Power Quality Improvement of Fuel Cell and Wind Farm Based Distributed Generation System

Anumol C.G.
Deparment of Electrical and Electronics
Mangalam College of Engineering
Kottayam, India

Reema Manavalan
Assistant Professor, Dept. of Electrical and Electronics
Mangalam College of Engineering
Kottayam, India

***Abstract*—Inthis work a fuel cell and a wind farmare integrated to a three phase four wire distribution system. When small renewable energy systems are connected to the electric grid it will inject harmonic components that may deteriorate the power quality.The inverter is controlled on the basis of hysteresis control and thus it can be utilized as a power converter injecting power generated from fuel cell and wind farm to the grid and as a shunt APF to compensate the current harmonics. Simulations are carried out using MATLAB/SIMULINK software to demonstrate the control concept.**

Keywords—*distributed power generation; power quality; renewable energy; shunt active filter*

I. Introduction

Nowadays, more and more distributed generation and renewable energy sources are connected to the public grid through power inverters. Distributed generation (DG) systems offer high reliable electrical power supply. The concept is interesting when different kinds of energy resources are available, such as photovoltaic panels, fuel cells, or speed wind turbines. Due to increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution [1].

There are many control schemes based on droop control method to achieve good active and reactive power sharing when communication between the inverters is difficult due to its physical location.An instantaneous current control loop is also used to ensure proper sharing of harmonic components when supplying nonlinear loads [2]. Power quality phenomenon is investigated by using extensive laboratoryexperiments, as well as computermodelingof different inverter topologies [3]. In [4] aload sharing technique is used that will share harmonic currents among converters equipped with active compensation for harmonic distortion without mutual communication. To solve the harmonic propagation active filters are installed on power distribution systems. The theoretical researches on active filters for mitigating voltage harmonics have done in [5]. A Shunt Active Filter along with a controller which is able to dynamically limit the output current allows an effective protection of the inverter semiconductors without diminishing the active filter performance [6].

An overview of the main distributed power generation systems and the control structures for grid side converter are discussed in [7]. In [8] new trends in power electronic technology for the integration of renewable energy sources and energy storage systems are presented. In [9] the behavior of grid coupled DG units during voltage dips in low voltage distribution grids are investigated. The presence of a DG unit on the distribution feeder will mitigate the voltage dips as experienced by the load connected to the equipment terminals. A new control strategy is proposed in [10] for series APF which is based on unit vector template generation to compensate the current unbalance present in the load currents by expanding the concept of single phase P-Q theory. The modeling and performance analysis of wind energy conversion system (WECS) under different kind of grid disturbances are presented in [11].The work in [12] presents an alternative detection method to be used in unbalanced power networks,namely the decoupled double synchronous reference frame PLL (DDSRF-PLL). The proposed technique defines an unbalanced voltage vector, consisting of both positive and negative sequence components and expresses it on the double synchronous reference frame in order to detect the positive sequence component.

In this work, fuel cell and wind farm are connected in parallel to the grid. By the control of the grid interfacing inverter it can be utilized as a multifunction device. The existing inverter acts as Shunt Active Power Filter (SAPF) that is capable of simultaneously compensating problems like current unbalance current harmonics and also of injecting the energy generated by renewable energy source. This eliminates the need for additional power conditioning equipment to improve the quality of power at Point of Common Coupling (PCC).

Section II describes the system under consideration and control circuit modeling. Simulation study and the results are presented in section III. Finally section IV concludes the work.

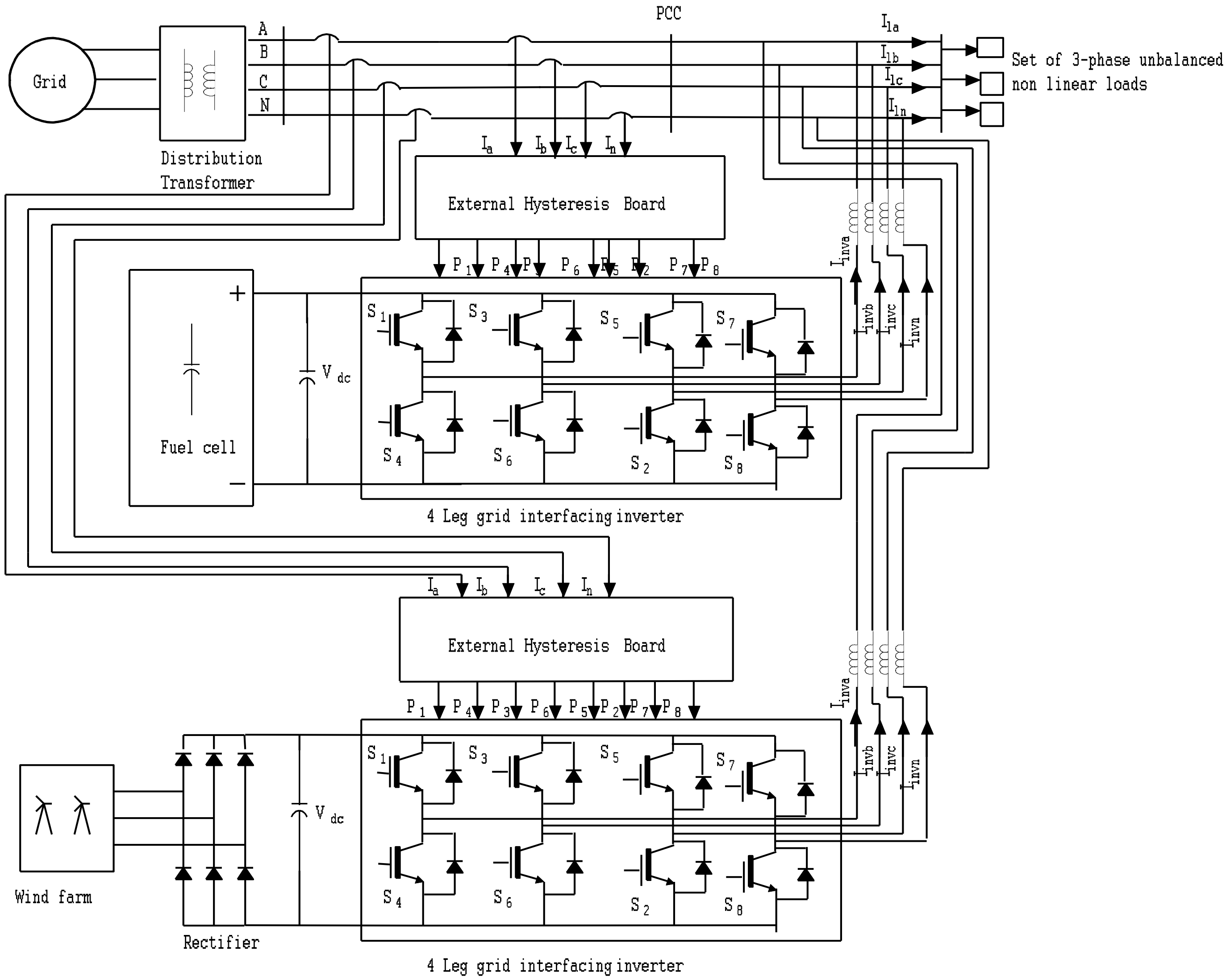


Fig. 1. Schematic of fuel cell and wind farm based distributed generation system

II. SYSTEM DESCRIPTION

The system consists of a fuel cell and a wind farm connected to the dc-link of the grid interfacing inverter as shown in Fig. 1. The three phase four wire voltage source inverter is key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. Fuel cell generates power at variable low dc voltage while variable speed wind turbines generate power at variable ac voltage. Thus the power generated from these renewable energy sources needs power conditioning before connecting to the dc-link. The dc- capacitor decouples the fuel cell from grid and also allows independent control of converters on either side of dc- link.

A. Shunt Active Power Filter (SAPF)

The Shunt Active Power Filter consists of a three phase four wire Voltage Source Inverter with four legs that uses IGBTs. The capacitor voltage can be kept constant by the renewable energy sources. If there is no energy available from these sources, the controlalgorithm changes and the energy required to maintainthis voltage constant is drained from the electric grid. The inductors (L_{sh}) are used to connect the inverter to the electric grid. The controller requires the three system voltages (v_a, v_b, v_c), the dc link voltage (V_{dc}), the fourload currents (Il_a, Il_b, Il_c, Il_n), and the four inverter currents (I_{inva}, I_{invb}, I_{invc}, I_{invn}). When the Shunt Active Power Filter is connected, the source currents (I_a, I_b, I_c), become balanced and sinusoidal.

B. Control Circuit Modelling

The control diagram of grid- interfacing inverter for a 3-phase 4-wire system is shown in Fig. 2.The neutral current of load is compensated by the fourth leg of inverter. The main aim of the control is to regulate the power at Point of Common Coupling.The inverter is actively controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid in addition to the power management operation. If

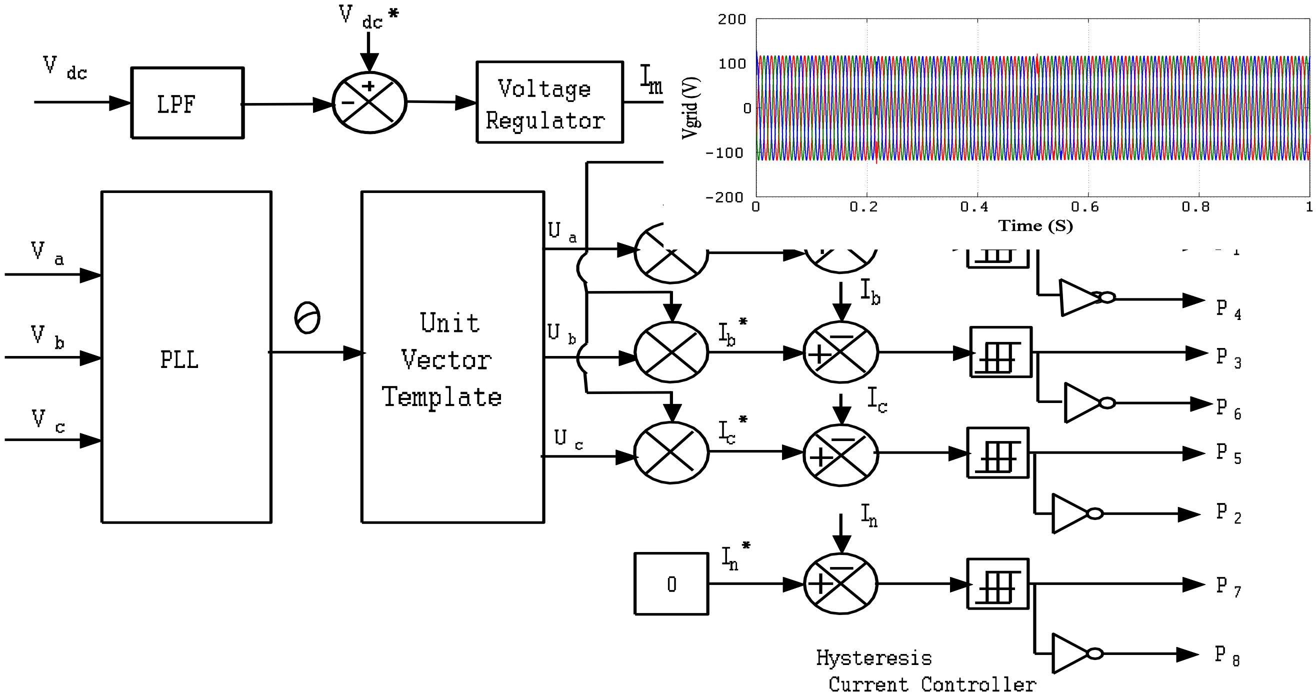


Fig.2. Control diagram of the grid interfacing inverter

anunbalanced non-linear load is connected to point of common coupling the control also compensates the harmonics unbalance and neutral current.

Active power filters are power electronic devices that cancel out unwanted harmonic currents by injecting compensation current. Shunt active power filters compensate load current harmonics by injecting equal-butopposite harmonic compensating current. Generally, four-wire APFs have been conceived usingfour leg converters. This topology has proved better controllability than the classical three-leg four-wire.

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 exchange of active power between renewable source and grid is determined by the regulation of the dc-link voltage. Thus the output of dc-link voltage regulator results in an active current (I_m). The multiplication of active current component (I_m) with unity grid voltage vector templates (U_a, U_b,andU_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) which is obtained fromphase locked loop (PLL) is used to generate unity vector template.

$$U_a = \sin\theta \quad (1)$$

$$U_b = \sin\left(\theta - \frac{2\pi}{3}\right) \quad (2)$$

$$U_c = \sin\left(\theta + \frac{2\pi}{3}\right) \quad (3)$$

In order to eliminate the presence of switching ripples on the dc-link voltage and generated reference current, the actual dc link voltage (V_{dc}) is sensed and passed through a first-order low pass filter (LPF). The difference of this filtered dc-link voltage and reference dc-link voltage is given to a PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error $V_{dcerr(n)}$ at *n*thsampling instant is given as:

$$V_{dcerr(n)} = V_{dc(n)}^* - V_{dc(n)} \quad (4)$$

The instantaneous values of reference three phase grid currents are calculated as

$$I_a^* = I_m . U_a \quad (5)$$

$$I_b^* = I_m . U_b \quad (6)$$

$$I_c^* = I_m . U_c \quad (7)$$

The reference current for the grid neutral current is considered as zero and can be expressed as

$$I_n^* = 0 \quad (8)$$

The reference grid currents (I_a^*, I_b^*, $I_c^*$and I_n^*)are compared with actual grid currents (I_a, I_b, $I_c$and I_n) to compute the current errors as

$$I_{aerr} = I_a^* - I_a \quad (9)$$

$$I_{berr} = I_b^* - I_b \quad (10)$$

$$I_{cerr} = I_c^* - I_c \quad (11)$$

$$I_{nerr} = I_n^* - I_n \quad (12)$$

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 drivers of grid-interfacing inverter.

III. SIMULATION RESULTS

Simulation study is carried out using MATLAB/Simulink for verifying the control approach to achieve multi-objectives for grid connected DG systems. Fuel cell and wind farm with variable output power are connected to the dc-link of the grid-interfacing inverter. The system parameters used for the simulation are shown in table 1. An unbalanced nonlinear load is connected to the point of common coupling. The waveforms of grid voltage (V_a, V_b, V_c), grid currents (I_a , I_b, I_c), unbalanced load currents (I_{la}, I_{lb} , I_{lc}) and inverter currents (I_{la}, I_{lb} , I_{lc}) and inverter currents (I_{inva} , I_{invb} , I_{invc}) are shown in Fig. 3.

Before time t = 0.2 sec. the grid interfacing inverter is not connected to the system, i.e., the grid alone supplies the total load power demand.At this time the grid current in Fig. 3.(b) is same as the load current in Fig..3. (c). At t = 0.2 sec. single fuel cell is connected to the grid through the inverter. At this time the inverter injects current and the grid current changes from unbalanced non-linear to balanced sinusoidal current as shown in Fig.3.(b). At time t = 0.5 sec. wind farm is connected to the grid through the interfacing inverters. At this time the grid current increases and it is also balanced sinusoidal as shown in Fig.3.(b). At time t = 0.8sec wind farm is disconnected and single fuel cell is connected to the system as in time t = 0.2 sec as shown in Fig.3(b).

The active powers of grid (P_{grid}), load (P_{load}) and inverter (P_{inv}) are shown in Fig.4. Positive values of grid power andinverter power means that these powers flow from grid side

TABLE 1.SYSTEM PARAMETERS

3-phase supply (r.m.s)	Vg = 120 V, 50 Hz
3- phase Non-linear Load	R= 9 Ω , Rs = 1*10^5 Ω
3-phase Linear Load	P=3100 W, Q_L=2000VAR
3- phase Unbalanced Load	R1= 7Ω , R2 & R3 = 30 Ω
DC- link Capacitance & Voltage	C_{dc}= 3000 mF, V_{dc} = 292 V
Coupling Inductance	L_{sh} = 2 mH

(a)

(b)

(c)

(d)

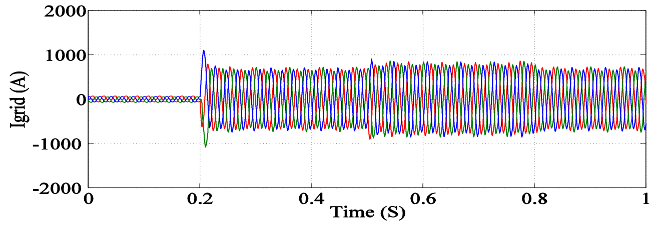
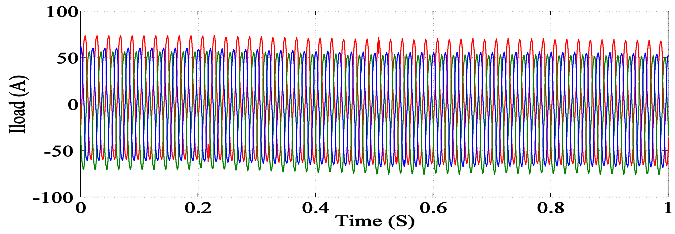
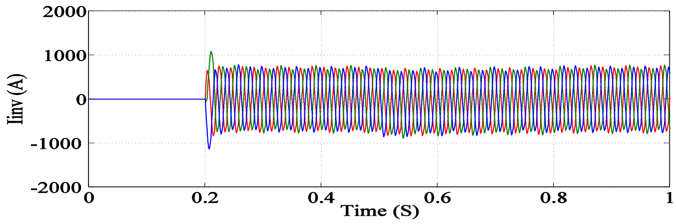


Fig.3. Simulation Results: (a) Grid voltages (b) Grid currents (c) Unbalanced

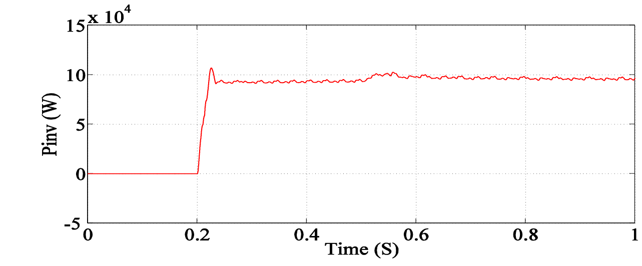


load currents (d) Inverter currents.

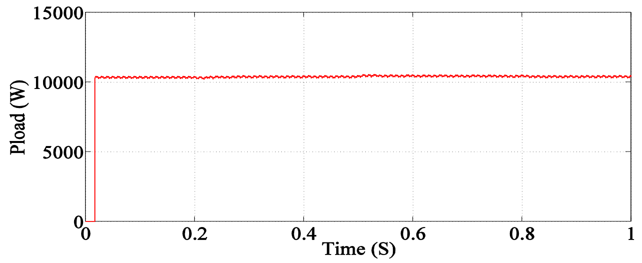


towards PCC and from inverter towards PCC as shown in Fig. 4.(a) and 4.(c).

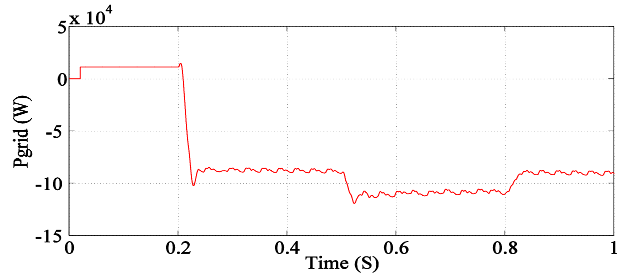
The power absorbed by load is denoted by positive signs as shown in Fig. 4. (b). At t = 0.2 sec. inverter injects active power generated from fuel cell. At this time the generated power is more than the load power demand the additional power is fed back to the grid. After t= 0.2 sec. The negative sign of P_{grid} means that the grid is now receiving power from fuel cell as shown in Fig. 4. (a). At t = 0.5 sec wind farm is connected to the system and inverter injects power generated from wind farm to the grid as shown in Fig.4 (a). At t = 0.8 sec wind farm is disconnected from the systemand the grid is



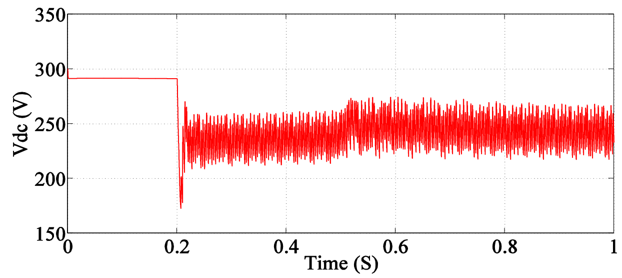
(a)



(b)



(c)



(d)

Fig.4. Simulation Results :(a) P-Grid , (b) P- Load , (c) P- Inverter. (d) Vdc

receiving power from fuel cell only as in shown in Fig.4 (a). The dc link voltage Vdc is shown in Fig. 4 (d). When at t = 0.2 sec inverter is connected to the system and the dc link voltage fluctuates. Due to this fluctuation in dc link voltage the compensated current still contains some amount of dc component. The current harmonics are compensated by controlling the grid interfacing inverter. Thus the power quality is improved.

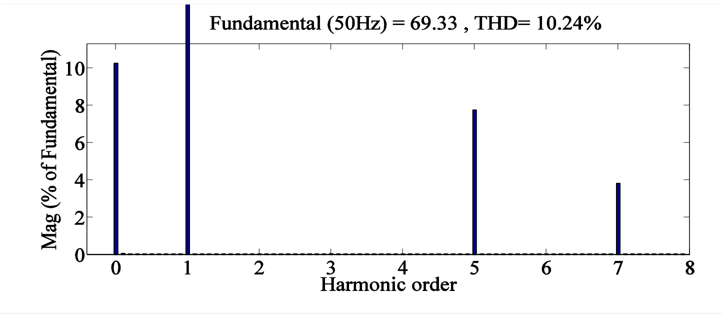


Fig.5. THD of grid current before compensation

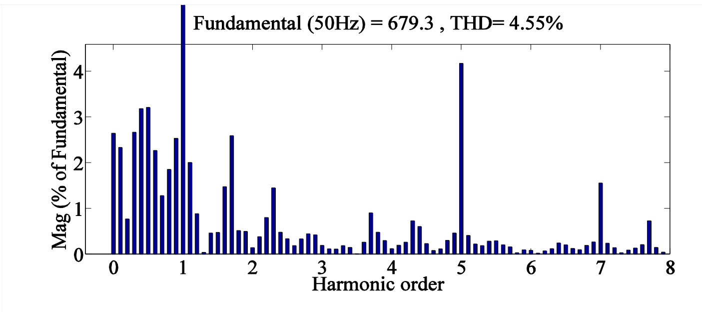


Fig.6. THD of grid current after compensation

Total Harmonic Distortion of grid current before compensation is 10.24 % as shown in Fig. 5. Fig.6. shows Total Harmonic Distortion of grid current after compensation. The small amount of dc component in Fig.6 is due to the fluctuation in dc link voltage. A four leg inverter is used for grid interfacing and it contains harmonics. So after compensation the THD contains some lower order harmonics. After compensation the THD is reduced from 10.24 % to 4.55 % which is below the recommended 5 % limit.

IV. CONCLUSION

This work presents the power quality improvement of fuel cell and wind farm based distribution generation system. The existing grid interfacing inverter is utilized as a power converter and also as a shunt active power without additional hardware cost. The MATLABsimulation validates the control approach and shows that the grid–interfacing inverter is utilized as a multi-function device. The quality of power at the point of common coupling is improved by the control of the grid-interfacing inverter.

REFERENCES

[1] Mukhtiar Singh, ,VinodKhadkikar, ,Ambrish Chandra, and Rajiv K. Varma, "Grid Interconnection of RenewableEnergy Sources at the Distribution Level With Power-Quality Improvement Features", *IEEE transactions on power delivery*,vol.1,pp 12-34,August 2011.

[2] 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. 20a04.

[3] 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.

[4] 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.
[5] 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," *IEEETrans. Ind. Appl.*, vol. 39, no. 2, pp. 556–564, Mar./Apr. 2003.
[6] 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.
[7] 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.
[8] 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 them grid integration of renewable energy sources: A survey," *IEEE Trans. Ind. Electron*, vol. 53, no. 4, pp. 1002– 1016, Aug. 2006.
[9] B. Renders, K. De Gusseme, 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.
[10] 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.
[11] 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.
[12] 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.