller

Farah Fahem Hussein¹, M. Manjula²

PG Student, Dept. of Electrical Engineering, University College of Engineering, Osmania University, Hyderabad, India¹

Associate Professor, Dept. of Electrical Engineering, University College of Engineering, Osmania University, Hyderabad, India²

ABSTRACT: 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 the grid-interfacing inverters when installed in 3-phase 4-wire distribution system. A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a misoperation of end user equipment. 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. The inverter is utilized as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All of these functions are accomplished either individually or simultaneously. With such a control, the combination of grid-interfacing inverter and the 3-phase 4-wire linear/non-linear unbalanced load at point of common coupling appears as balanced linear load to the grid. The system is modelled in MATLAB/ Simulink environment and simulations carried out to verify the operation and the control principle in the power system.

KEYWORDS: Active power filter (APF), distributed generation (DG), power electronic interface, distribution system, grid interconnection, power quality (PQ), renewable energy.

I. INTRODUCTION

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG), such as PV that can be considered for electric power generation at the distribution system level. In the present generation the use of RES plays an important role in the power system. The need to use the renewable energy sources like the photo voltaic power to integrate into power system is to make it possible to minimize the environmental impact on conventional plant. The integration of solar energy into existing power system presents technical challenges and that requires consideration of power quality problems like voltage instability and harmonic distortions etc [1-4].

Power Quality is defined as power that enables the equipment to work properly. It can be also defined as the degree to which both the utilization and delivery of electric power affects the performance of electrical equipment. As per the IEC 51000-4-30: power quality is defined as "The characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical [2] parameters". The power quality problems will results in Frequency fluctuation, Voltage Sag, Voltage Swell, Harmonics and Inrush currents [7]. The non-linear loads are the causes for the harmonic disturbances and several power quality problems. One of the solution to this problem is to use shunt active Power Filter, however it is not economical. But this paper instead of shunt active filter a grid interfacing inverter is used for power quality improvement features. The sources of the grid interfacing inverter used in this work are PV. The main functions of the proposed grid connected inverter are as follows. The block diagram of the proposed system is shown in Figure.1.

- 1) Active power flow from Renewable Sources like solar source
- 2) Support of Load Reactive Power;

- 3) Harmonics compensation; and
- 4) Unbalance current correction.

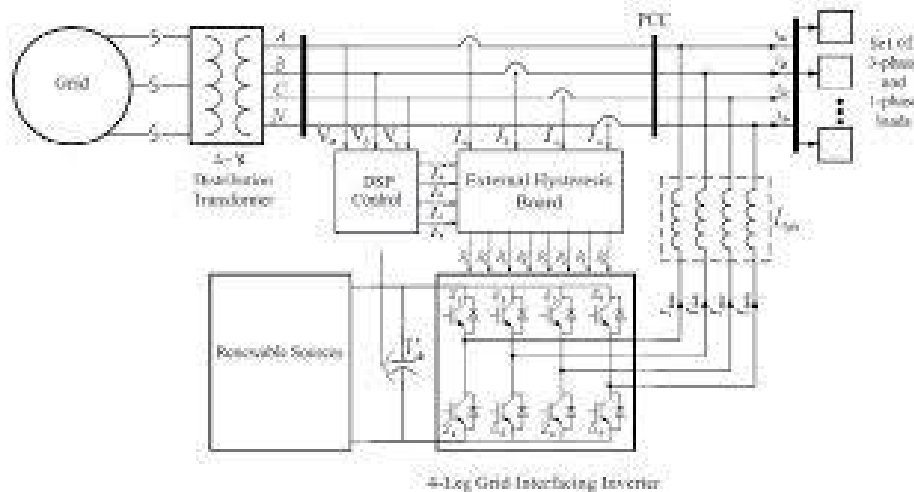


Fig.1. Block Diagram of Proposed System

II. PHOTO VOLTAIC CELL MODULE

A PV cell is the basic structural unit of the PV module that generates current carriers when sunlight falls on it [9]. The power generated by these PV cell is very small. To increase the output power the PV cells are connected in series or parallel to form PV module [10]. The equivalent circuit of the PV cell is shown in figure 2.

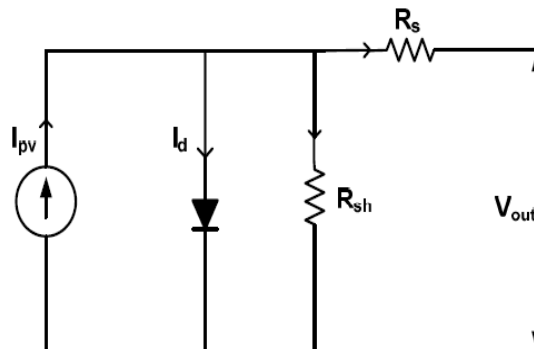


Fig.2. Equivalent circuit of the PV cell

The main characteristics of the PV cell are given by

$$I = I_{pv} - I_o \left[\exp \left(\frac{q(V + IR_s)}{\alpha KT} \right) - 1 \right] - \frac{V + IR_s}{R_{sh}}$$

$$I_o = I_{o,n} \left(\frac{T_n}{T} \right)^3 \exp \left[\frac{qE_g}{\alpha K} \right] \left(\frac{1}{T_n} - \frac{1}{T} \right)$$

$$I_{pv} = [I_{sc} + K_i(T - T_n)] \frac{G}{G_n}$$

Where

I and V- Cell output current and voltage
Io- Cell reverse saturation current

- T- Cell temperature in Celsius
- K- Boltzmann's constant
- q- Electronic charge
- Ki- short circuit current/temperature coefficient
- G- Solar radiation in W/m²
- G_n- nominal solar radiation in W/m²
- E_g- energy gap of silicon
- I_{0,n}- nominal saturation current
- T_n- nominal temperature in Celsius
- R_s- series resistance
- R_{sh}- shunt resistance
- α- ideality factor between 1.0 to 1.5
- I_{pv}- light generated current

The I-V characteristic of a PV module shown in Figure.3 is highly non-linear in nature. This characteristics drastically changes with respect to changes in the solar radiation and temperature. Whereas the solar radiation mainly affects the output current, the temperature affects the terminal voltage. The I-V characteristics of the PV module under varying solar radiation at temperature T=250 is shown below [4].The data of the PV system used in this are taken from msx50i type of panels.

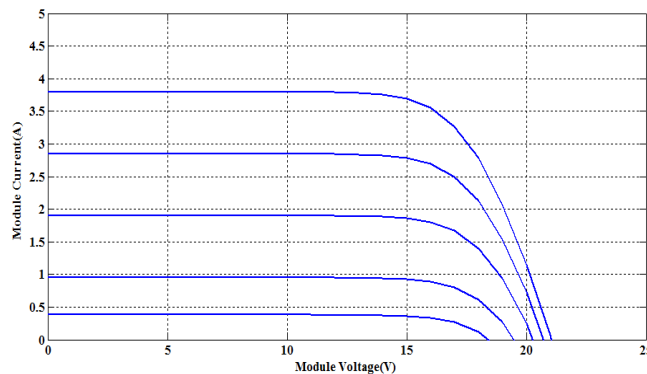


Fig.3. Current versus voltage at constant cell temperature T=250, irradiation G=100,250,500,750,1000w/m²

Figure 4, I-V characteristics of the PV module (varying cell temperature at constant solar radiation (1000 W/m²)).

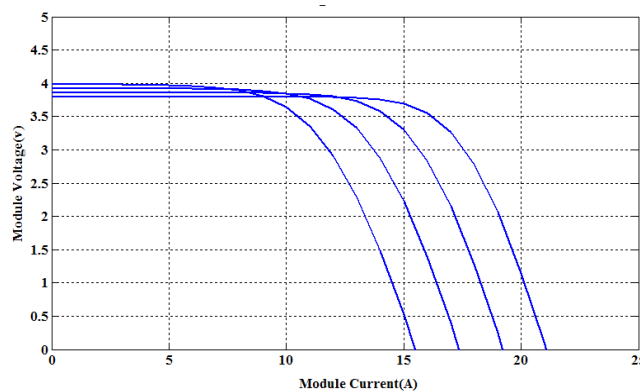


Fig. 4. Current versus voltage at constant solar radiation G = 1000 W/m², t=25,50,75,100deg cent

III. FOUR-LEG INVERTER

This topology is known to produce balanced output voltages even under unbalanced load conditions. In case of Four Leg Inverter the neutral point to the midpoint of the 4th neutral leg [5] & 4-leg inverter topology. The fourth leg of the inverter is used to compensate the load neutral current. This allows it to maintain balanced output voltage in case of unbalanced and non-linear loads. The main aim is to regulate the power at the point of common coupling.

Figure 5 shows the basic compensation principle of the APF. APF is designed to be connected in parallel with the load, to detect its harmonic current and to inject into the system a compensating current, identical with the load harmonic current. Therefore, the current draw from the power system at the coupling point of the filter. The 4-leg inverter uses 1-leg specially to compensate zero sequence (neutral) current.

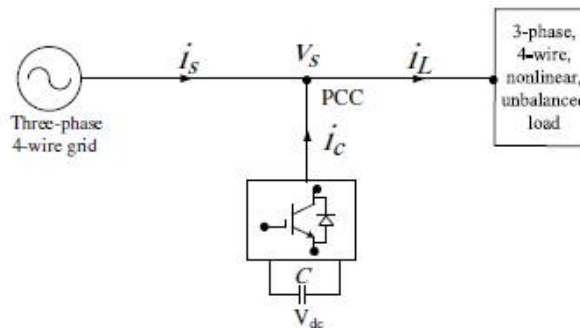


Fig.5. The basic compensation principle of the APF

The 3-leg inverter is preferred for due to its lower number of switching devices, the 4-leg inverter has advantage to compensation for neutral current by providing 4th-leg and to need for much less DC-link capacitance and has full utilization of DC-link voltage [8].

The active power filter consists of 8 switches in which 6 switches are used for the 3-phase line and the remaining 2 switches are used to compensate the neutral current. As the pulses are generated from the control circuit which is designed for the inverter for triggering the switches in order to switch on the switches alternatively by using the gate to compensate the harmonics in current at the point of common coupling. As the inverter is operated in such a way that it is used to draw and supplies the fundamental active power from to the grid.

IV. CONTROL CIRCUIT

This paper uses a Unit vector control based scheme as shown in Figure 7 for generating the gate pulses for the inverter. In this scheme first the source voltage is sensed and by using PLL the shape of the voltage is derived and it is taken as the reference shape for the current. Now the reference dc voltage and actual are compared and given to the PI controller to change it as the current magnitude. The obtained shape and magnitudes of the current are multiplied and such that the reference currents are obtained for the three phase in the same manner. The obtained reference and actual currents are compared and by using Hysteresis controller the pulses for the inverter are determined [5]

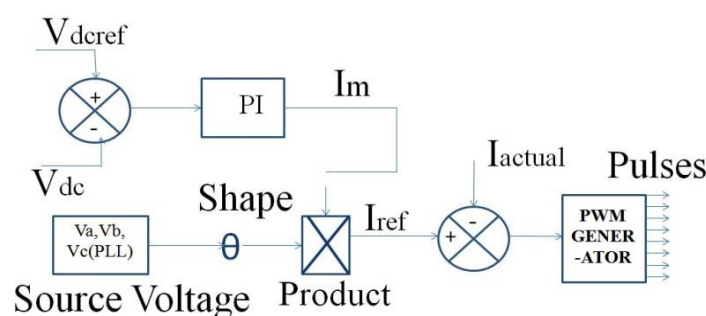


Fig.7. Control Scheme

From the control circuit the grid synchronizing angle is obtained and it is used for calculating the unit vector template.

$$\begin{aligned} U_a &= \sin\theta \\ U_b &= \sin(\theta - 120) \\ U_c &= \sin(\theta - 240) \end{aligned}$$

The reference DC voltage and actual DC voltages are compared and the voltage error is given to the PI controller to extract the current magnitude. The obtained current magnitude I_m is multiplied with the unit vector templates to generate the reference currents I_a^* , I_b^* , I_c^* .

$$\begin{aligned} I_a^* &= U_a * I_m \\ I_b^* &= U_b * I_m \\ I_c^* &= U_c * I_m \end{aligned}$$

The obtained source currents are compared with actual currents I_a , I_b , I_c and the error is given to the Hysteresis controller to generate the pulses to the switches of four leg Inverter.

In this paper fuzzy controller used as a new non-linear controller as shown in Fig.8.

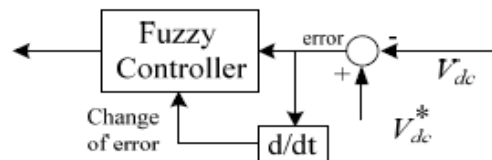


Fig.8. DC-link voltage FLC

FLCs are independent of system model. The design is mainly based on the intuitive feeling and designer experience of the process. The rules are expressed as: error e is and change of error de .

The controller fuzzy partitioned subspaces negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), and positive big (PB) are used. These seven membership functions are same for inputs and output. FLC rules are summarized in Table 1.

TABLE 1. ELEMENTS OF THE RULE TABLE TO FUZZY LOGIC CONTROLLER

e \ de	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	NL	NM	NS	ZE	PS	PM	PL

The FLC blocks; fuzzification, rule-base, inference and de-fuzzification, are shown in Fig.9.

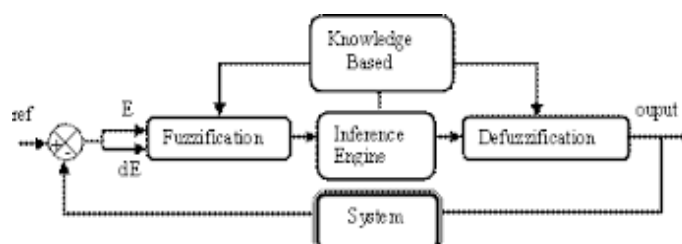


Fig.9. FLC block diagram

V. MATLAB/SIMULINK CIRCUITS AND RESULTS

Parameters of the System

In this work the grid voltage provides 3 phase rms voltage is 11kV that connected to the common coupling point through a distribution step down transformer to supply power to the load, the injected power from SAPF at pcc is provide from the solar equivalent circuit ,the table of parameters is :

TABLE 2. SYSTEM PARAMETERS

No.	System Quantities	Parameters Values
1	Source	3 phase, 11kV,50Hz
2	Solar DC voltage	800 vdc, 1200vref.
3	3 phase Δ/Y winding transformer	11kV Δ/415V Y
4	Non-linear load	3phase, 4 wire diode rectifier circuit, L1=(R= 20Ω , L=20mH), L2=(R=20Ω , L=20mH), L3=(R= 20Ω , L=20mH)
5	3 phase unbalance load	L7=(6Ω+4mH), L8=(15 Ω+8mH), L9=(8 Ω)
6	Shunt active power filter	IGBT Based, 3Ø, 4-leg inverter, Lsh=1mH, C=100e-3 F
7	Load ratings	P=8kW, Q= 14kVAR , I _{load} =20amp,
8	PI-Controller	K _p =1 , k _i =0.01

CASE 1: Simulink Model of the System with PI Controller

The below Fig. shows the Matlab/ simulink circuit of the system that consists of three phase grid, nonlinear unbalanced load, and a renewable energy sources based inverter. A breaker is connected in between the pcc and the four leg inverter this breaker keeps the inverter not connected until 0.6 s and at 0.6 s it makes the inverter connected at pcc.

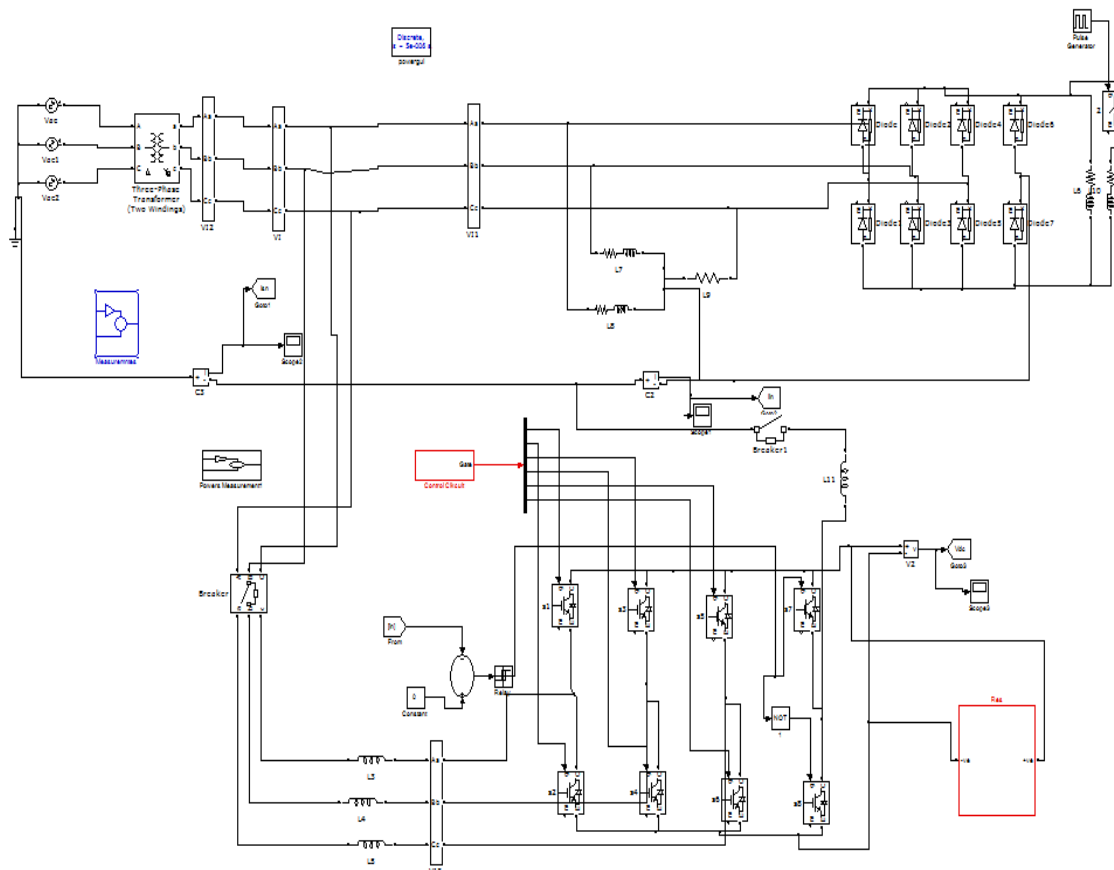


Fig.10. Matlab/simulink circuit of the system

The figure.11 shows the simulation of the 3 phase control circuit which uses PI controller as the voltage regulator and phase angle of one of the three phases from three phase sinusoidal voltages V_a , V_b and V_c as inputs to the PLL. The output computed when divided by $V_t = \sqrt{2/3} (v_a^2 + v_b^2 + v_c^2)$ and uses the relay as the hysteresis Current Controller to produce the triggering pulses for switching the SAPF.

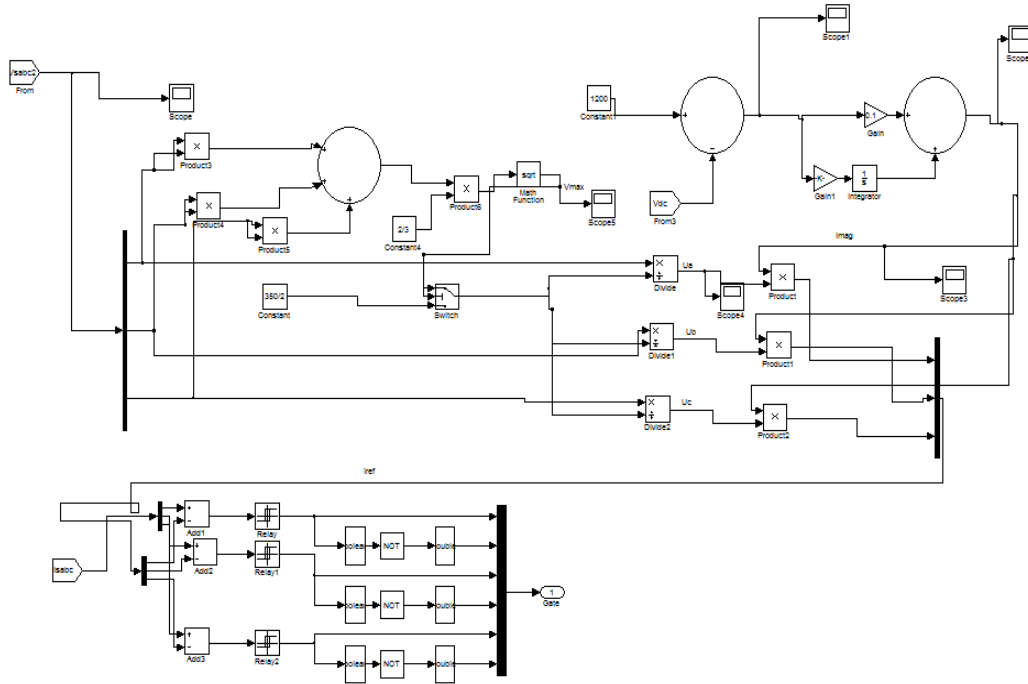


Fig.11. Matlab/simulink of the control circuit

The output waveforms of source current ,load current and inverter injected currents are as shown in Figure12. The source current is not sinusoidal till 0.6 s as inverter is not connected; when the inverter is connected the source current is sinusoidal and the load behaviour is resistive in nature.

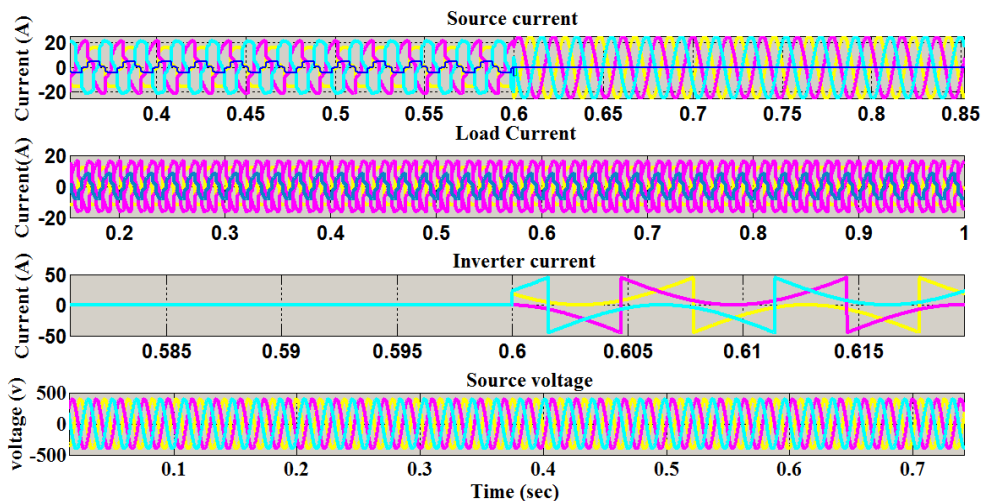


Fig.12. Output currents and voltage source of case 1

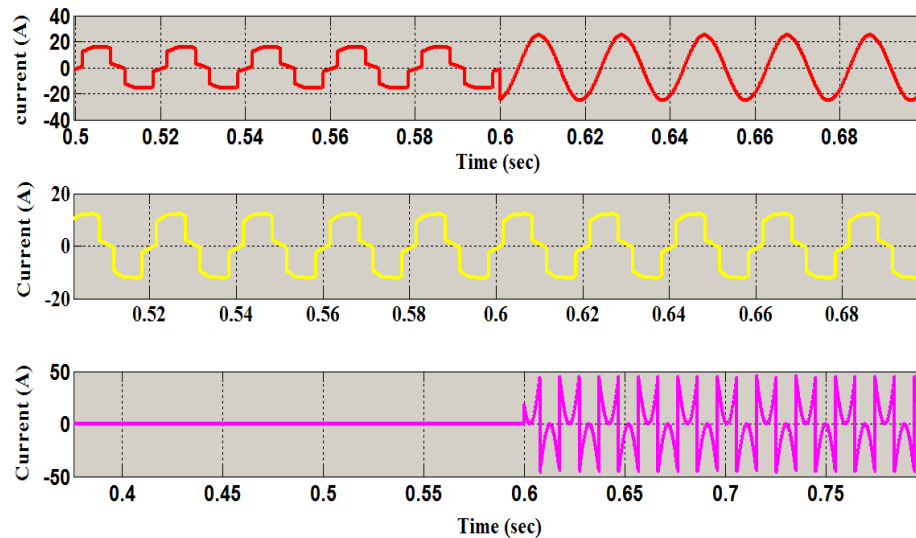


Fig.13. The simulation output of one phase to source, load and inverter currents respectively

The Figure14 shows the power factor waveform before inverter operation, both the source voltage and source current are not in phase. From 0.6s when inverter is switched on, the power factor is unity, voltage and current are in phase.

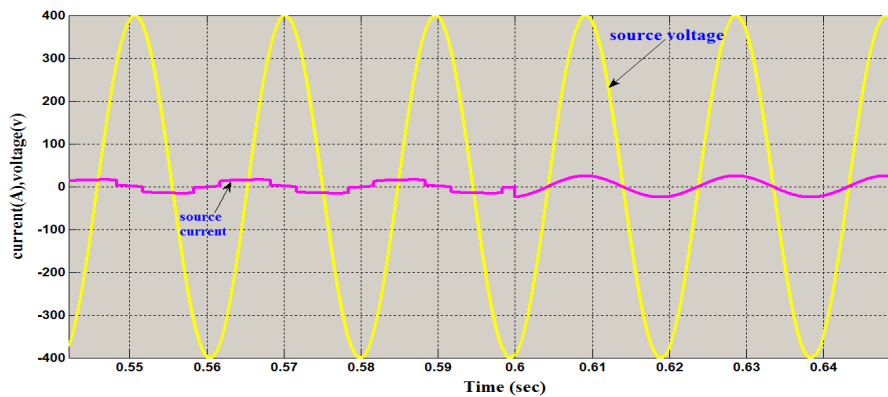


Fig. 14. The p.f wave form of case 1

The Figure 15 shows wave form of the neutral source current which has a value of the 3 phase unbalance nonlinear load and compensated after 0.6 s when the inverter connected to the pcc.

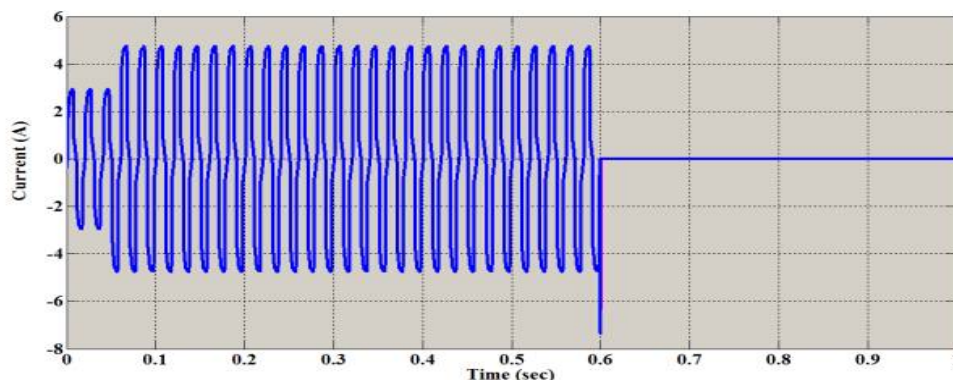


Fig.15. The neutral source current

The Figure 16(a) and 16(b) shows the total harmonic distortion analysis of both load current and source current .the total harmonic distortion values for load current is 24.13% while for source current is 4.79%.

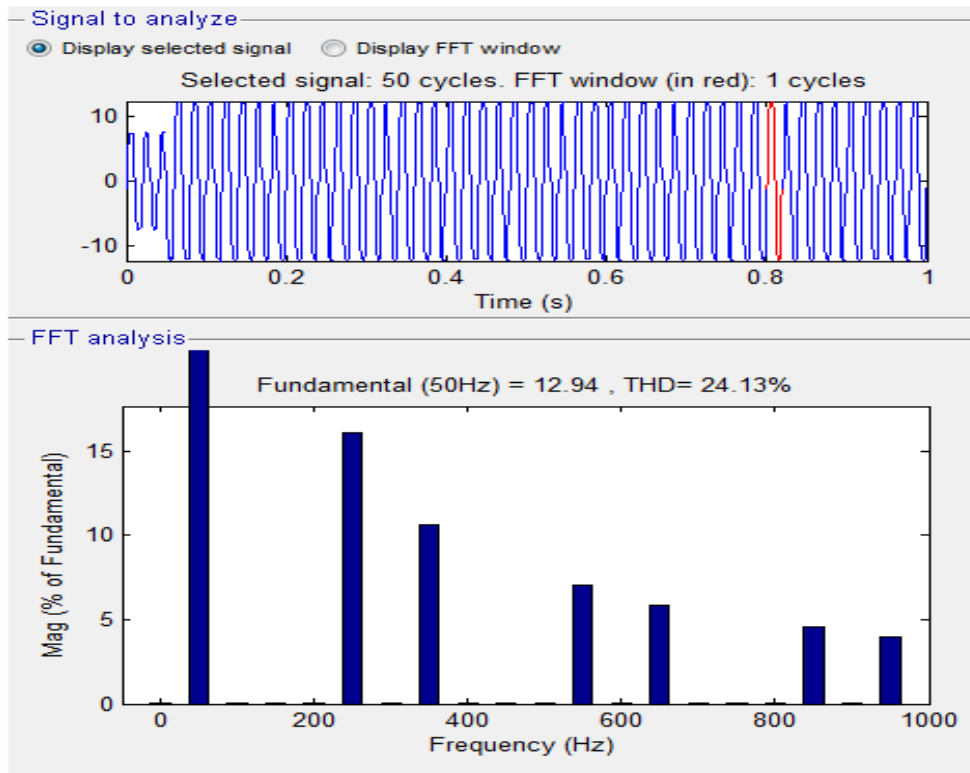


Fig.16(a). Load current THD

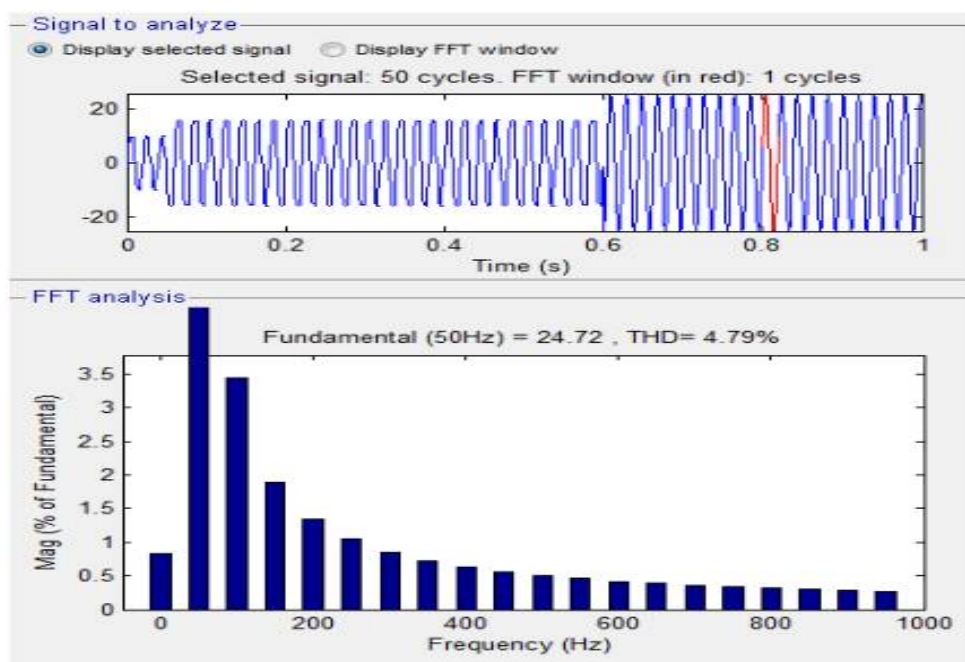


Fig.16(b). Source current THD

The active-reactive powers of grid, load and inverter are shown in that Fig. 18(a), (b) and (c) Positive values of grid active-reactive powers and inverter active-reactive powers imply that these powers flow from grid side towards PCC and from inverter towards PCC, respectively.

At 0.6 s, the inverter injected active power generated from RES. Since the generated power is more than the load power demand the additional power is feedback to the grid. The negative sign of P_{grid} , after time 0.6 s suggests that the grid is now receiving power from RES.

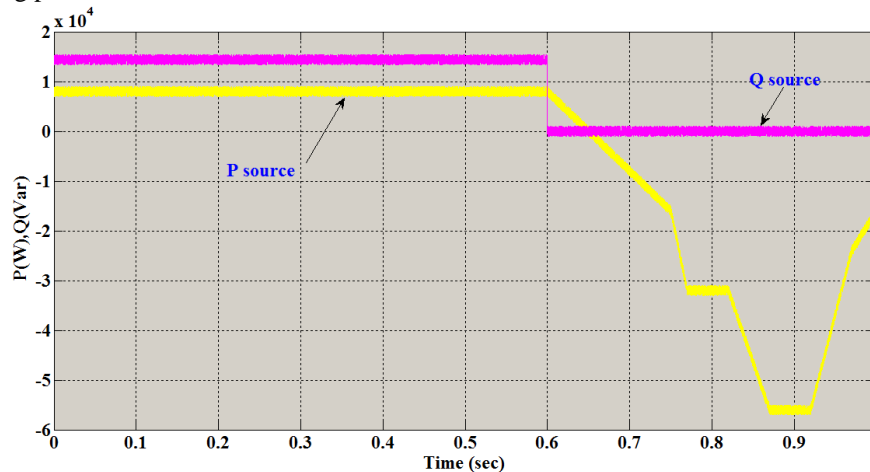


Fig.17(a). PQ-Grid

The active and reactive power for load is constant and negative sign because the load absorbs power, the active power is 8kW and the reactive power is 14 kvar .

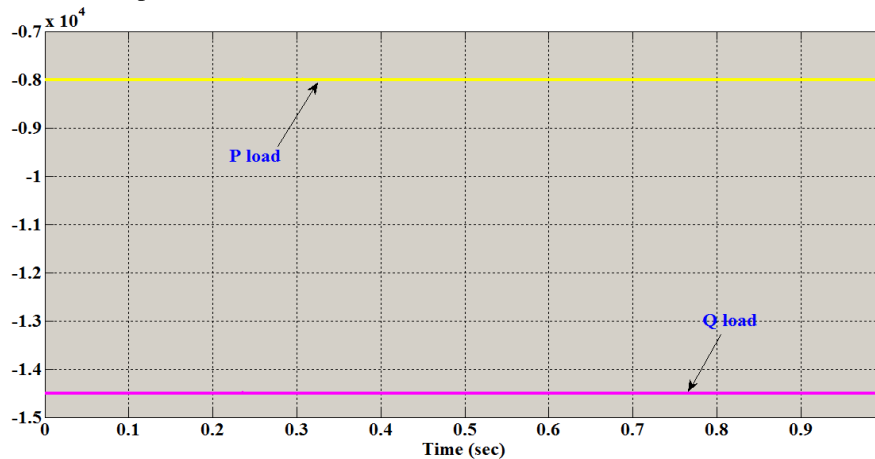


Fig.17(b). PQ-Load

Figure 17(c) below shows the waves for P and Q for inverter are opposite to that of source (grid), because of the power which absorbs by grid it is same that power injected from SAPF.

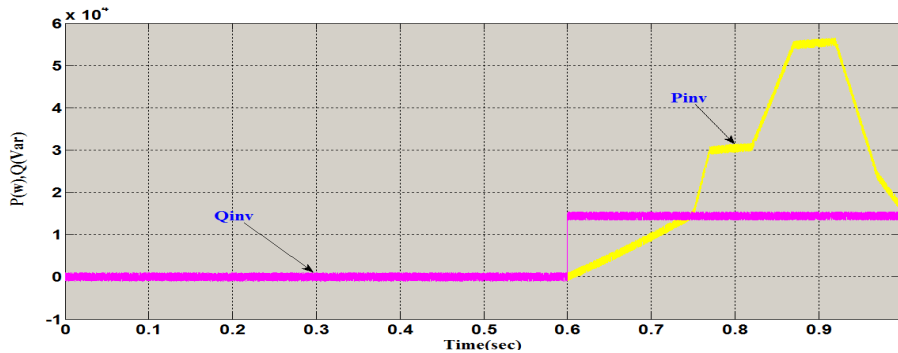


Fig.17(c). PQ-Inverter

Case2: Simulink Model to Control Circuit of the System with FLC

The below Figure 20 shows the Matlab/ simulink of the control circuit with fuzzy controller which connected instead of PI-controller where the two inputs to fuzzy controller are error and change of error when used the derivative

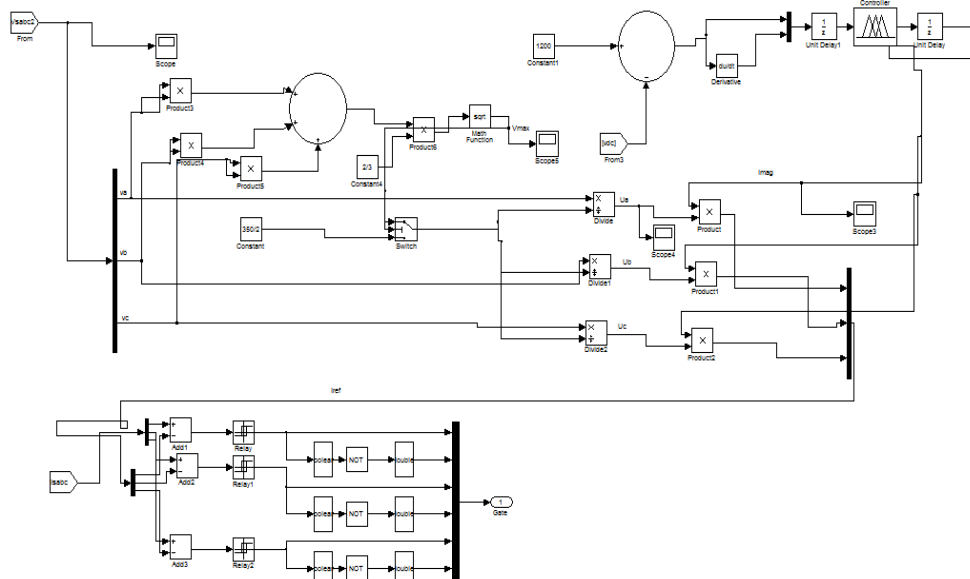


Fig.18.The Matlab/simulink of the control circuit with fuzzy controller

The below Fig.19.(a), (b), (c) and (d) shows the simulation output waveforms of source current, load current, inverter injected currents and source voltage. It is clear that the source current is unsinusoidal until 0.6 sec as inverter is not connected; when the inverter is connected at that time the source current becomes sinusoidal.

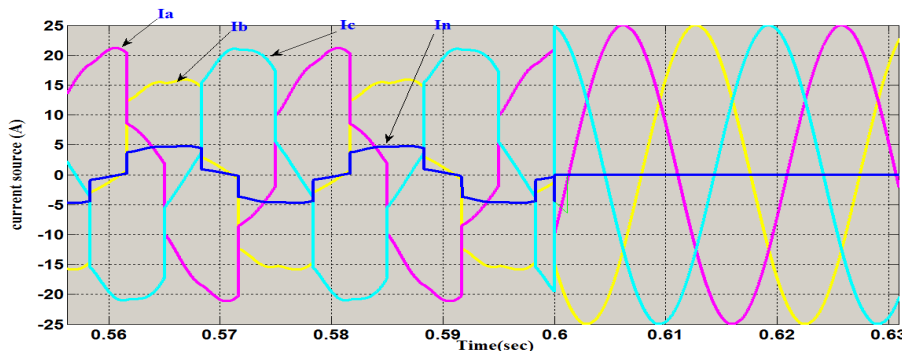


Fig. 20(a). source current

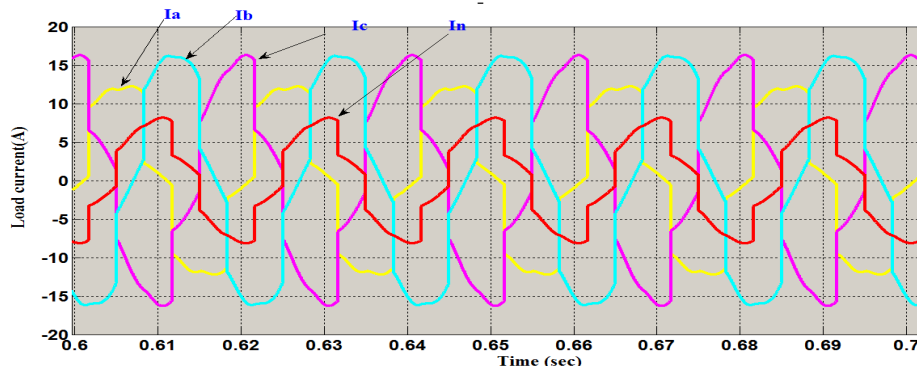


Fig. 20(b). Load current

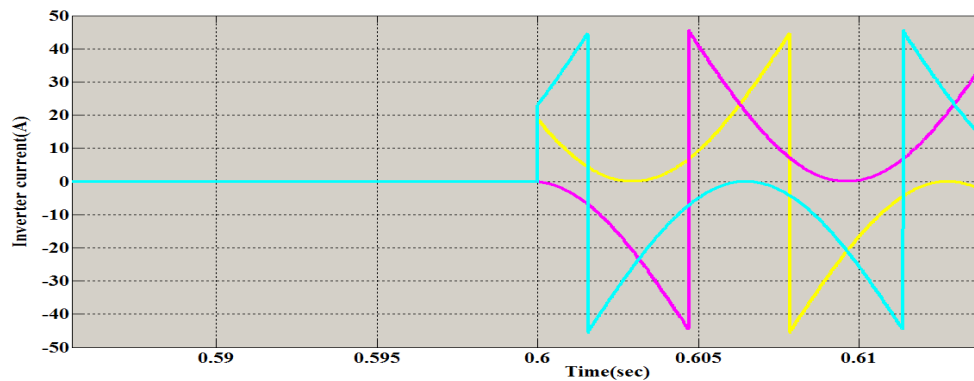


Fig. 20(c). Inverter current

Also this work in case of FLC circuit that improve the p.f as unity power factor after inverter injected at 0.6s is as shown in Figure 21 .

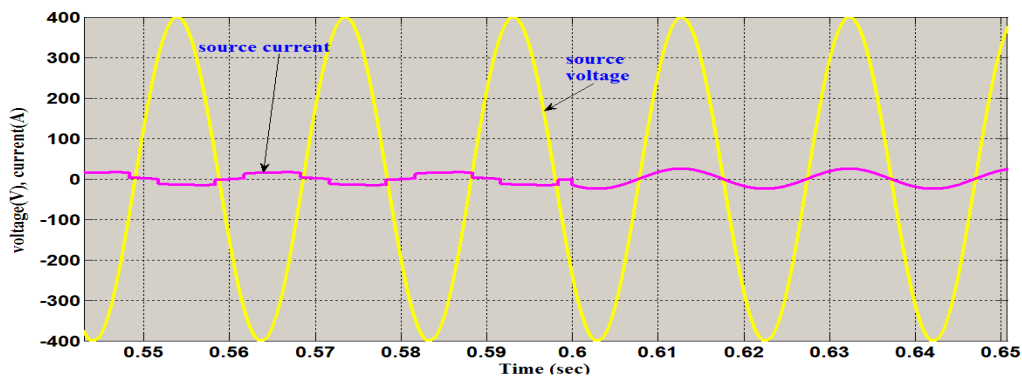


Fig.21. The p.f wave form of case 2

In case of FLC circuit that compensate neutral source current equal to zero after inverter injected at 0.5 sec is as shown in Figure 22..

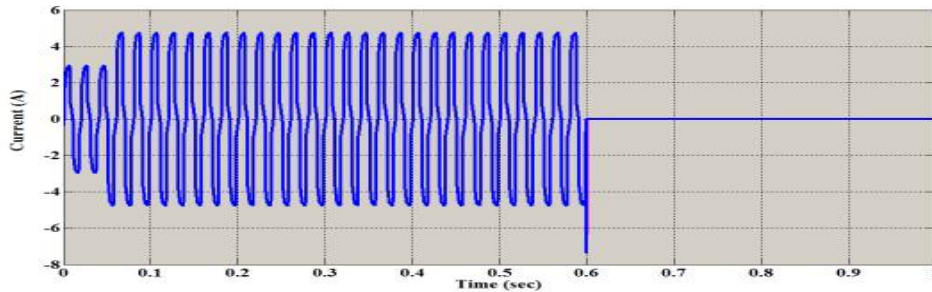


Fig.22. The neutral source current

The Figure 23(a) and (b) shows the total harmonic distortion analysis of both load current and source current, the total harmonic distortion is 24.13% while for source current it is 1.98% with Fuzzy controller.

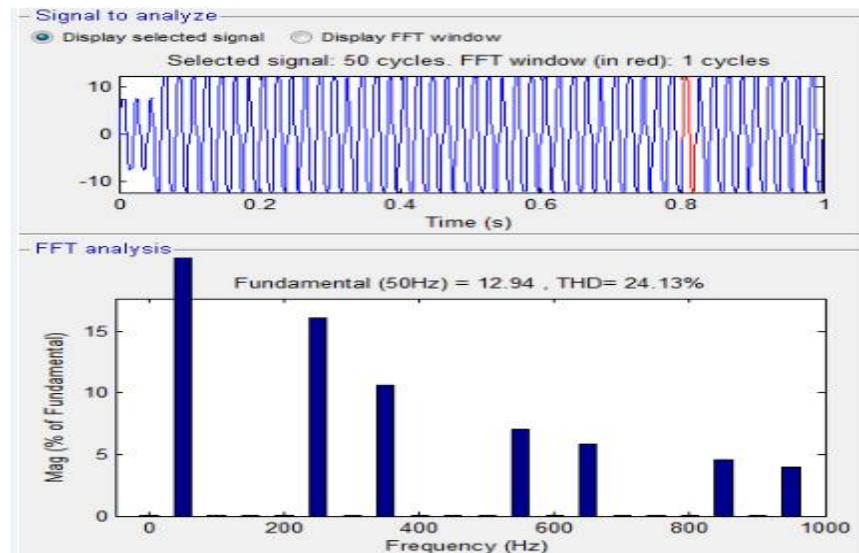


Fig.23(a). Load current THD

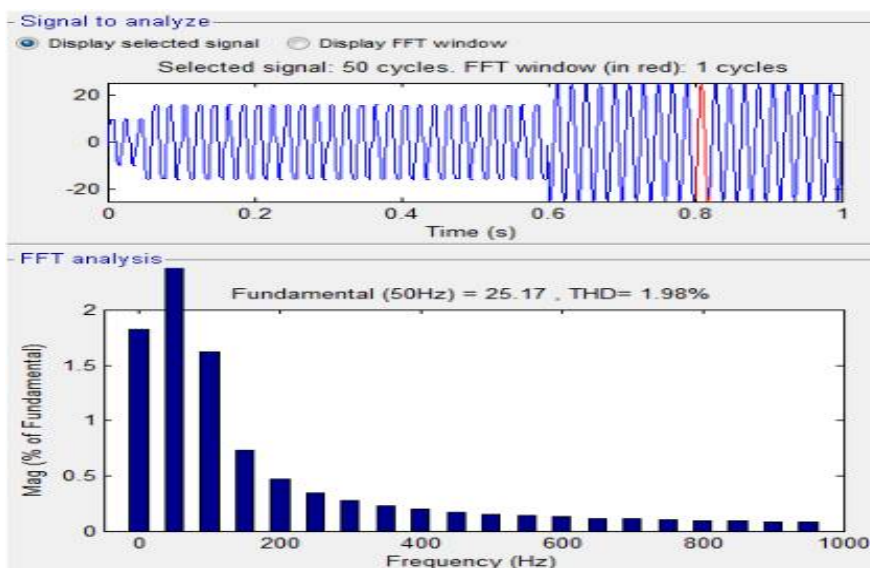


Fig.23(b). Source current THD

The active and reactive powers for source, load and inverter are shown in Fig. 24. below where the active power is injected the grid in 0.6s as feedback power to the grid as negative sign and the reactive power become zero value at 0.5s injected time because the load behavior as resistive load .

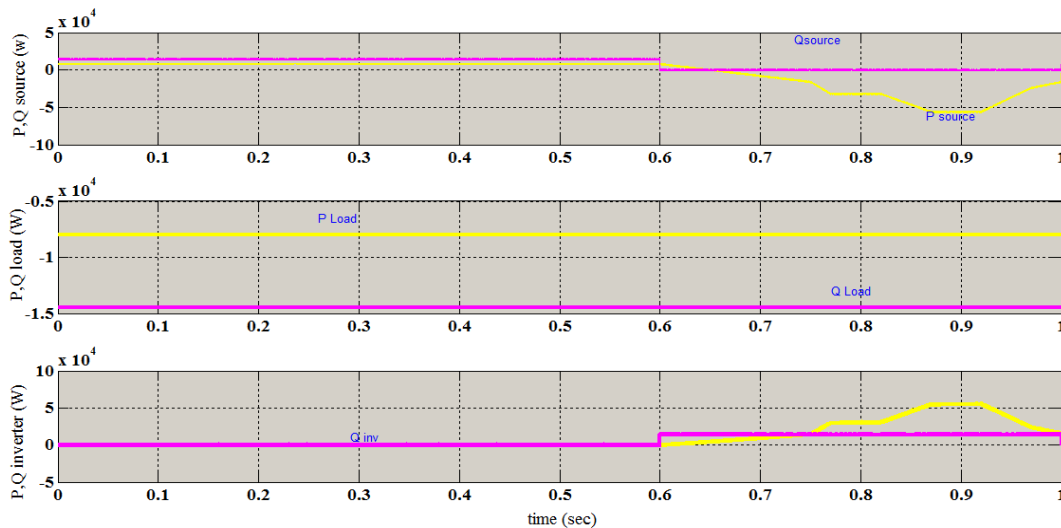


Fig.24. PQ for source, load and inverter

TABLE 3. THD OF LOAD AND SOURCE CURRENTS

No. of Cases	THD % (load)	THD % (source)
Case 1 (PI)	24.13	4.79
Case 2 (FLC)	24.13	1.98

Case 3: Results of the System with Two Parallel Solar Sources

In this result the load current is increased after adding extra load at 0.8 sec. at the same time the inverter current also increased which supplied the increased in load. Figure 25 shows source, load and inverter currents respectively.

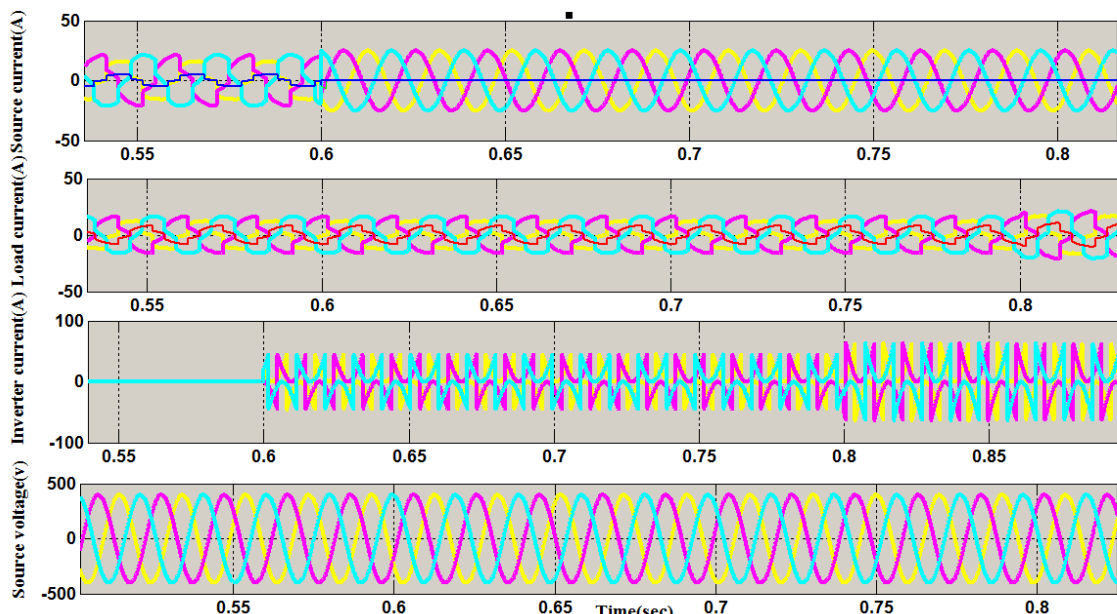


Fig.25. Waveforms of source, load ,inverter currents and source voltage respectively

VI. CONCLUSIONS

This paper has presented a novel control of an existing grid interfacing inverter to improve the quality of power at PCC for a 3-phase 4-wire DG system. It has been shown that the grid-interfacing inverter effectively utilizes the power conditioning without affecting its normal operation of real power transfer. The grid-interfacing inverter with this approach is utilized to

- i) inject real power generated from RES to the grid, and/or
- ii) operate as a shunt Active Power Filter (APF).

This paper also describes the performance of the controller with fuzzy logic. The simulation of power system scheme is evaluated under three cases:

- Using PI controller.
- Using Fuzzy Logic Controller.
- Using Fuzzy Logic Controller with two parallel solar sources connection.

The fuzzy logic controller has given the better results and is more efficient than PI controller. The harmonics are reduced as the THD level is decreased. Also when connected solar source in parallel the system becomes more efficient to supply extra inverter current which is injected at PCC when the load is increased.

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. Jintakosonwitt, 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] J. P. Pinto, R. Pregitzer, L. F. C. Monteiro, and J. L. Afonso, "3-phase 4-wire shunt active power filter with renewable energy interface," presented at the Conf. IEEE Renewable Energy & Power Quality, Seville, Spain, 2007.
- [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, "Power electronic 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] B. Renders, K. De Gussemme, W. R. Ryckaert, K. Stockman, L. Vandevelde, and M. H. J. Bollen, "Distributed generation for mitigating voltage dips in low-voltage distribution grids," *IEEE Trans. Power Del.*, vol. 23, no. 3, pp. 1581–1588, Jul. 2008.
- [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] M. Singh and A. Chandra, "Power maximization and voltage sag/swell ride-through capability of PMSG based variable speed wind energy conversion system," in *Proc. IEEE 34th Annu. Conf. Indus. Electron. Soc.*, 2008, pp. 2206–2211.
- [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. 2007.