ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ACTIVE AND REACTIVE POWER CONTROL AND QUALITY MANAGEMENT IN DG-GRID INTERFACED SYSTEMS

R. D. Patidar and S. P. Singh
Department of Electrical Engineering, Indian Institute of Technology, Roorkee, India
E-Mail: rdpatdee@iitr.ernet.in

ABSTRACT

The main focus of this paper is to control the active power supplied by distributed generation (DG) system while compensating harmonics and reactive currents caused by the nonlinear loads using shunt active power filter (APF). The APF control is based on load currents sensing for reference current estimation in a-b-c reference frame. In order to get the grid currents sinusoidal and in-phase with the distorted grid voltages, the positive sequence components of the grid voltages are computed. The active power transfer is based on phase angle between DC-AC converter and grid voltages and reactive power management is based on magnitude of these voltages. The extensive simulation of the study is carried out under MATLAB /Simulink environment to show the usefulness of the control algorithm. Various simulation results are presented with integrated modes (forward and reverse power flow) of operation of distributed generation system interfaced with grid.

Keywords: active power filter, distributed generation, harmonics, reactive power, power quality.

INTRODUCTION

The rising concern on a more efficient use of the energy is boosting the interest in expanding electric generating capacities through the use of distributed energy generation (DEG) [1-2]. The main objective of the distributed generation system connected with grid is to control the power that the inverter injects into the grid. According to the grid demands the controller also injected the reactive power. Distributed generation (DG) encompasses a wide range of prime mover technologies, such as internal combustion (IC) engines, gas turbines, micro turbines, photovoltaic, fuel cells and wind-power. These distributed generators are characterized mainly by their unplanned location and by a low nominal power rating(less than 1 MW). The integrated DG along with grid system can solve many typical problems of conventional AC network such as energy security, reduces transmission and high voltage equipment cost *etc.* However, a small DG has some significant problems of frequency and voltage variation when it is operated in stand-alone mode. Therefore, a small DG should be interconnected with the power system in order to maintain the frequency and the voltage.

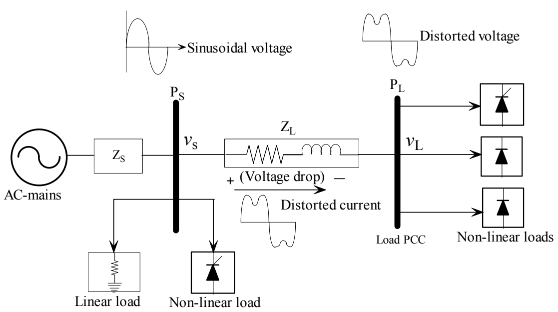


Figure-1. Harmonic voltage distortion at load PCC.

Further tremendous proliferation of power electronics load may produce different power quality problems such as harmonics, unbalancing, excessive neutral current, etc. [4]. Figure-1 represents the harmonic voltage distortion at point-of-common-coupling (PCC) due to harmonic current flowing through the system impedance. These power quality problem causes many adverse effects like additional heating, amplification of harmonics due to presence of power factor correction capacitor banks, reduction of transmission system efficiency, overheating of distribution transformers, malfunctioning of electronic equipment, spurious operation of circuit breakers and relays, errors in measuring instruments, interference with communication and control signals etc.[3-5]. Therefore, the power quality issue has become important nowadays. The DG-grid interfaced system with power electronics helps to improve the power quality problems at PCC. Figure-2 shows a general purpose block diagram of DG-grid system with power electronics interface which can be subdivided into four major sections [7-10]. These include: the AC-DC converter, DC-AC inverter, the output interface and the controller modules. The unidirectional arrows show the power flow path for the distributed energy sources whereas the bidirectional arrows indicate the bidirectional power flows for the distributed energy storages. The input converter module can be either used with alternating current (AC) or direct current (DC) DG systems and is most likely to be specific for the type of energy source or storage. The DC-AC inverter module is the most generic of the modules and converts a DC source to grid-compatible AC power. The output interface module filters the AC output of the inverter. The fourth major module is the monitoring and control module that drives the entire interface and contains protection for both the DG source and the utility at the PCC.

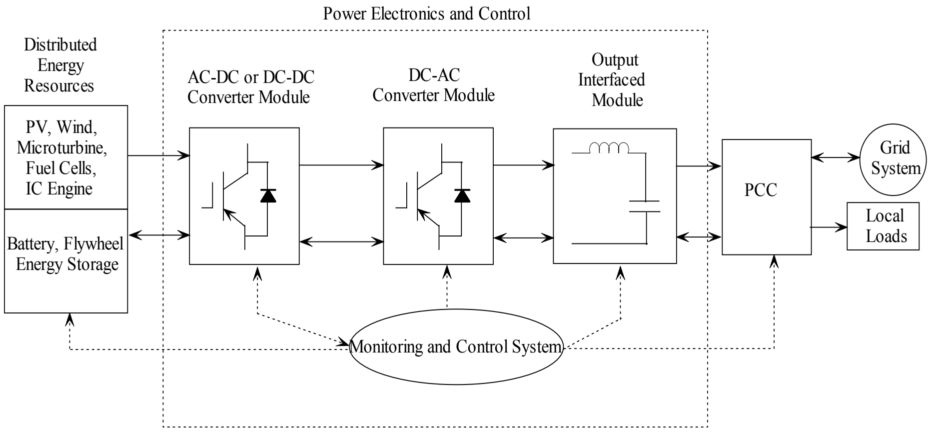


Figure-2. General purpose block diagram of DG-grid system with power electronic interfaced.

Several studies proposed an interconnection system for DG with the power system through inverter because the inverter gives versatile functions for improving the performance of DG [6]-[12], [15]. References [11] and [12] have reported the field test results of active filters intended for installation on power distribution systems. Liang *et al.* [13] have presented a power control method for a grid-connected voltage source inverter which achieves good (*P*, *Q*) decoupling and fast response. However, this approach requires knowledge of the value of power system equivalent impedance, which is not viable. Illindala *et al.* [14] have presented a different power control strategy based on frequency and voltage droop characteristics of power transmission, which allows decoupling of *P* and *Q* at steady state. This paper presents the combined operation of APF and DG which is connected to a dc-link energy storage system through rectifier. The proposed APF system is capable for simultaneously compensating harmonics, reactive current, and load imbalance and also for injecting energy generated by DG system to grid.

ACTIVE POWER FILTER

The basic compensation principle of APF is explained with the help of Figure-3.

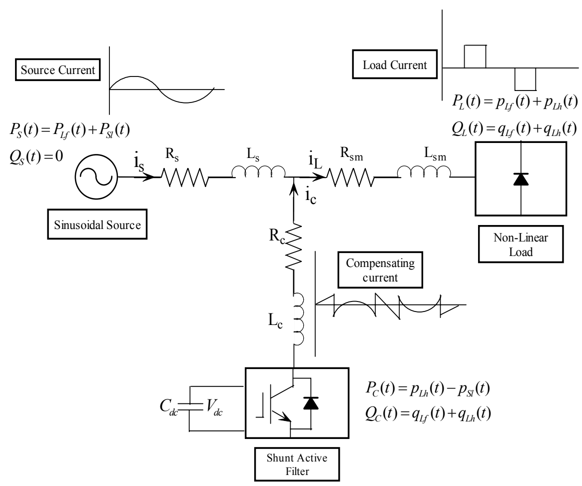


Figure-3. Basic circuit topology of active power filter.

The instantaneous nonlinear load current can be represented by [5].

$$i_L(t) = \sum_{h=1}^{\infty} I_h \sin(h\omega t + \phi_h) = I_1 \sin(\omega t + \phi_1) + \sum_{h=2}^{\infty} I_h \sin(h\omega t + \phi_h) \quad (1)$$

The instantaneous load power can be given as:

$$\begin{aligned} p_L(t) &= v_s(t) i_L(t) \\ &= V_m I_1 \sin^2(\omega t)\cos(\phi_1) + V_m I_1 \sin(\omega t)\cos(\omega t)\sin(\phi_1) \\ &\quad + V_m \sin(\omega t) \sum_{h=2}^{\infty} I_h \sin(h\omega t + \phi_h) \\ &= p_{Lf}(t) + p_{Lq}(t) + p_{Lh}(t) \end{aligned} \quad (2)$$

Where, I_1 is the peak value of the fundamental load current, I_h is the peak value of the harmonic load current, $\Phi_1$and Φ_h are the phase angle of the fundamental and harmonic component of the load currents, respectively. In (2) the instantaneous power of nonlinear load is divided into three terms. The first term $p_{Lf}(t)$ is the instantaneous load fundamental power. The second term $p_{Lq}(t)$ is instantaneous load fundamental quadrature (reactive) power and the third term $p_{Lh}(t)$ is the instantaneous load harmonic power. A shunt APF is designed to be connected in parallel with the load, to detect its harmonic and reactive current and to inject into the system a compensating current, identical with the load harmonic and reactive current. Therefore, instantaneous supply current i_s having only fundamental component which is in-phase with source voltage $v_s(t)$.

PROPOSED SYSTEM DESCRIPTION

The schematic diagram of the proposed distributed generation grid interface with power electronics i.e. active power filter is shown in Figure-4 Three-phase grid system of source resistance R_s and inductance L_s per phase, supplying power to local nonlinear loads. A current controlled three-phase shunt active power filter with energy storage capacitor C_{dc} is connected in parallel with local nonlinear loads. The APF consists of an inductor L_c and a resistance R_c (equivalent resistance of the inverter loss, the inductance loss) per phase and a three-phase IGBT bridge current-controlled voltage source inverter (CC-VSI). A constant speed DG unit is connected to the dc-link of APF through AC-DC converter. A smoothing inductor of impedance (R_{sm}+jωL_{sm}) per phase to avoid the spikes in the grid current is also connected in series with nonlinear load.

The APF can compensate the current harmonics, load power factor, and imbalance in the source currents, while the DG supplies power to the grid and local load. Two interconnected modes other than islanding mode are possible of the proposed DG-grid interfaced system. One is called the forwarded interconnected mode in which the DG and grid both will supplies power to local loads. And another is reverse interconnected mode in which DG will supplies power to local loads as per load requirement and rest of the power is injected into the grid. In the islanding mode the DG supplies power to the local loads only.

THE PROPOSED CONTROL TECHNIQUE

The proposed APF control structure of the DG-grid interconnected system is shown in Figure-5. Three major elements of the proposed scheme are the positive sequence detector, reference current calculator and PWM signals generator. The control strategy is designed for controlling the power in interconnected and the islanding mode. The system works in forwarded interconnected mode when both the DG and the grid supplies power to the local load.

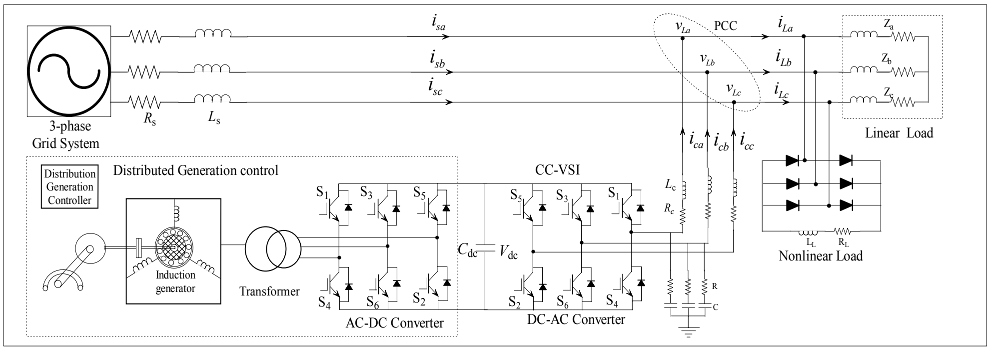


Figure-4. Schematic diagram of the DG-Grid interfaced system with active power filter.

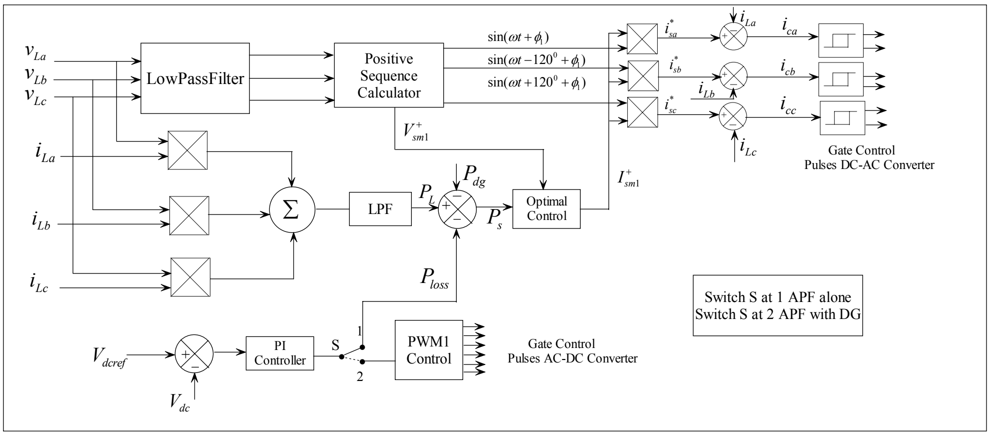


Figure-5. Proposed controller for active and reactive power control in a DG-grid interfaced systems.

But it works in islanding mode when the voltage interruption on grid occurs. Once the voltage interruption is removed, the system operation transfers from the islanding mode to the interconnected mode. The controls of inverter involve the control of active power supplied by DG and reactive power requirement of load in such a way that reactive power supplied by the main source remains zero. The ac-side voltages of the active power filter inverter (DC-AC module) are controlled both in magnitude and phase to control the active and reactive power.

In order to examine the compensation mechanism let's assume that distribution generation uses a constant speed induction generator and the grid voltages of vector $v_s(t)$ and load currents of vector $i_L(t)$ consist of a set of harmonic components h are expressed in (3) and (4) respectively, where H= {1, 2, 3……..N} and where N is the highest order of harmonics under considerations.

$$v_L(t) = \begin{bmatrix} v_{La} = \sum_{h \in H}^{H} V_{Lha} \sin(h\omega t + \alpha_{ha}) \\ v_{Lb} = \sum_{h \in H}^{H} V_{Lhb} \sin(h(\omega t - 2\pi/3) + \alpha_{hb}) \\ v_{Lc} = \sum_{h \in H}^{H} V_{Lhc} \sin(h(\omega t + 2\pi/3) + \alpha_{hc}) \end{bmatrix} \quad (3)$$

$$i_L(t) = \begin{bmatrix} i_{La} = \sum_{h\in H}^{H} I_{Lha}\sin(h\omega t + \alpha_{ha} - \phi_{ha}) \\ i_{Lb} = \sum_{h\in H}^{H} I_{Lhb}\sin(h(\omega t - 2\pi/3) + \alpha_{hb} - \phi_{hb}) \\ i_{Lc} = \sum_{h\in H}^{H} I_{Lhc}\sin(h(\omega t + 2\pi/3) + \alpha_{hc} - \phi_{hc}) \end{bmatrix} \quad (4)$$

Where (V_{sha} V_{shb} V_{shc}) and ($I_{Lha,}$ I_{Lhb}, I_{Lhc}) are the peak value of supply voltages and load currents corresponding to hth order harmonics, (α_{ha} α_{hb} α_{hc}) and (Φ_{ha}, Φ_{hb}, Φ_{hc}) are the arbitrary as well as phase angles. Grid voltages are filtered using the 5th order low-pass filters (LPF) with a cut-off frequency at 50 Hz.

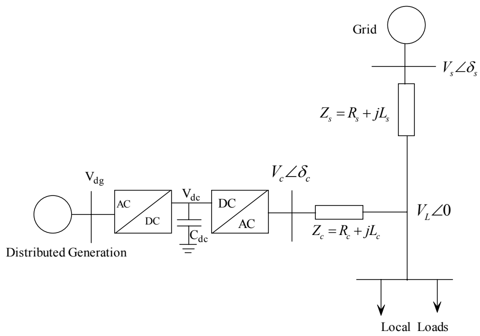


Figure-6. Single line diagram of DG-grid interfaced system.

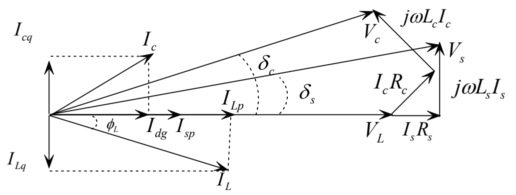
The single line diagram of the DG-grid system representing a 3- phase, symmetrical, balanced steady state system is shown in Figure-6. The active and reactive power (P_{cp}, Q_{cp}) transfer between the inverter and the grid system are given by the (5)-(6). The active power transfer is the function of power angle δ_c and the reactive power transfer is the function of voltage magnitude difference between the inverter voltages and the grid voltages.

$$P_{cp} = \frac{V_L V_c \sin\delta_c}{\omega L_c} \quad (5)$$

$$Q_{cq} = \frac{V_c}{\omega L_c}(V_c - V_L\cos\delta_c) \quad (6)$$

Where V_L and V_C are the load and DC-AC converter (AC side) voltages and δ_c is the phase angle between them. The APF reference current is function of active power flow between inverter and PCC. Figure-7-8 shows the vector diagrams of active power flow at unity power factor for forward and reverse interconnected mode of operation. In which I_{SP}, I_{Lp}, and I_{dg} are the active fundamental currents of the grid, load and DG (ac-side of the inverter) respectively. And V_s, V_L, and V_c are the voltages at grid, load and ac side of the DC-AC converter. The Φ_L is the load power factor angle and δ_s are the power angle between grid and load voltage and δ_c is the power angle between filter inverter and load voltage. I_{Lq} and I_{cq} are the reactive component of load and APF currents respectively.

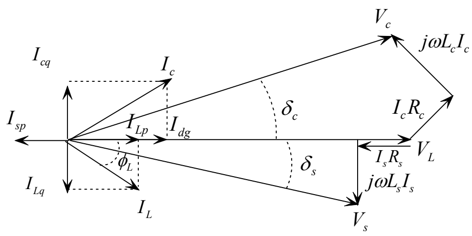
Figure-7 shows the vector diagram of active power flow at unity power factor in forward interconnected mode (DG and grid both supply power to local load). In this case the load active current is higher than the DG active current and hence the grid will support to meet the load active power requirement. The grid currents in the case will be in-phase with the respective grid voltages.



$$I_{sp} = I_{Lp} - I_{cp}\ ,\ I_{sp} = I_s\ ,\ I_{Lq} = I_{cq}\ , I_{sq} = 0, I_{Lp} > I_{cp}$$

Figure-7. Phasor diagram at unity power factor in forward interconnected mode.

Figure-8 shows the phasor diagram of active power flow at unity power factor in reverse interconnected mode in which DG supply power to local load and grid. The active component of local load current I_{Lp} in this case is lower than the active current component of DG and hence the DG will supply extra power to grid. The grid currents in the case will be 180^0 out of phase with the respective grid voltages.



$$I_{sp} = I_{Lp} - I_{cp}\ ,\ I_{sp} = I_s\ ,\ I_{Lq} = I_{cq}\ , I_{sq} = 0, I_{Lp} < I_{cp}$$

Figure-8. Phasor diagram at unity power factor in reverse interconnected mode.

The proposed compensation strategy of the shunt APF to maintain the desired source currents to be balanced, sinusoidal, and in-phase with the fundamental component of source voltages. The PCC voltages and load currents are used to obtain the average value of three-phase load active power P_{lavg} is computed as:

$$P_{lavg} = \frac{1}{T}\int_0^T \left[v_{La}(t).i_{La}(t) + v_{Lb}(t).i_{Lb}(t) + v_{Lc}(t).i_{Lc}(t)\right]dt \quad (7)$$

Where T is the time period of voltage and current waveforms. Apart from the load active power source has also supplied the active loss power P_{Sl} of the inverter. The losses in the inverter are because of the switching loss in the devices, iron and copper losses in the circuit components, *etc*. [5]-[6]. This loss component is obtained using an energy PI controller as expressed as:

$$P_{Sl} = \left[K_{pe}(V_{dcref} - V_{dc}) + K_{ie}\int(V_{dcref} - V_{dc})dt\right] \quad (8)$$

The average value of active power supplied by the grid P_s is calculated by (10)

ARPN Journal of Engineering and Applied Sciences

$$P_S = P_L - P_{sl} - P_{dg} \quad (9)$$

Where P_L is the load active power and P_{dg} is the active power supplied by DG. When P_s is positive that means the both grid and DG will supply power to the load. Conversely if P_s is negative the DG supply power to load as per load requirement and rest of the power is supplied to grid. In order to get the balance currents after compensation under the condition of unbalanced PCC voltages and load currents it is required to determine the desired source currents magnitude I^+_{sm1} from the sequential instantaneous PCC voltages and real power components supplied by the source. The active power supplied by the source can be written as,

$$P_S = \frac{3V^+_{Lm1} I^+_{sm1} \cos\phi_s}{2} \quad (10)$$

Where V^+_{sm1} is the peak value of three-phase positive sequence components of the PCC (grid) voltages expressed as (11)?

$$V^+_{Lm1} = \sqrt{\frac{2}{3}\{V^2_{La1} + V^2_{Lb1} + V^2_{Lc1}\}} \quad (11)$$

The peak value of the desired source currents after compensation can be obtained as (12)

$$I^+_{sm1} = \frac{2P_S}{3V^+_{sm1}\cos\phi_s} \quad (12)$$

For unity power factor operation the $cos\Phi_s$=1.Once the peak value of the desired source currents are obtained the instantaneous value of the desired source currents can be obtained by (13)

$$i^*_s(t) = \begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = \begin{bmatrix} I^+_{sm1}\sin(\omega t - \phi_s) \\ I^+_{sm1}\sin(\omega t - 2\pi/3 - \phi_s) \\ I^+_{sm1}\sin(\omega t + 2\pi/3 - \phi_s) \end{bmatrix} \quad (13)$$

The reference currents are now compared with load currents to calculate active and reactive power compensating currents which are used to generate PWM pulses to switch the devices connected in the inverter configuration. The APF compensating current vector can be expressed as:

$$i_c(t) = \begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = \begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} - \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (14)$$

RESULTS AND DISCUSSIONS

The performance of the proposed APF controller for DG-Grid interfaced system as per Figures 4 and 5 is simulated under MATLAB/Simulink environment. The APF performance is analyzed in forward and reverse interconnected mode for power flow. The DG unit is connected by switching-on the APF at 0.05s in both the cases and further load is changed at o.25s and 0.5s.The parameters used for the simulation study are given in Appendix.

A. Forward interconnected mode

Figures 9 and 12 show the performance of DG-grid interfaced system for active and reactive power control in forward interconnected mode. The In this case the active power demand of load is more than DG capacity and hence grid and DG both will supply active power to load. The compensator is switched on at t = 0.05s and further load is changed at t = 0.25s and t = 0.5s.

The grid, load and DG active power in this case are shown in Figure-9. After switching-on the APF the source or grid currents become sinusoidal and in-phase with respective voltages. It is assumed that DG and grid provides 10kW power to load during 0.05s < t < 0.25s, 11.8kW during 0.25s < t < 0.5s, and 12.2kW during t > 0.5s in which DG will supply constant 5kW power. The phase-wise grid voltages and currents are shown in Figure-10 in which the gird currents are in-phase with the respective phase voltages proves that grid is supporting to meet out the load active power demand along with DG. Three-phase grid voltages, load currents, grid currents, APF currents are shown in Figure-11. The FFT of the grid current signal also has been carried out a sample of FFT of the load and grid currents are shown in Figure-12 in which the THD in grid current after compensation are reduced from 23.28% to 1.25% well within the IEEE recommended limits.

B. Reverse interconnected mode

In this case the load active power demand (P_L) is less than DG capacity (P_{dg}) and hence DG supply active power to load as per load requirement and rest of the power is injected into the grid system. The compensator is switched on at t = 0.05s and further load is changed at t = 0.25s and t = 0.5s as shown in Figures 13 and 16. The grid, load and DG active power in this case are shown in Figure-13. It is assumed that out of 5kW power DG provides 1.1kW power to local load during 0.05s < t < 0.25s, 2.2kW during 0.25s < t < 0.5s, and 3.3kW during t > 0.5s. The rest of the power in the above mentioned durations are injected into the grid. The three-phase grid voltages and currents are phase-wise and together are shown in Figure-14 and Figure-15, respectively in which the grid currents are 180^0 out of phase with respective phase voltages proves that DG system is injecting extra power into the grid. A sample of FFT of the load and grid currents are shown in Figure-16 in which the THD in grid current after compensation are reduced from 27.76% to 0.75% well within the IEEE recommended limits

VOL. 4, NO. 3, MAY 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

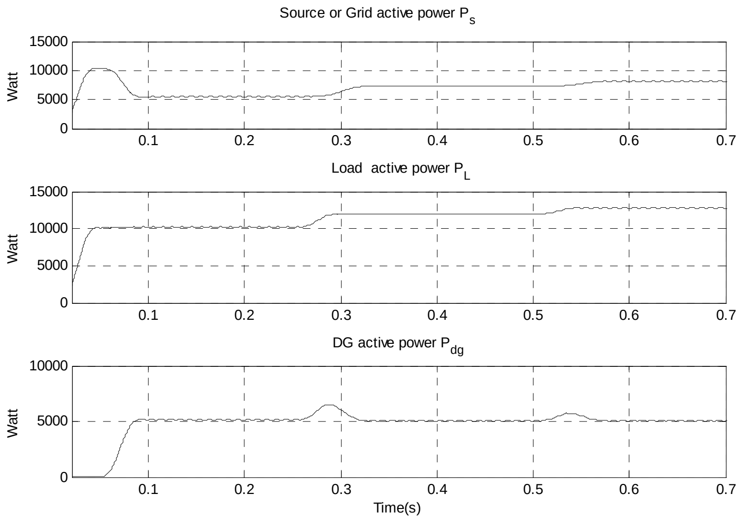


Figure-9. Grid, load and DG active powers in forward interconnected mode of operation.

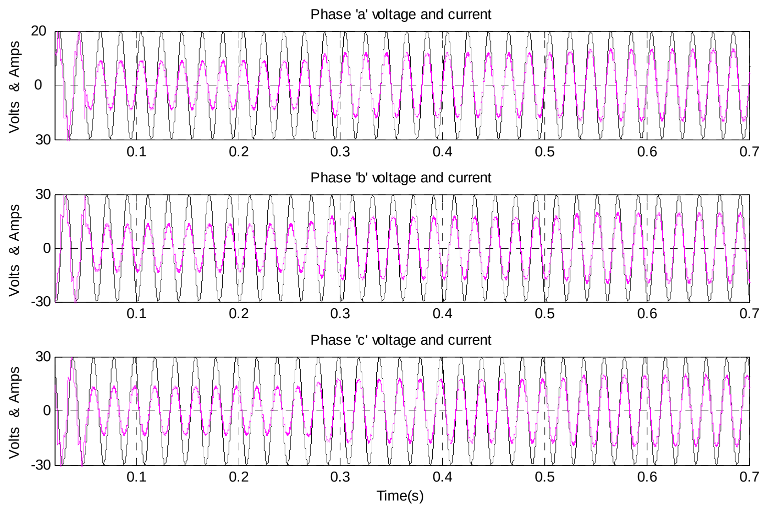


Figure-10. Phase a, b and c grid voltages (scaled by a factor of 0.1) and currents in forward interconnected mode.

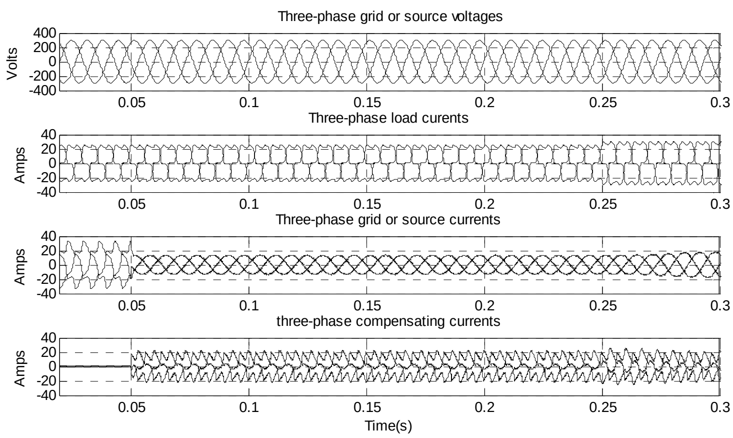


Figure-11. Three-phase grid voltages, load currents, grid or source currents and filter compensating currents in forward mode.

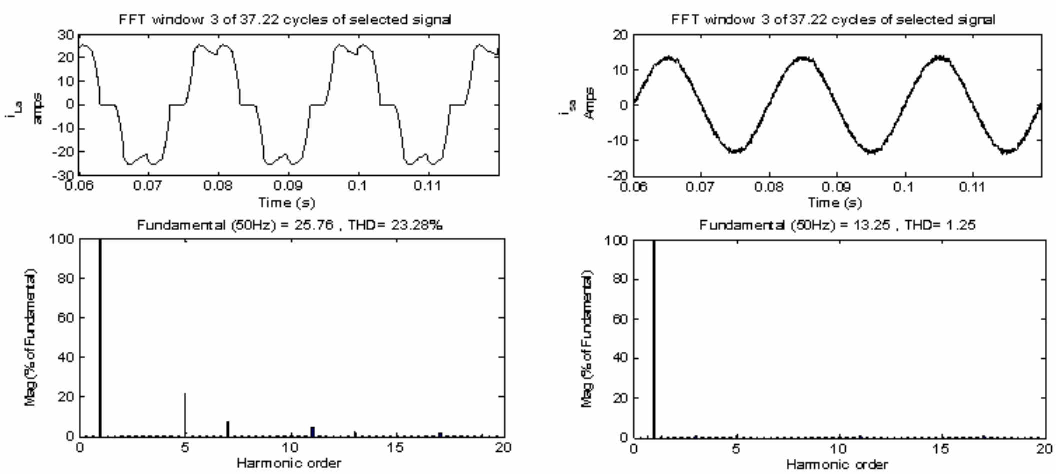


Figure-12. FFT of a selected signal of load and grid currents for phase-*a* in forward interconnected mode.

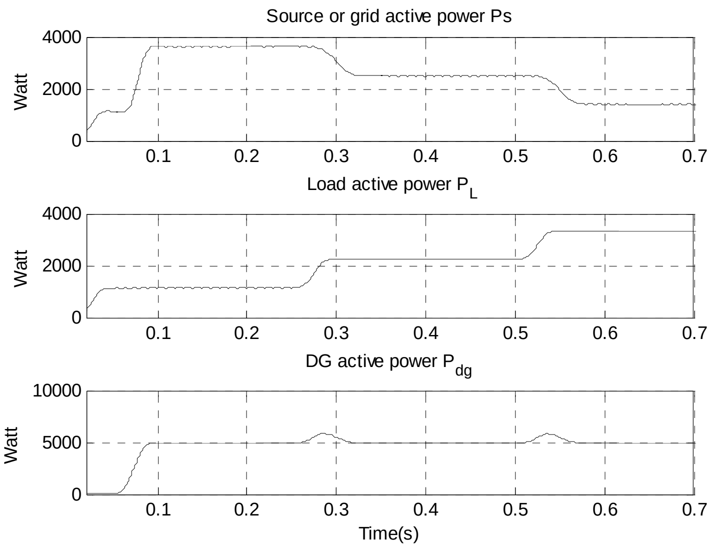


Figure-13. Grid, load and DG active powers in reverse interconnected mode of operation.

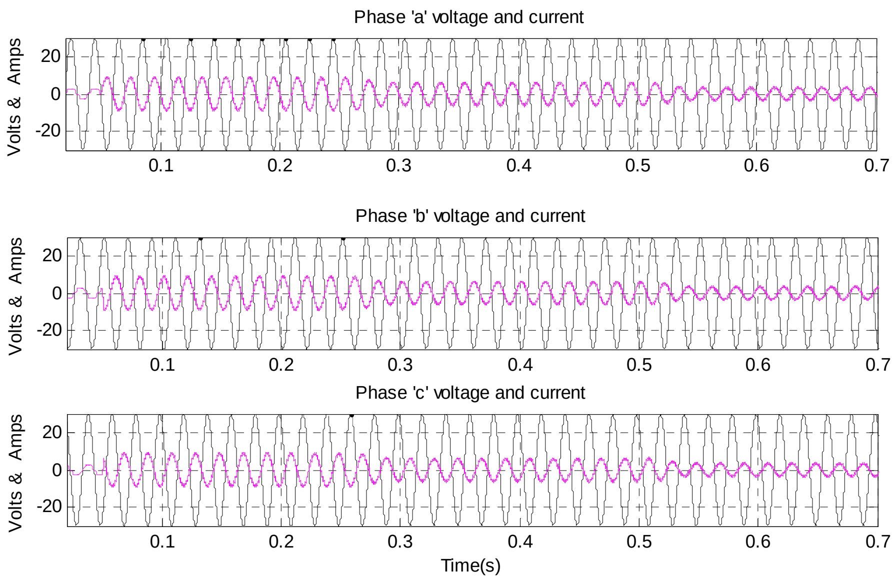


Figure-14. Phase-*a*, *b* and *c* grid voltages (scaled by a factor of 0.1) and currents in reverse interconnected mode.

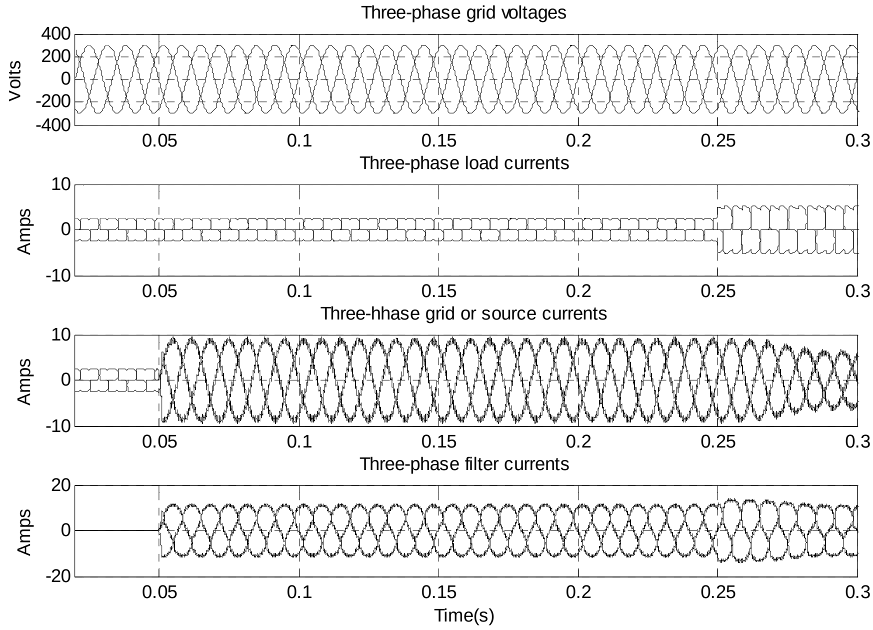


Figure-15. Three-phase grid voltages, load currents, grid or source currents and filter compensating currents in forward mode.

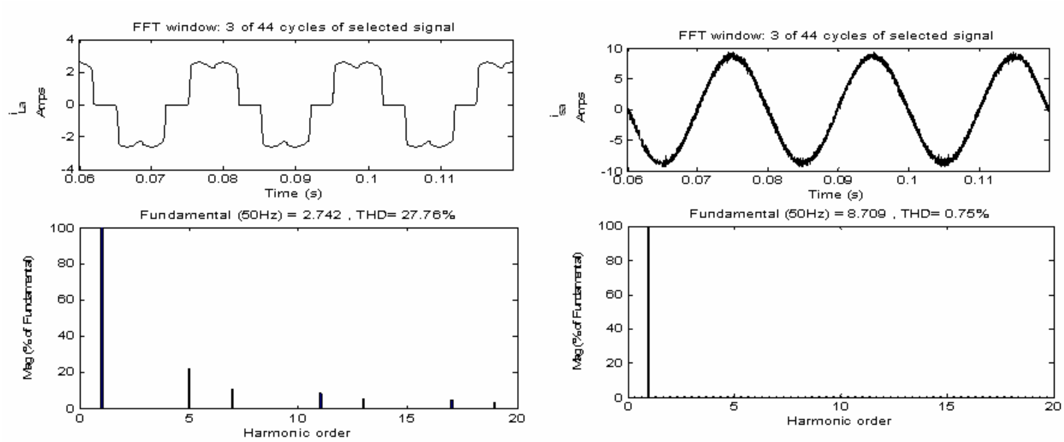


Figure-16. FFT of a selected signal of load and grid currents for phase-*a* in reverse interconnected mode.

CONCLUSIONS

This paper discusses the application of active power filters as an interface between distributed generation and grid. The proposed APF system is capable for injecting DG power to electric grid while compensating load power factor, harmonics and load balancing. The utility currents are sinusoidal and in-phase with their respective voltages (forwarded mode) and sinusoidal and 180^0 out of phase in (reverse mode).The source currents THD after compensation is well within the IEEE 519-1992 recommended limits. The proposed controller is also suitable under unbalanced and distorted grid voltages. Apart from these the proposed control strategy is suitable for islanding mode of operation. The computation of reference source (grid) currents in natural reference frame rather then transformation reduces the computational burdens.

REFERENCES

[1] T. Ackermann, G. Andersson and L. Soder. 2001. Distributed generation: a definition, Electric Power System Research. 57: 195-204, 4/20.

[2] T. Ackerman, G. Anderson, and L. Soder. 2000. Electricity market regulations and their impact on distributed network, in Proc. Electric Utility Deregulation Restructuring Power Technologies. pp. 608-613.

[3] H. Fujita, H. Akagi. 1998. The unified power quality conditioner: The integration of series and shunt active filters, IEEE Transactions on Power Electronics. 13(2): 494-501.

[4] B. Singh, K. Al-Haddad and A. Chandra. 1999. A review of active filters for power quality improvement. IEEE Transactions on Industrial Electronics. 46(5): 960-971.

[5] R. D. Patidar, S. P. Singh, and J. D. Sharma. 2008. Harmonics Elimination and Var Compensation for 3P3W and 3P4W Distribution Systems Using Shunt Active Filters, IASTED International Conference on Power and Energy Systems (PES-2008), Baltimore, USA. April. Paper No. 617-085.

[6] H. Akagi. 1996. New trends in active filters for power quality conditioning. IEEE Transactions on Industry Applications. 32(6): 312-1322.

[7] A. Chandra, B. Singh, B. N. Singh, and K. Al-Haddad. 2000. An improved control algorithm of shunt active filter for voltage regulation, harmonic elimination, power-factor correction, and balancing of nonlinear loads. IEEE Transactions on Power Electronics. 15(03): 495-507.

[8] F. Blaabjerg, Z. Chen, and S.B. Kjaer. 2004. Power Electronics as Efficient Interface in Dispersed Power Generation Systems. IEEE Transactions on Power Electronics. 19(5): 1184-1194.

[9] P.S. Sensarma, K.R. Padiyar, V Ramanarayanan. 2001. Analysis and performance evaluation of a distribution Statcom for compensating voltage fluctuations. IEEE Transaction on Power Delivery. 16(2): 259- 264.

[10] S. Barsali, M. Ceraolo, P. Pelacchi, and D. Poli. 2002. Control techniques of dispersed generators to improve the continuity of electricity supply, in Proc. IEEE Power Eng. Soc. Winter Meeting. 2: 789-794.

[11] F. Blaabjerg, R. Teodorescu, M. Liserre, A.V. Timbus. 2006. Overview of control and grid synchronization for distributed power generation systems. IEEE Transactions on Industrial Electronics. 53(5): October.

[12] T. Tenma, T. Genji, K. Mizuki, and Y. Fujita. 1999. Suppression performance analysis of active filter by neural network control with voltage detection on distribution network Trans. Inst. Elect. Eng. Jpn. vol. 119-D, No. 5. pp. 713-719.

[13] Y. Susaki, T. Matsumura, T. Genji, J. Inoue, K. Yoshioka, and M. Kohata. 2000. Development and proof examination result of active filter for power distribution systems Trans. Inst. Elect. Eng. Jpn. vol. 120-B. 5: 746-752.

[14] J. Liang, T. C. Green, G. Weiss, and Q. C. Zhong. 2000. Evaluation of repetitive control for power quality improvement of distributed generation in Proc. 2002 IEEE Power Electronics Specialists Conference, Cairns, Qld., Australia. June. 4: 1803-1808.

[15] M. Illindala and G. Venkataramanan. 2002. Control of distributed generation systems to mitigate load and line imbalances. In Proc. 2002 IEEE Power Electronics Specialists Conference, Cairns, Qld., Australia. June. 4: 2013-2018.

[16] S. V. R. Kumar and S. S. Nagaraju. 2007. Simulation of D-STATCOM and DVR in power systems, ARPN Journal of Engineering and Applied Sciences. 2(3): June.

VOL. 4, NO. 3, MAY 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

APPENDIX

Para-meters	Values	Parameters	Values	
V_S	400V, 50Hz	K_p: K_i	0.5 : 10	
R_s	0.1Ω per phase	**Load for forward mode**		
L_s	0.15mH per phase	0.05s < t < 0.25s	0.25s < t < 0.5s	t > 0.5s
R_c	0.1Ω per phase	10kW	11.8kW	12.2kW
L_c	2.5mH per phase	**Load for reverse mode**		
C_{dc}	2200μF and	0.05s < t < 0.25s	0.25s < t < 0.5s	t > 0.5s
L_{sm}	1.0 mH per phase	1.1kW	2.2kW	3.3kW