International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 3, September 2017, pp. 1251~1259
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i3.pp1251-1259

Filter Implementation Using Output Transformer of UPS for Power Quality Improvement

Anandh N., Pramod Antony D'Sa, M.V. Gautam, V. Sai Sandeep
Department of Electrical and Electronics Engineering, Manipal Institute of Technology, Manipal University, India

Article Info

Article history:

Received Mar 27, 2017
Revised Jul 26, 2017
Accepted Aug 14, 2017

Keyword:

DAQ system
Harmonics
Passive shunt tuned filter
Power quality improvement
Uninterrupted power supply

ABSTRACT

Power electronics play a significant role in different areas of technology, more usage of power electronic devices lead to more harmonic content and various power quality issues in the system. Therefore, power quality gains more significance in the current era of research. Power electronics equipment's with non-linear loads concludes with more harmonic disturbances and lower power factor. Harmonic impurities are the major problem ingredient due to the connection of non-linear load. To lessen the harmonics usually passive filters are used. The major objective of this work is to monitor and analyse the power quality of uninterrupted power supply by means of DAQ system that gathers real time data on the system and then the data is analysed using National Instruments LabVIEW. Once power quality analysis is done, a new technique of filter implementation using output transformer of the UPS was explored and passive filter was simulated using MATLAB/Simulink and then simulated filter was implemented in order to achieve power quality improvement.

Corresponding Author:

Anandh N,
Department of Electrical and Electronics Engineering,
Manipal Institute of Technology, Manipal University,
Manipal – 576104, Karnataka, India.
Email: anandh.n@manipal.edu.

1. INTRODUCTION

Recently power electronics devices are widely used for rectification, inversion and several other applications. Besides being effective they also introduce harmonics in the power system. Arrangement of many sine waves with different frequencies than the fundamental frequency is termed as harmonics. Normally, the voltage and current waveforms are expected to be purely sinusoidal, but when the system is attached to any non-linear load it gets distorted. Examples of non-linear load include static power converters (rectifiers, adjustable speed drives, switched mode power supply and rotating electrical machines etc) [1]. Harmonics causes many ill-effects such as overheating, mechanical and electrical oscillations in alternators and prime movers, faulty operation of protective relays, intervention with communication equipments and decreasing the power generation, transmission and utilization efficiency. To overcome these harms, harmonic mitigation is significant for both utility and consumer ends. Using passive filters to filter out harmonics from the power system is one of the most primitive method used [2].

The power quality issues in power system became very severe because of vast usage of non-linear loads and power electronic components. Researchers are working upon to resolve the power quality issues, like current harmonics, reactive power etc. Hybrid active power filter (HAPF) comprises of passive filters (PF) and a series APF [3]. Thus, HAPF takes the benefits of both PF and APF. PFs can withstand high voltage and capacity alternatively, APF can filter harmonics efficiently. At all time, PF can only pay compensation to current harmonics with stable frequencies as like 5th and 7th harmonics. For other current harmonics, impedance is quiet high in PF branches and the load voltage waveforms gets worsen. To overwhelm these drawbacks, a unified power quality conditioner was used linking shunt APF and series APF, UPQC can increase voltage and also current quality [4]-[6].

The fast growth of power electronics technology lead to the huge usage of non-linear, rectifier and impulse loads in the power grid [7]. The above mentioned loads creates harmonic contamination in power system and increases source voltage hindrances. The traditional power quality monitoring devices usually works in offline mode and it is measured by power quality indicator [8-9]. These equipments does not have the functions of complete measurement, statistical analysis and conclusion. The power quality monitoring system network completely observes the power quality. On-line monitoring of electric load by PLC based system provides access to a web page wherein the current waveforms of electric load can be examined was discussed in literature [10]. An electrical power quality evaluation scheme is developed by using web-based distributed measurement system was highlighted in the paper [11] wherein, a network power quality monitor system was established. Web centered network monitoring system has independent language, cross-platform, cross-regional and fast transmission characteristics. Monitoring and managing the power quality through a browser is done very easily by the workers. Meanwhile, the necessities of real-time, accessability and reliability are confirmed. An idea on shunt hybrid filter design using PQ theory in order to improve the power quality for 3 phase distribution system feeding various non-linear loads was proposed in literature [12]. An Artificial Neural Network controller based shunt active power filter produces the controlled pulses needed for IGBT inverter in order to mitigate the harmonics of distribution system was discussed [13].

The main goal of this work is to monitor and analyse the power quality of uninterrupted power supply using a DAQ system that collects real time data on the system and then the data is analysed using National Instruments LabVIEW. Once power quality analysis is done, a new technique of filter implementation using output transformer of the UPS was explored and passive filter is simulated with MATLAB/Simulink then the simulated filter was implemented in order to achieve power quality improvement.

2. CIRCUIT ANALYSIS AND METHODOLOGY

PQ monitoring system comprises of both hardware and software modules. It has current and voltage sensors. The UPS is connected to load (i.e. 10 computers). Power quality analysis is progressed with the aid of a DAQ system, which gathers real time data on the system. Later the data is analysed with the assistance of National Instruments LabVIEW. Once analysis is done appropriate filter is chosen, simulated with MATLAB/Simulink and then implemented. The Figure 1 below shows the block diagram of power quality monitoring system.

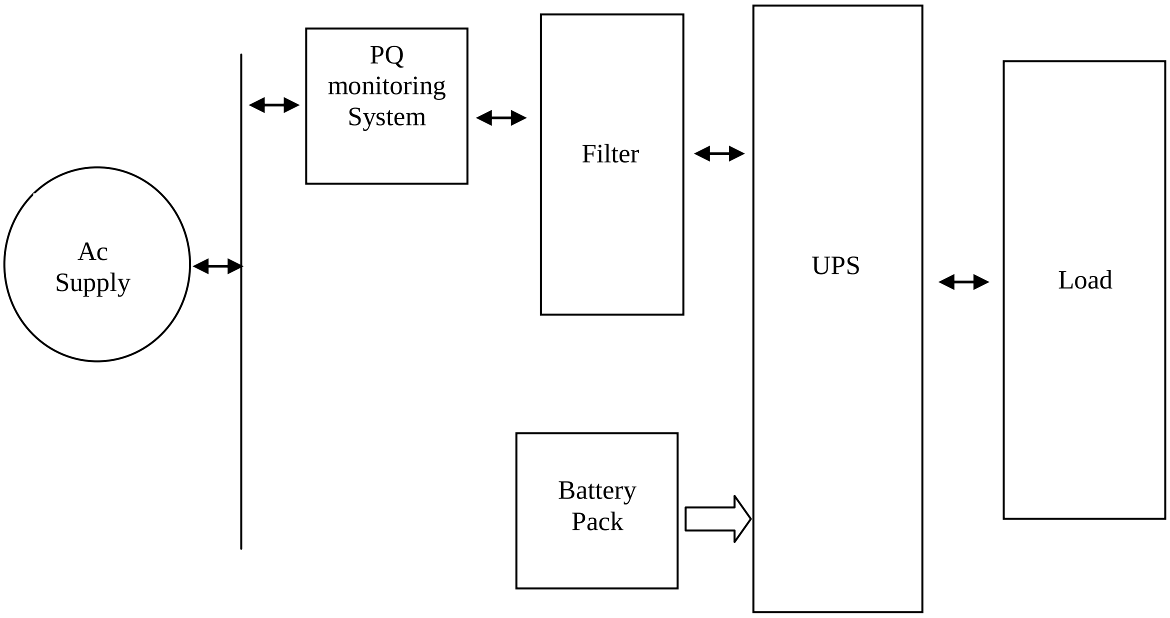

Figure 1. Power quality monitoring system block diagram

A PC centered power quality analyser, comprising a group of tools in one real-time system, proficient to run all devices in parallel and can be easily accessible in future. Based on recent IEC and EN standards, measurement and data processing procedures are accounted and have a remote accessible instruments through ethernet design following SPIPI standard. A software application can be developed by using the National Instruments LabVIEW graphical development environment that behaves as instrument firmware. The current sensor is attached serially with input and voltage sensor is connected in parallel with supply and UPS. This work combines monitoring of power quality of single phase UPS. The data analysis was done on PC using National Instruments LabVIEW. The input data is 24 bit sampled at 50kS/s.

2.1. Power Quality Monitoring

To process and display the gathered data from the sensors LabVIEW 2015 32-bit version with electrical power suite add-on is used. Power quality monitoring system has indicators to indicate THD_i, IHD_1, IHD_3, IHD_5, IHD_7, IHD_9, distorted power factor, active power, FFT spectrum of current waveform. It also shows RMS values of current and voltage with the aid of gauges and numeric indicators. Data from DAQ assistant contains data from all the connected sensors. Hence, it is divided and each signal is multiplied with its matching multiplication factor. Later RMS waveforms of current and voltage to be used in calculation of active, reactive and apparent power flowing through the system.

Amplitude and measurement blocks determine the RMS values of current and voltage. Spectral measurements block is utilised for FFT analysis of current waveform. FFT analysis of voltage waveform is not done because voltage waveform appears perfectly sinusoidal without any abnormalities. Once all the required variables are calculated the data is to be stored in an excel sheet. IHD_n calculation was done in a sub VI. IHD value upto 9th harmonic component was calculated. Distortion measurement block is used to calculate specific harmonic current value for each component. Then the specific harmonic current value is separated with specific harmonic current of fundamental to get IHD value.

2.2. Power Factor Calculation

Power factor calculation in systems with non-sinusoidal load current is different from that of sinusoidal load current systems. To calculate power factor in such cases distortion power factor is to be taken into account. In case of normal loads PF is calculated by

$$\mathrm{PF} = \frac{Active\ Power}{Apparent\ Power} = \frac{Vrms * Irms * \cos(\Theta - \phi)}{Vrms * Irms}$$

Where, Θ is phase angle of voltage and ϕ is phase angle of current. But in case of non-linear loads

$$\mathrm{PF} = \frac{V1,rms * I1,rms * \cos(\Theta 1 - \phi 1)}{V1,rms * Irms}$$

$$\text{Distorted Power factor (DPF)} = DF * \cos(\Theta 1 - \phi 1)$$

Inductance of transformer is measured by short circuit test. In standard SC test, current and voltage transducers are used rather than using wattmeter and voltmeter. Values from these sensors is processed using LabVIEW. Values of power, resistance, impedance, reactance and inductance of the transformer are calculated pertaining to low voltage side of the transformer. MATLAB/Simulink is used for simulation of designed filter because it is difficult to simulate with non-linear load. Therefore, supply current is simulated to match the observed current. This is done by connecting current sources of different amplitudes and frequency in parallel. Filter is simulated using a RLC series component by giving appropriate R, L, C values. A current measurement block and scope is used to observe the waveform. A powergui block is added and FFT analysis for the simulated circuit is carried out.

2.3. Hardware Implementation

2.3.1. NI cDAQ-9184

It is a 4-slot NI CompactDAQ Gigabit ethernet chassis intended for distant or dispersed sensor and electrical calibrations. Solitary NI CompactDAQ chassis measures till 128 sensor signal channels, analog I/O, digital I/O and counter/timers with an ethernet interfaced to a PC or laptop.

2.3.2. NI 9227

It is a 4 channel current input C series module. It has a built in anti-aliasing filter. It is compatible with compactRIO and compactDAQ intended to calculate 5 A nominal and upto 14 A peak on separate channel with channel-to-channel segregation.

2.3.3. LEM LA 25-NP

This is basically a current transducer for measuring the currents, DC, AC, pulsed with galvanic separation amid of primary and secondary circuits. It has 10 terminals on input side which can be connected in different configurations for various input current limits. It can measure maximum primary nominal current of 25 A corresponding to a nominal secondary current of 25 mA. It has to be powered by a +/- 15 V supply. For the range of connection available and with a maximum current value at 25 A this sensor is selected.

2.3.4. LEM LV 25-400

This is normally a voltage transducer for measuring the voltages, DC, AC, pulsed with galvanic separation amid of primary and secondary circuits. It has primary nominal voltage of 400 V. Its output is in current with nominal value of 25 mA. It has to be powered by a +/- 15 V supply. The Figure 2 below shows the power quality monitoring system implemented in our laboratory.

Figure 2. Power quality monitoring system implemented

The current and voltage transducers are connected to UPS. The output of the sensors is current which is converted to voltage over a resistor. The analog output is connected to National Instruments analog input card which is connected to a National Instruments compact data acquisition with an ethernet chassis. The data acquisition system is connected to PC which is running LabVIEW software.

2.4. Passive Filter Calculation

Initial power quality study was done on a 3 KVA UPS and the filter configuration calculation. Passive shunt filters fundamentally consist of serial connection of an inductor and a capacitor adjusted to a certain frequency and behaves as low-impedance path for the harmonics. Initial capacitor size is calculated from reactive power requirement (Q_c) of the load.

$$\text{Value of Capacitor } (C_n) = \frac{Qc}{m*w*Vs^2}$$

Where, Q_c - Reactive Power; m - number of branches in passive filter; V_s - fundamental voltage per phase. To eliminate n^{th} current harmonics, the n^{th}-order inductor is calculated as

$$L_n = \frac{1}{n^2*w^2*Cn}$$

The series resistance for the n^{th}-order filter inductor is calculated as

$$R_n = \frac{n*w*Ln}{QF}$$

The values of capacitance obtained for mitigation of 3^{rd} and 5^{th} harmonic components are not manufactured for single phase system because factor of safety goes down. For this reason, power quality study was done on a modular 1 KVA UPS. In this configuration instead of using external inductance, inductance of output transformer is used. To limit high di/dt in the circuit, additional inductance is added. This inductance value was also designed to change effective value of inductance in the circuit and to change capacitance value to values easily available in the market. The Figure 3 shows the filter implementation using internal transformer of UPS. Since, inductance value is fixed from the measured inductance of transformer and additional inductance is to be chosen, the capacitance value easily available in the market for single phase systems are 2.5 uF, 8 uF and 50 uF. The Figure 4 shows the passive filter implementation in our laboratory.

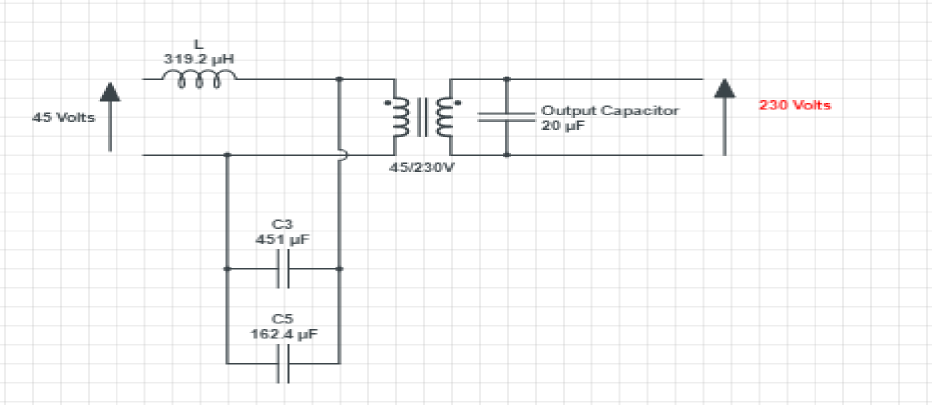

Figure 3. Filter implementation using internal transformer of UPS

Figure 4. Passive filter implementation

The above picture displays the passive filter implementation for mitigating 5th harmonic component using 50 mfd x 3 and 8 mfd x 3 capacitors. These capacitors are connected in parallel to get 164 mfd capacitor bank. This capacitor bank and the inductance from the components of the UPS act as a single tuned passive filter. Thus 5th harmonic component is mitigated.

3. RESULT ANALYSIS AND DISCUSSIONS

3.1.1 KVA UPS System Results

When filter calculation where done for 3 KVA system the values for a passive filter components for reducing 3rd harmonic component was, Capacitance: 7650 Micro farad, Inductance: 147 Micro henry.The passive filter components value for reducing 5th harmonic component was, Capacitance: 7650 Micro farad, Inductance: 52.9 Micro henry.This value of capacitance is not manufactured for low powered single phase systems because factor of safety becomes low. For this reason, we had to do power quality analysis on a lower model 1 KVA UPS. Figure 5 and 6 shows the current waveform and FFT analysis of harmonic spectrum with load as 6 systems of 1 KVA UPS. Figure 7 shows the IHD 5 variation with time. Figure 8 depicts the comparison of THD and current for different loads and Figure 9 shows the distorted power factor for different systems.

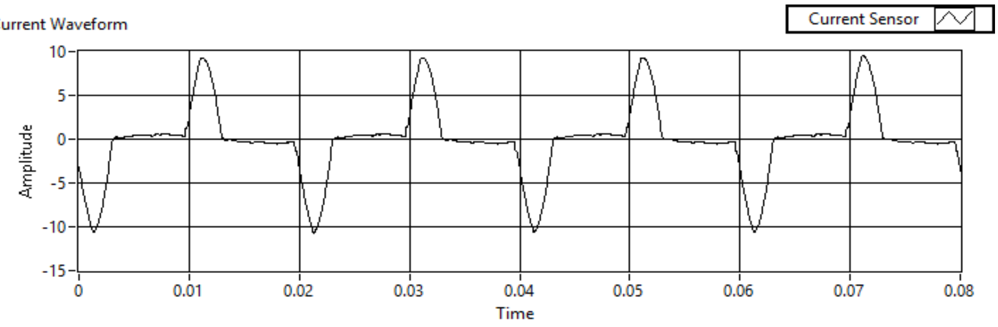

Figure 5. Current Waveform with load as 6 systems of 1 KVA UPS

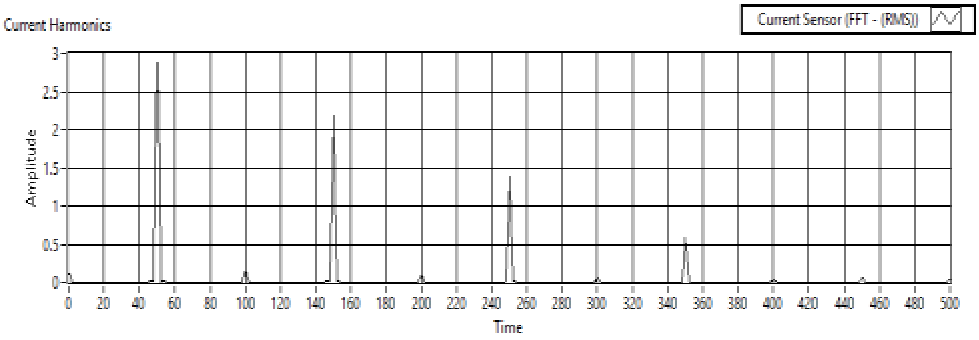

Figure 6. FFT analysis for current waveform of 1 KVA system

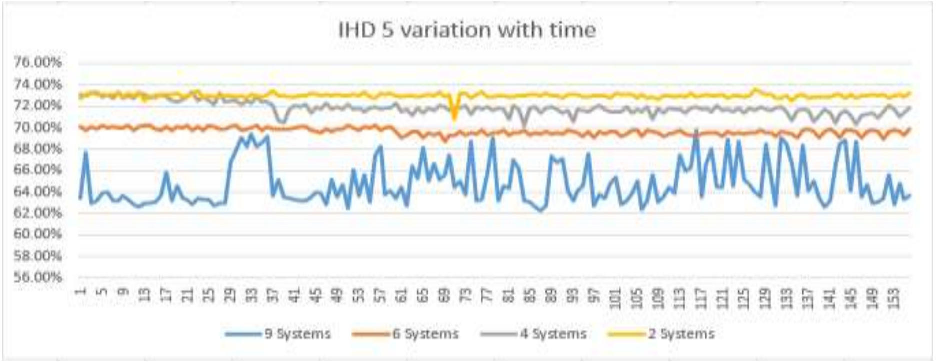

Figure 7. IHD 5 variation with time

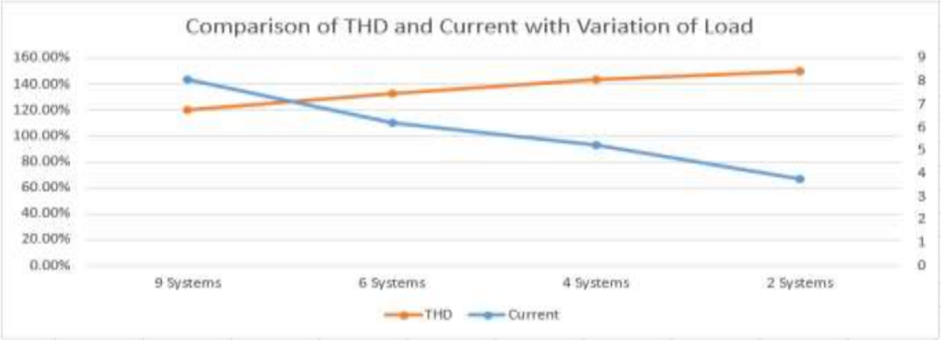

Figure 8. Comparison of THD and Current for different loads

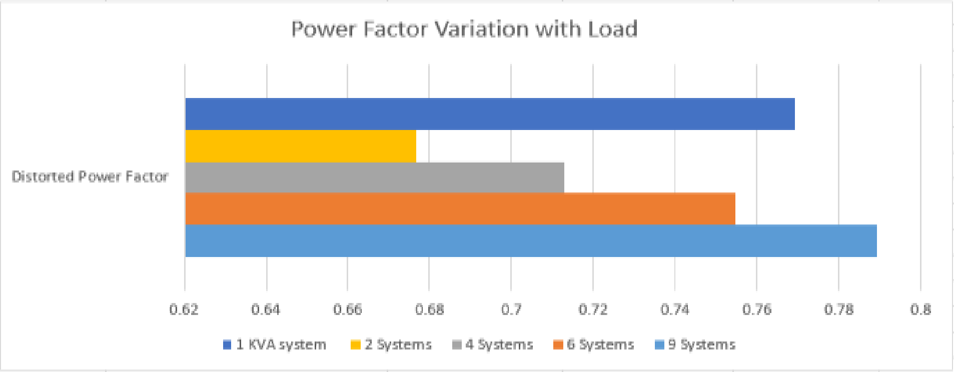

Figure 9. Distorted power factor for different systems

3.2. Filtered Output Results of I KVA UPS System

Transformer is used as inductor for the passive filter. Inductance value of transformer is measured using short circuit test. Short circuit on transformer was done with standard method but with aid of current, voltage sensors and LabVIEW. The transformer is part of the UPS. The transformer is rated at 1 KVA, 45/230 V. The passive filter is shunt connected to the transformer on LV side. Filter uses inductance of transformer for L of filter. Capacitance used was 164 mfd. This was used to remove 5th harmonic component. Capacitance required to remove 3rd harmonic component is 451 mfd. When 164 mfd capacitor was connected the power through the transformer exceed the limit. For that reason, 451 mfd was not connected. Therefore, it difficult to implement harmonic filter for single phase low powered systems. As the power rating increases availability of required capacitance value also increases. Since the system was single phase low power rated, passive filter branch to remove 3rd harmonic component was not implemented. With the connection of a filter branch the core of the transformer starts vibrating due to resonance between the filter branch and remaining system. For this reason, filter required to remove 3rd harmonic component was not connected as the capacitance required is higher and the vibration caused because of that branch might spoil the transformer. As it can be observed from above picture 5th harmonic component value decreased. THD_i value improved. Initial value of THD was at 92 %. Figure 10 and 11 shows the current waveform for 1 KVA system and FFT analysis for current waveform of 1 KVA system with passive filter implementation. Figure 12 depicts Power Factor vs Load Current graph.

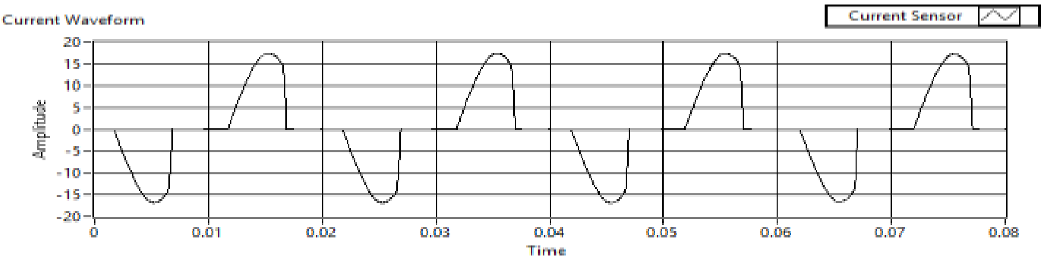

Figure 10. Current waveform for 1 KVA system with passive filter implemented

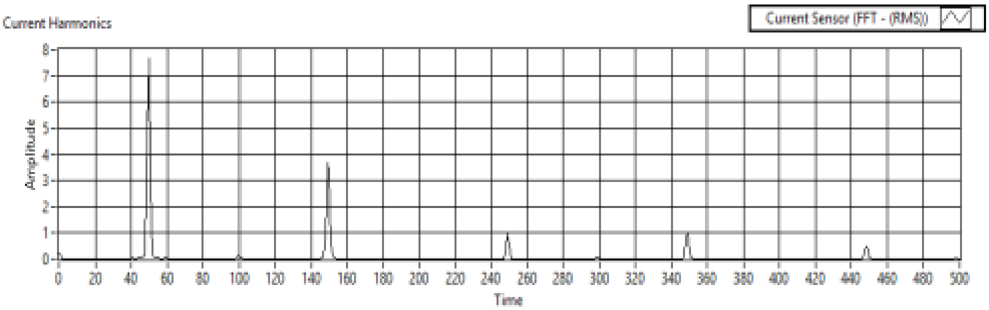

Figure 11. FFT analysis for current waveform of 1 KVA system with passive filter implemented

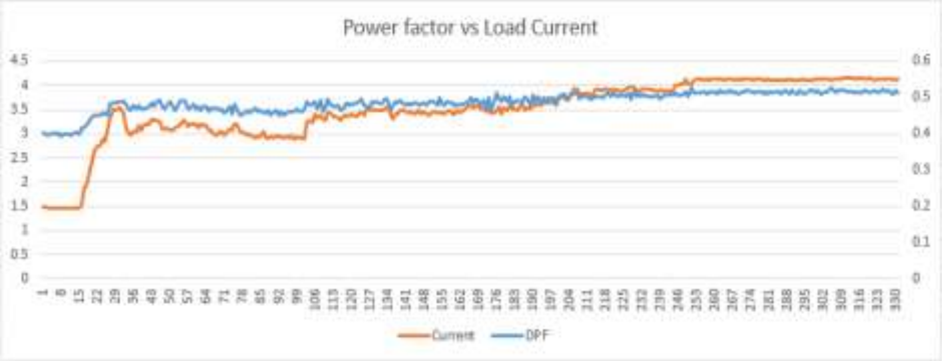

Figure 12. Power Factor vs Load Current

Initial analysis on power quality of the system showed high harmonic content with 3rd and 5th harmonic components dominating and power factor value was poor. With the implementation of shunt passive filter branch to reduce 5th harmonic component THDi value decreased and power factor value improved.

4. CONCLUSION

A complete power quality analysis on the system was done and various mitigation techniques were studied. The deep understanding of mitigation schemes made us to select passive filter for simulation and implementation. While implementing the mitigation technique a new method of implementation of filter circuit was explored. Implementation of filter by means of output transformer of the UPS was done. The main constraint of such scheme is the power rating of the filter, because the amount of power flows through the transformer is fixed during the design of UPS. Adding extra circuits will rises the power flowing through the transformer and surpasses its limit. While surpassing its limit the transformer core begins to vibrate and starts making noise. This limits the quantity of harmonic contents and can be detached easily. Alternatively this work can be implemented by using active filters or unified power quality compensators or shunt active compensators. Though this work concentrates on low powered system similar principles and techniques can be stretched to high powered systems and three phase systems.

REFERENCES

[1] D. Gonzalez, J. McCall. Design of Filters to Reduce Harmonic Distortion in Industrial Power Systems. *IEEE Trans. on Industry Applications*. 1987; 23(3): 504-511.

[2] M. Tali, A. Obbadi, A. Elfajri, Y. Errami. *Passive Filter for Harmonics Mitigation in Standalone PV System for Non-Linear Load*. Renewable and sustainable energy conference, Morocco. 2014; 499-504.

[3] Lee G M, Lee D C, Seok J K. Control of series active power filters compensating for source voltage unbalance and current harmonics. *IEEE Transactions on Industrial Electronics*. 2004; 19(1): 132-139.

[4] Fujita H, Akagi H. The unified power quality conditioner: the integration of series-and shunt-active filters. *IEEE Transactions on Power Electronics*. 1998; 13(2): 315-322.

[5] Hideaki Fujita, Hiromi Akagi, Yasuhiro Watanabe. Dynamic control and performance of a unified power flow controller for stabilizing and an AC transmission system. *IEEE Transactions on Power Electronics*. 2006; 21(4): 1013-1020.

[6] Jong-Kun Lee, Jul-Ki Seok, Dong-Choon Lee. *Unified Active Power Filters for Source Voltage Unbalance/Current Harmonics Compensation and Power Factor Correction.* The 30th Annual Conference of the IEEE Industrial Electronics Society, Busan, Korea. 2004; 540-545.

[7] M. H. J. Bollen. Understanding Power Quality Problems: Voltage Sags and Interruptions. *IEEE Press*, New York, 2000.

[8] Waclawiak M, Mc Granaghan M, Sabin D. *Substation power quality performance monitoring and the internet.* IEEE Power Engineering Society Summer Meeting. 2001; 2: 1110-1111.

[9] Batista J, Monso JL, Martins JS. *Low-cost power quality monitor based on a PC.* EEE International Symposium on Industrial Electronics. 2003; 1: 323-328.

[10] Wei-Fu Chang, Yu-Chi Wu, Chui-Wen Chiu. Development of a web-based remote load supervision and control system. *Electrical Power and Energy Systems*. 2006; 28: 401–407.

[11] Juan José González de la Rosa, Antonio Moreno Muñoz, Aurora Gil de Castro, Víctor Pallarés López, Jose Antonio Sánchez Castillejo. A web-based distributed measurement system for electrical power quality assessment. *Measurement*. 2010; 43: 771–780.
[12] R. Balasubramanian, S.Palani. Simulation and performance evaluation of shunt hybrid power filter for power quality improvement using PQ theory. *International Journal of Electrical and Computer Engineering*. 2016; 6(6): 2603-2609.
[13] Jarupula Somlal, Venu Gopala Rao.Mannam, Narasimha Rao.Vutlapalli. Power quality improvement in distribution system using ANN based shunt active power filter. *International Journal of Power Electronics and Drive Systems*. 2015; 5(4): 568-575.