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Distributed Generation Integration to Grid with Harmonic Filtering in Distribution System

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Abstract: Non-linear loads induce harmonics in to the distribution system and causes disturbance in operation for other loads connected to the same distribution system. Also, use of fossil fuels creates pollution problems which are not acceptable globally now-a-days. This paper addresses the two mentioned issues utilizing renewable energy source for power generation at distribution level and using APF for harmonic mitigation in distribution system. Integrating renewable energy source generating active power requires a voltage source converter. The voltage source converter acts as an integrating converter and the same converter is used to mitigate harmonics in the distribution system acting as APF. APF is controlled by instantaneous active and reactive power (IARP) theory. PV system is considered in this paper as renewable source for power generation. Results were presented for the proposed work with and without integration of distributed generation for fixed and variable load conditions. The proposed work has been carried out using MATLAB/SIMULINK software.

Keywords: Harmonics, distributed generation, APF, renewable energy source, integration.

1. INTRODUCTION

Loads are generally classified into two types' linear loads and non-linear type of loads. Linear loads when connected to distribution system does not cause any harm to the connected system but when non-linear loads are connected to distribution system causes non-linearity in the system inducing disturbance [1-2]. These disturbances can lead to malfunctioning of other linear loads connected to the same distribution system. Induced harmonics due to non-linear loads should be limited to 5% as per IEEE standards insisting for harmonic mitigation.

Filters can effectively eliminate harmonics in the distribution system and filters are classified in to two types, active and passive filters. As the order of harmonics is higher, passive filters can easily eliminate harmonics with low sizing of filter components. But as the order of induced harmonics are of low, sizing required to filter out lower order harmonics for filters increases eventually increasing the cost and availability risk [3-4].

Active power filters (APF) are filters using power electronic components for harmonic elimination in connected electrical system. With the use of APF filter size reduces with effective reduction in total harmonic distortion [5-8]. Active power filter is one of the shunt power electronic compensator used in electrical system for the elimination of harmonics. Power system line consists of source with connected non-linear type of load. To mitigate harmonics that were induced due to the presence of non-linear load APF is connected [9]. APF is a shunt active device and is connected in parallel to the system. APF is energized from a DC-link capacitor as shown in the line diagram. APF is connected to electrical system with an interfacing inductor.

In this paper, PV system [10-11] integration to grid needs a voltage source converter (VSI) but the same converter which is APF is used to integrate PV system to grid without need of additional converter for PV

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integration. APF for harmonic elimination and as integration converter is controlled by using instantaneous active and reactive power (IARP) theory [12]. Control of active power is not the main aspect here in this paper and gives future expansion of the concept. Results are obtained for model of distribution system with and without integration of distributed generation. Models and results were obtained using MATLAB/SIMULINK software.

2. INTEGRATION OF ACTIVE POWER FILTER TO GRID WITH DISTRIBUTED GENERATION

Active power filter configuration connected to power system for harmonic elimination was shown in Figure 1. The complete power system configuration with connected non-linear type of load inducing harmonics in to the power system and the harmonic mitigation compensator APF connected to system was depicted. APF is energized from a DC-link voltage source. APF consists of power electronic switches and the compensating currents from the APF are fed to power system line through interfacing inductors. APF produces negative harmonic currents and are induced in to the power system to reduce the total harmonic distortion in source components of power system. APF is connected in shunt to power system and the point where APF is connected to power system for harmonic elimination is called point of common coupling (PCC). The switches in APF are controlled by switching signals obtained from control circuit. Control circuit is fed with signals like load current, DC-link voltage, point of common coupling (Vpcc) voltage and reference APF currents to be fed to main power system. Gate signals fed from control circuit activates switches in APF and thus APF induces negative harmonic compensating currents.

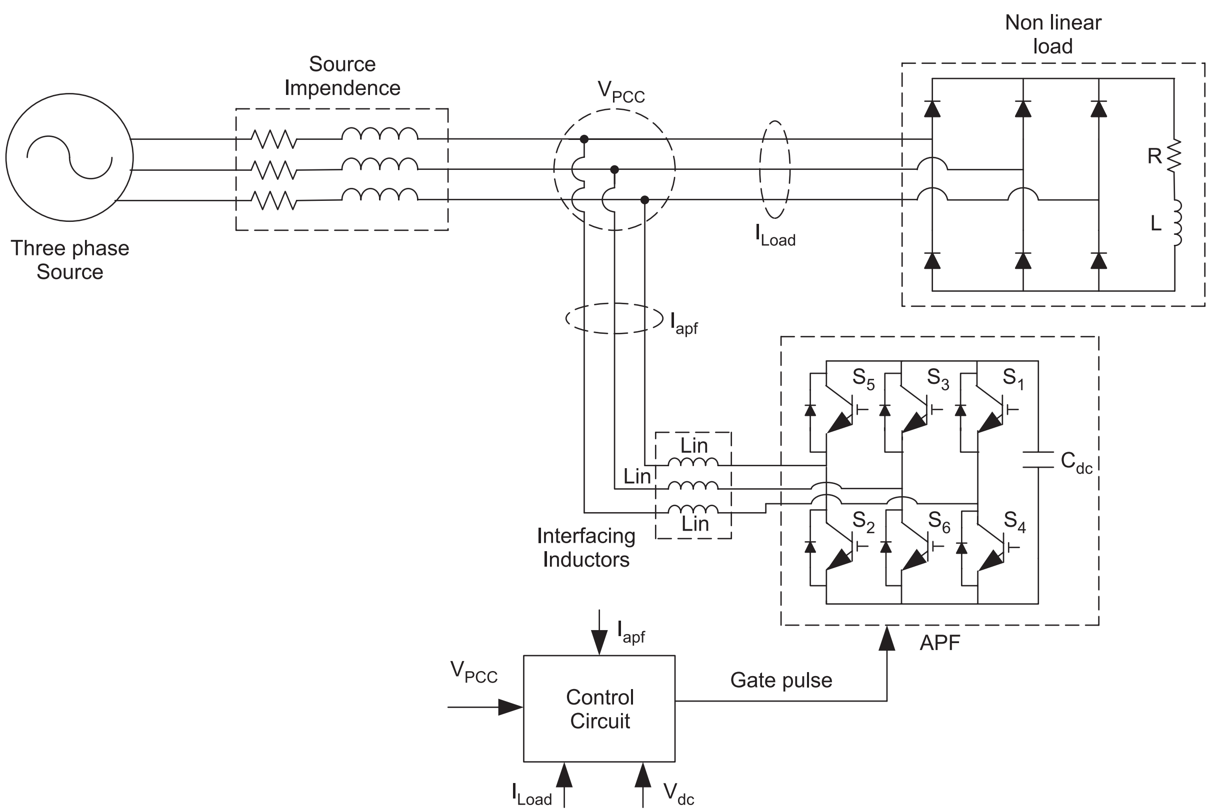

Figure 1: APF configuration connected to electrical power system

2.1. Instantaneous Active and Reactive Power (IARP) Control Strategy of APF

Instantaneous active and reactive power (IARP) theory to control switches in APF by generating gate pulses is shown in Figure 2. Initially three-phase line voltages and three-phase currents are measured from the power system line and are transformed in terms of α and β voltages and currents by using parks transformation. Then instantaneous powers of both active and reactive component were calculated. Active power component obtained contains fundamental component and the harmonic component.

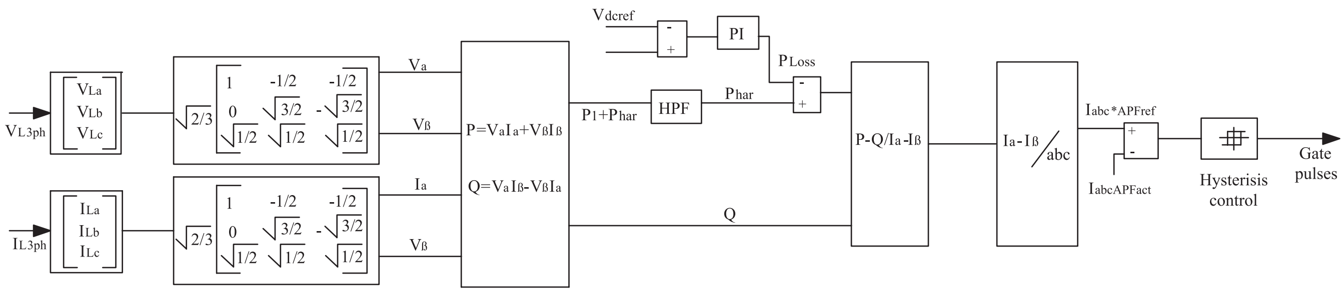

Figure 2: Instantaneous active and reactive power (IARP) theory for controlling APF

This active power component when passed through high pass filter (HPF) allows only harmonic component of active power. DC-link actual voltage is measured and is compared with reference DC-link voltage and the error signal is sent to PI controller to obtain the power loss component. The power loss component is again compared with harmonic component of active power and thus the reference current signals were generated. Reference current signals in α and β terms are re-transformed to abc values using inverse parks transformation. The reference current signals are compared with actual line currents to send error signal to hysteresis current controller (HCC) producing gate signals to switches in APF.

2.2. Grid Interconnection of PV System

Fossil fuels like coal, gas, nuclear energy can generate electrical energy in bulk supplying power to sufficient loads. The drawback with the use of fossil fuels is their availability which increases their cost. Another major setback of fossil fuels is that they emit carbon gases affecting the environmental condition which is a global constraint these days. Use of alternative source of energy for electrical energy generation reduces the global environmental constraints along with reduction in running cost of the generation. Renewable energy source are good option for electrical power generation with zero green house gas emission and also energy is freely available from the environment. Photo-voltaic (PV) system is one of the prominent energy to produce electrical energy and is used in this paper for purpose.

As the load increases, power generation to meet increased load is not an efficient answer with employing fossil fuels. DG can generate and deliver energy to main grid with reduced transmission losses and with no harmful gas emission. The complete schematic arrangement of PV integration to grid through integrating converter was depicted in Figure 3. Load demand increased will be fed from PV system and integration of PV to grid is through converter.

The same converter also acts as an APF to filter out harmonics by inducing compensating currents to grid. Converter performing two tasks was controlled with IARP theory as shown in Figure.

3. RESULTS AND DISCUSSIONS

Case 1: APF without DG and Fixed Load

The three-phase source voltage in distribution system with connected APF and no DG. Source voltage is maintained with constant magnitude of 9 kV. Source voltage is maintained with no disturbance. Three phase source currents in distribution system were balanced and with minimum distortion indicating low total harmonic distortion. Source current is maintained at 100A. Three-phase load current absorbed by the load was 100A. Since non-linear load is connected to distribution grid, non-linearity in load current is observed. Induced compensating three-phase currents from the Active Power Filterreduces the induced harmonics in source current, Active Power Filter induces set of three-phase compensating currents to the system.

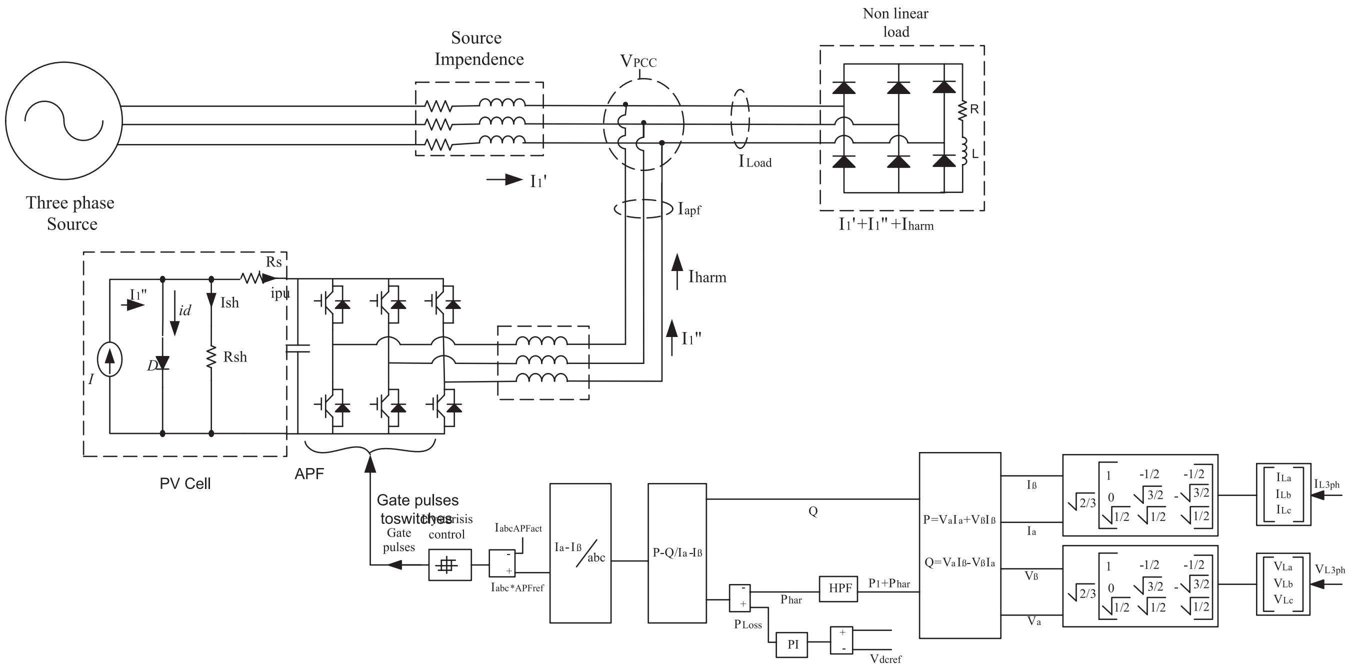

Figure 3: Schematic arrangement of PV system integration to grid with control theory

Power factor is maintained nearer to unity since minimum phase angle difference is maintained between source current and voltage as shown with the system with APF and without DG. Load current distortion is about 30.21% as compared to 1.27% harmonic distortion in source current. Since load is of non-linear type, lad draws only non-linear components of current and thus % THD is high. Due to presence of APF, the % THD in source current is well maintained within nominal values in system with APF and without DG.

Case 2: APF with Incremental Balanced Load & Without DG

The three-phase source voltage in distribution system with connected APF and no DG. Source voltage is maintained with constant magnitude of 9 kV. Source voltage is maintained with no disturbance. The Three phase source currents in distribution system were shown in Figure 4.Source currents in distribution grid were balanced and with minimum distortion indicating low total harmonic distortion. Source current is maintained at 100A initially till 0.15 sec and after 0.15 sec load demand is increased and thus source current also increases till 0.27 sec. after 0.27 sec load is restored to 100A.

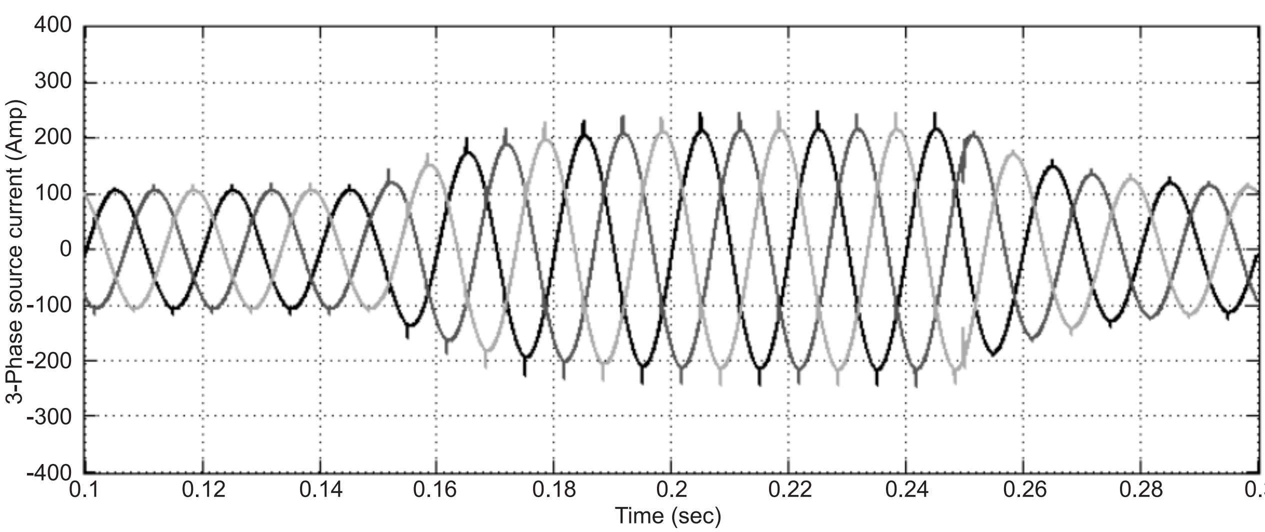

Figure 4: Three-phase source current (Amp)

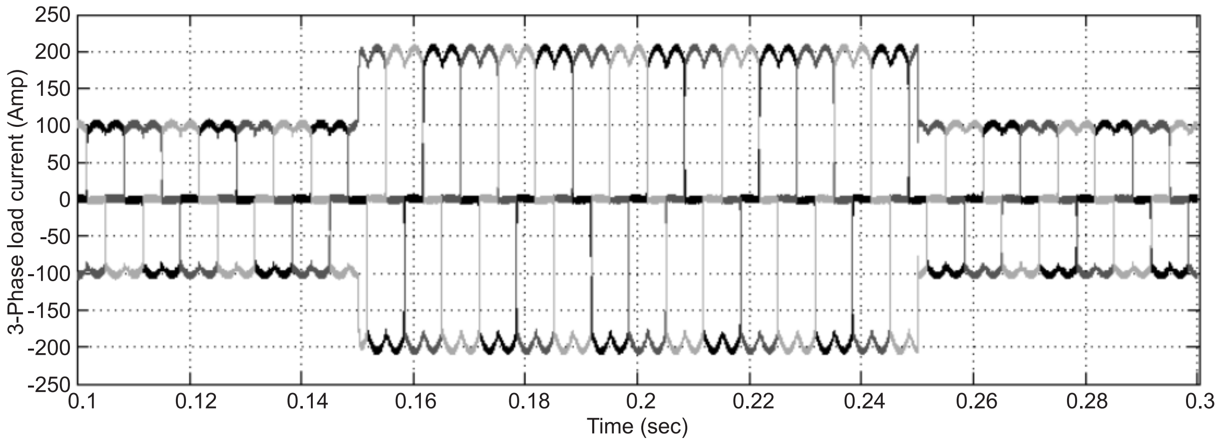

Figure 5: Three-phase load current (Amp)

Three-phase load current absorbed by the load were shown in Figure 5. Source current of 100A was absorbed by load and thus showing 100A load current till 0.15 sec. load demand is increased to 200A till 0.27 sec and thus incremental load current is observed. Since non-linear load is connected to distribution grid, non-linearity in load current is observed.

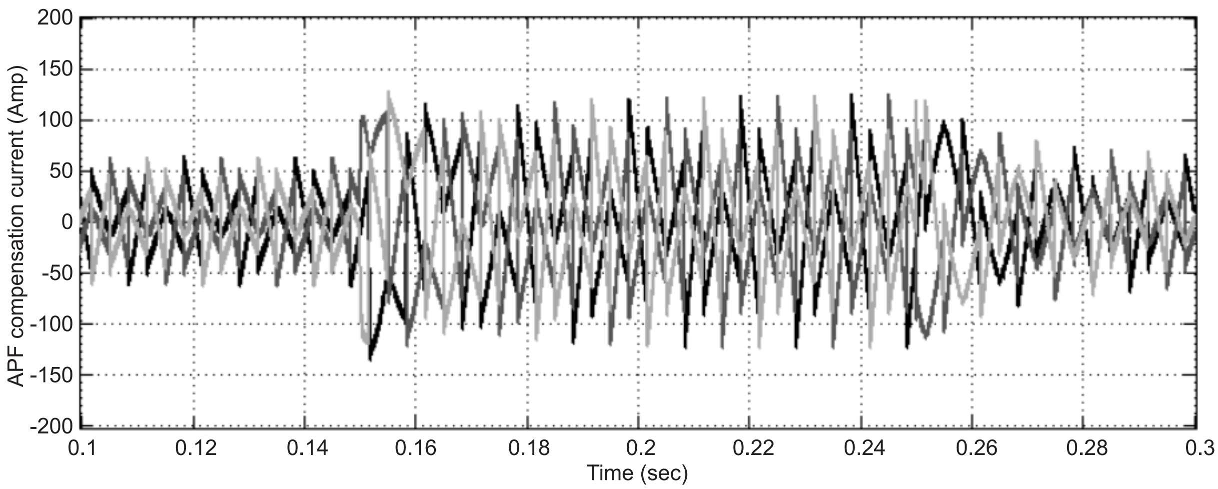

Figure 6: Compensation current of APF

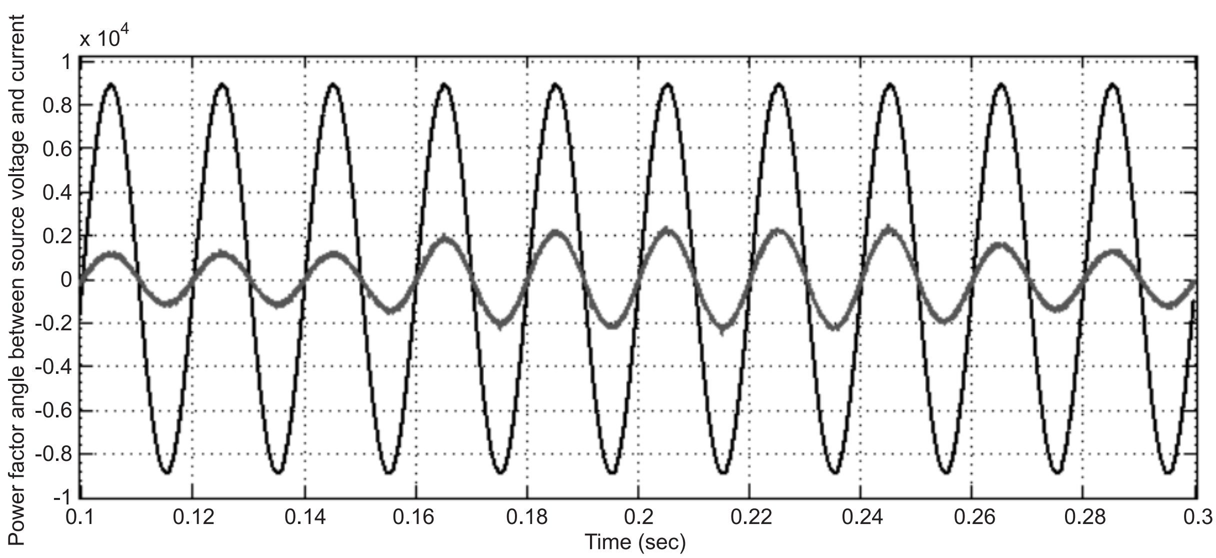

Figure 7: Power factor angle between source voltage and current

Induced compensating three-phase currents from the APF were shown in Figure 6. To reduce the induced harmonics in source current, APF induces set of three-phase compensating currents to system. Due to increase in load, compensating currents to reduce the harmonic distortion also increases in time band of incremental load demand from 0.15 sec to 0.27 sec.

Power factor angle between source voltage and source current was shown in Figure 7. Power factor is maintained nearer to unity since minimum phase angle difference is maintained between source current and voltage as shown with the system with APF and without DG.

Total harmonic distortion in load current and source current were shown in Figure 8 and Figure 9 respectively for the system with incremental load demand. Load current distortion is about 29.97% as compared to 3.97% harmonic distortion in source current. Since load is of non-linear type, lad draws only non-linear components of current and thus % THD is high. Due to presence of APF, % THD in source current is well maintained within nominal values in system with APF and without DG.

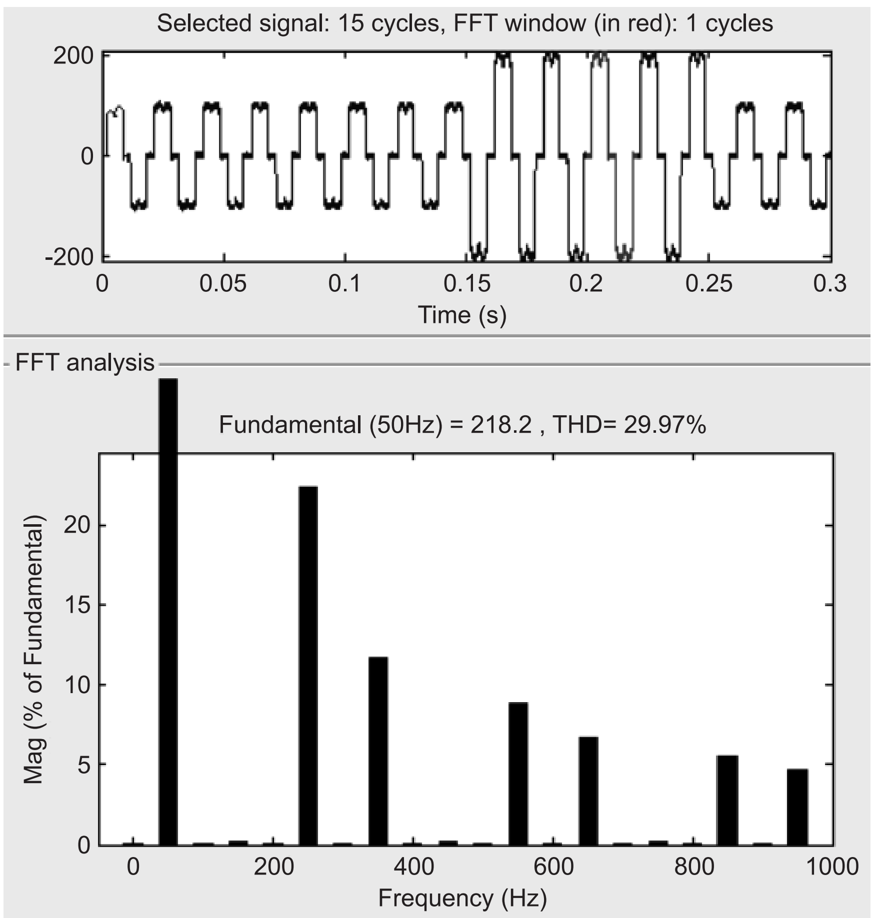

Figure 8: % THD of load current

Case 3: APF with Balanced Load with DG

The three-phase source voltage in distribution system with connected APF and DG. Source voltage is maintained with constant magnitude of 9 kV. Source voltage is maintained with no disturbance. Three phase source currents in distribution system were shown in Figure 10. For the system with APF and DG connected. Source currents in distribution grid were balanced and with minimum distortion indicating low total harmonic distortion. Source current is maintained at 100A.

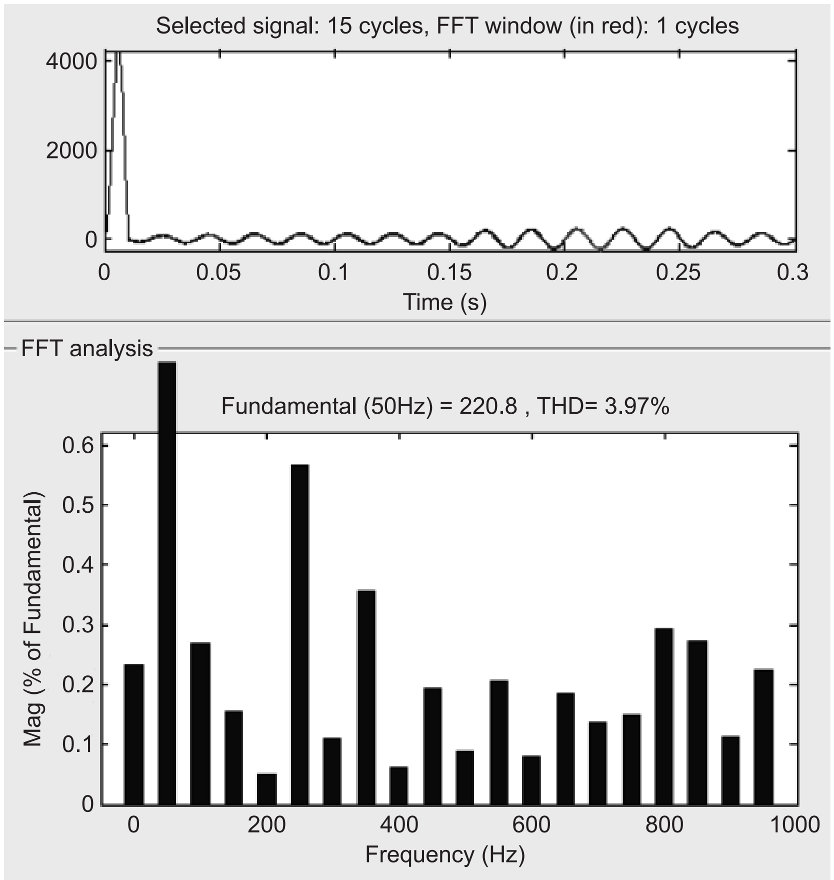

Figure 9: % THD of source current

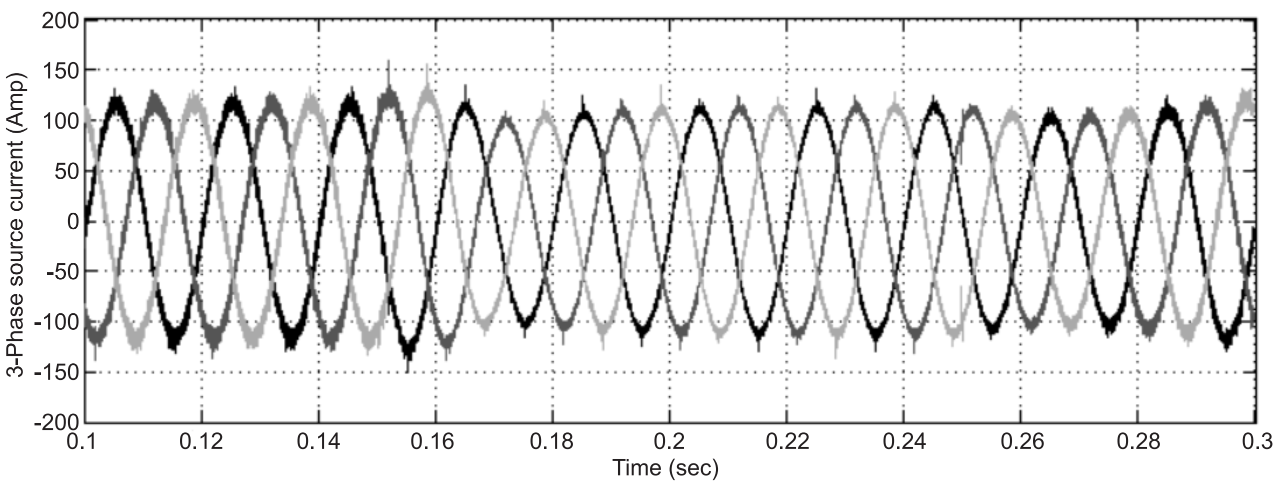

Figure 10: Three-phase source current (Amp)

Three-phase load current absorbed by the load were shown in Figure 11. Source current of 100A was absorbed by load and thus showing 100A load current till 0.15sec.Load demand is increased from 0.15sec to 0.27sec and thus load current increases. Since non-linear load is connected to distribution grid, non-linearity in load current is observed.

Induced compensating three-phase currents from the APF were shown in Figure 12, for system with APF and DG connected. To reduce the induced harmonics in source current, APF induces set of three-phase compensating currents to system. Since load demand is raised, compensated currents are also increased in incremental time period.

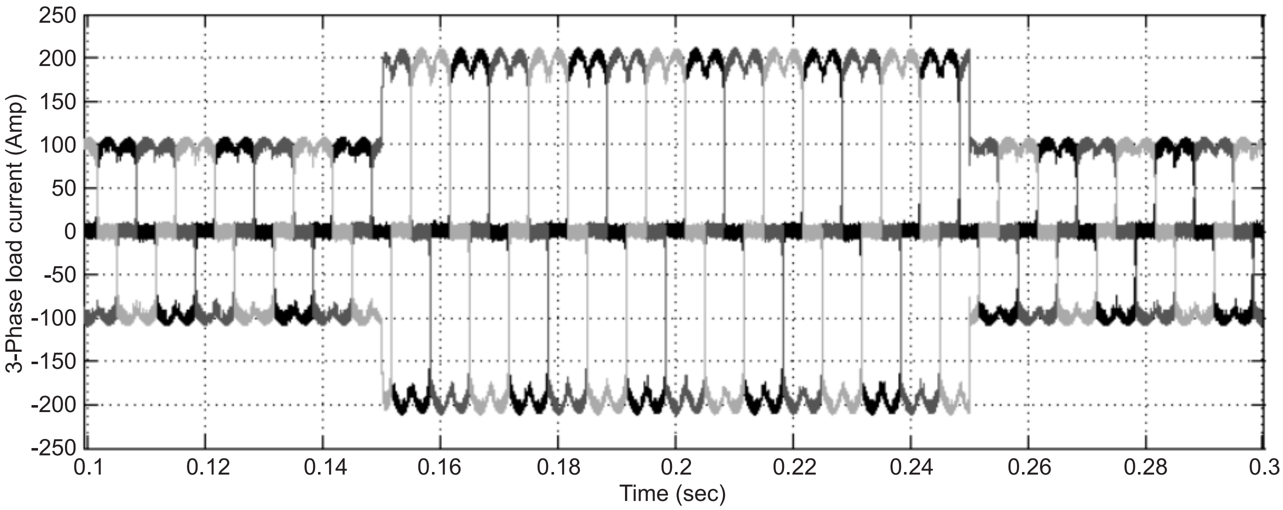

Figure 11: Three-phase load current (Amp)

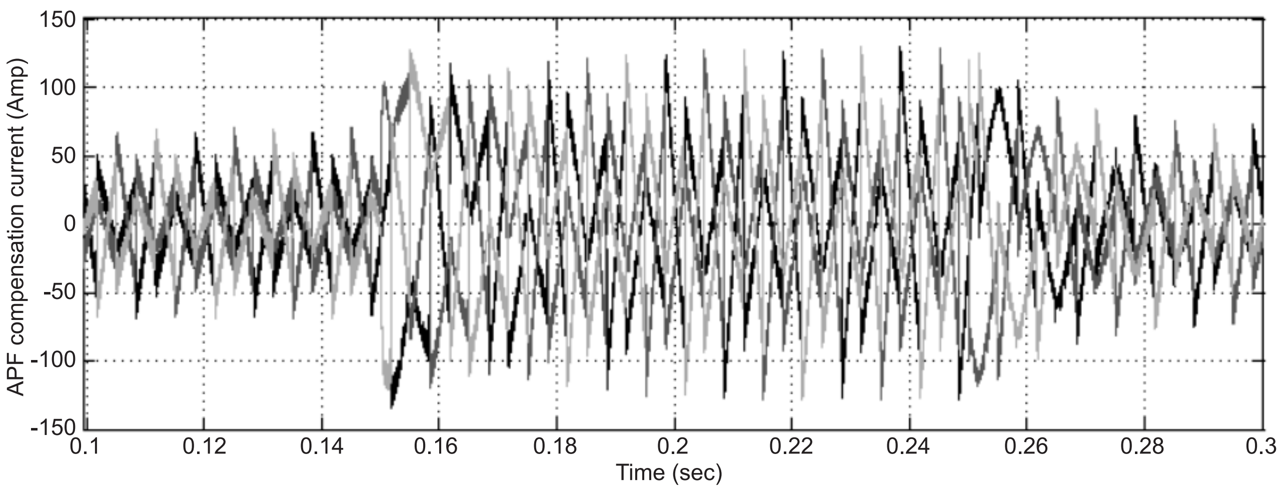

Figure 12: Compensation current of APF

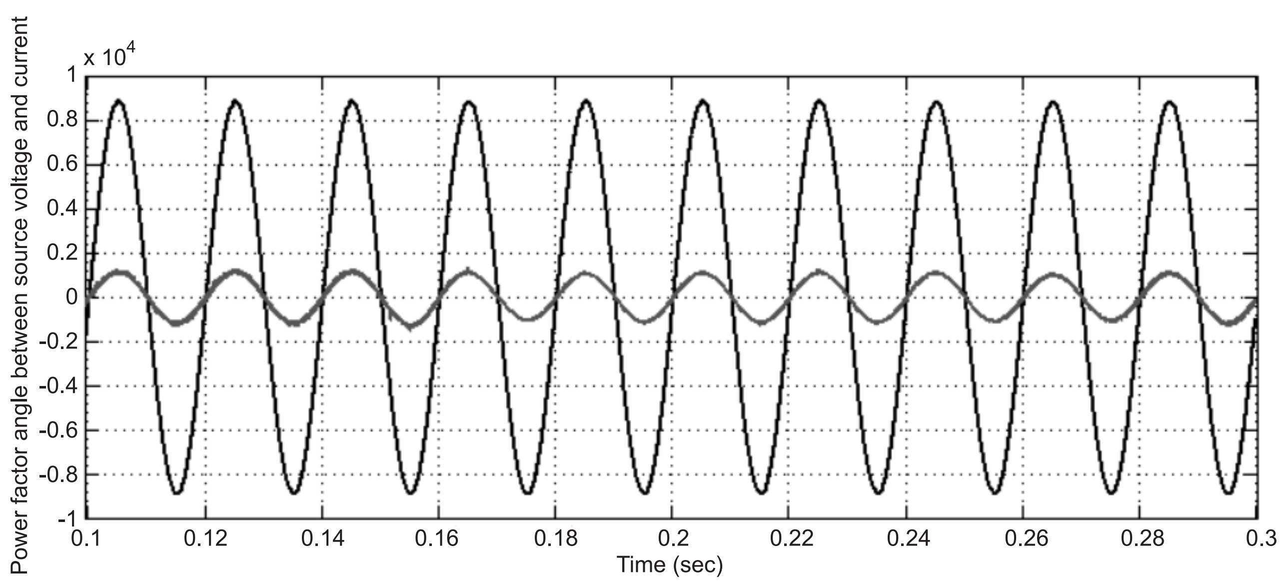

Figure 13: Power factor angle between source voltage and current

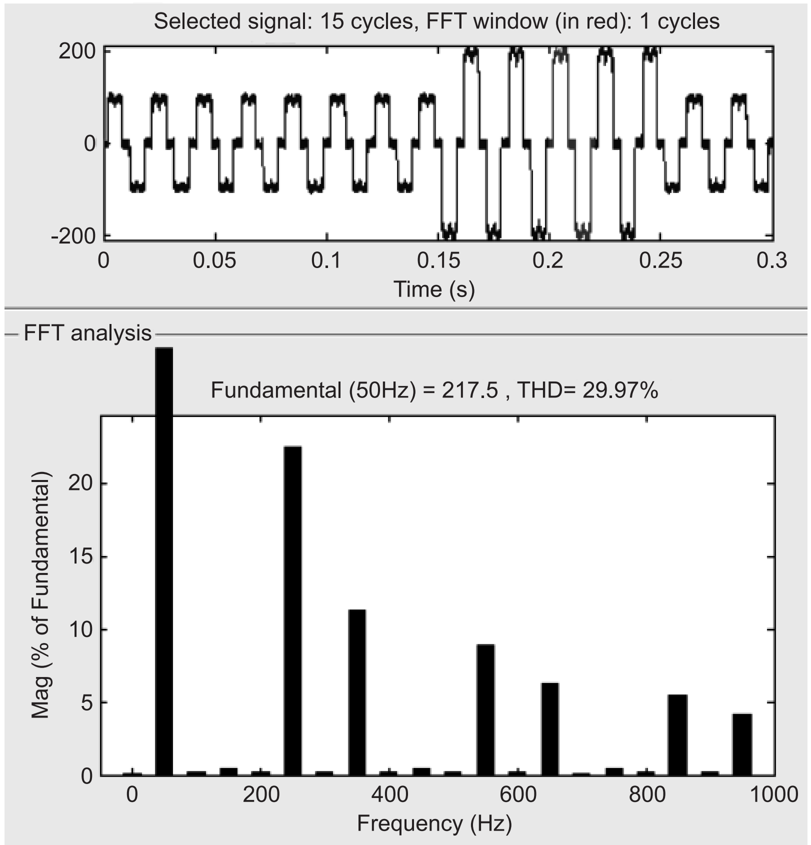

Figure 14: THD profile of load current

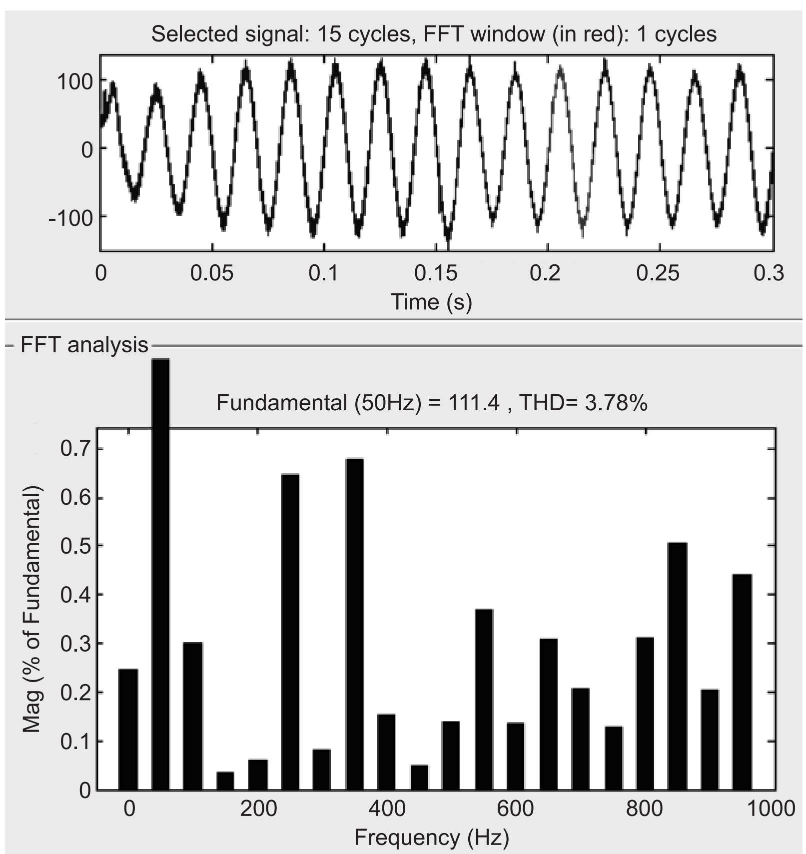

Figure 15: THD profile of source current

Power factor angle between source voltage and source current was shown in Figure 13. Power factor is maintained nearer to unity since minimum phase angle difference is maintained between source current and voltage as shown with the system with APF and with DG.

Total harmonic distortion in load current and source current were shown in Figure 14 and Figure 15 respectively. Load current distortion is about 29.67% as compared to 3.78% harmonic distortion in source current. Since load is of non-linear type, lad draws only non-linear components of current and thus % THD is high. Due to presence of APF, THD in source current is well maintained within nominal values in system with APF and with DG.

4. CONCLUSION

This paper presents the scheme of DG integration to grid. Harmonics induced due to presence of non-linear loads are eliminated with APF. DG integration employs a separate converter for integration but this paper presents the same one converter for DG integration to grid and also to eliminate harmonics in source components of power system. Total harmonic distortion in source current was reduced and maintained within nominal values with APF. APF was controlled with IARP theory which was explained in detail. Interconnection of DG to grid was illustrated. Results of source voltage and current, load current, filter currents induced and THD analysis were shown for different cases like system with APF without DG delivering fixed load, APF without DG delivering variable load and APF with DG delivering fixed load. THD FFT analysis was shown for different cases of DG integration and was maintained well below 5%.Controlling active power fed from the distributed generation is not the aspect of this paper and this line gives future scope for the concept when variable load conditions are present in distribution system.

References

1. Y. Tang, H. He, Z. Ni, J. Wen and T. Huang, "Adaptive Modulation for DFIG and STATCOM With High-Voltage Direct Current Transmission," in *IEEE Transactions on Neural Networks and Learning Systems*, Vol. 27, No. 8, pp. 1762-1772, Aug. 2016

2. N.R. Watson T. L. Scott S. Hirsch "Implications for distribution networks of high penetration of compact fluorescent lamps" *EEE Trans. Power Delivery*, Vol. 24 No. 4 pp. 1521-1528 Oct. 2009.

3. P. Bagheri, W. Xu and T. Ding, "A Distributed Filtering Scheme to Mitigate Harmonics in Residential Distribution Systems," in *IEEE Transactions on Power Delivery*, Vol. 31, No. 2, pp. 648-656, April 2016.

4. S. Jena, B. Mohapatra, C. K. Panigrahi and S. K. Mohanty, "Power quality improvement of 1-φ grid integrated pulse width modulated voltage source inverter using hysteresis Current Controller with offset band," *2016 3rd International Conference on Advanced Computing and Communication Systems (ICACCS)*, Coimbatore, India, 2016, pp. 1-7.

5. C. Mingfeng, L. Wanjun, N. Cheng, W. Huajia, S. Ling and W. Yue, "A novel control algorithm of shunt active power filter based on voltage detection," *2016 China International Conference on Electricity Distribution (CICED)*, Xi'an, China, 2016, pp. 1-5.

6. S. Bifaretti, A. Lidozzi, L. Solero and F. Crescimbini, "Modulation With Sinusoidal Third-Harmonic Injection for Active Split DC-Bus Four-Leg Inverters," *IEEE Transactions on Power Electronics*, Vol. 31, No. 9, pp. 6226-6236, Sep. 16.

7. J. F. Roseline, N. K. Sahoo and A. Abhinav, "Implementation of fuzzy logic in shunt active power filter for renewable power generation system," *2016 Second International Conference on Science Technology Engineering and Management (ICONSTEM)*, Chennai, 2016, pp. 451-456.

8. M. M. Hashempour, M. Savaghebi, J. C. Vasquez and J. M. Guerrero, "A Control Architecture to Coordinate Distributed Generators and Active Power Filters Coexisting in a Microgrid," in *IEEE Transactions on Smart Grid*, Vol. 7, No. 5, pp. 2325-2336, Sept. 2016.

9. R. S. Herrera and P. Salmeron, "Instantaneous Reactive Power Theory: A Reference in the Nonlinear Loads Compensation," in *IEEE Transactions on Industrial Electronics*, Vol. 56, No. 6, pp. 2015-2022, June 2009.

10. X. Su, M. A. S. Masoum and P. J. Wolfs, "Multi-Objective Hierarchical Control of Unbalanced Distribution Networks to Accommodate More Renewable Connections in the Smart Grid Era," in *IEEE Transactions on Power Systems*, Vol. 31, No. 5, pp. 3924-3936, Sept. 2016.

11. M. Steiner, G. Siefer, T. Schmidt, M. Wiesenfarth, F. Dimroth and A. W. Bett, "43% Sunlight to Electricity Conversion Efficiency Using CPV," in *IEEE Journal of Photovoltaics*, Vol. 6, No. 4, pp. 1020-1024, July 2016.

12. L. Zhu *et. al*., "Research on shunt active power filter based on the improved instantaneous reactive power theory," *Intelligent Control and Information Processing, Sixth International Conference on*, Wuhan, 2015, pp. 459-464.