

Harmonic Analysis and Mitigation scheme with Shunt Active Filter for Power Quality Enhancement using MATLAB & LabVIEW

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Abstract: The continuous increase of nonlinear loads, mostly uses power electronic devices bring a major concern on power quality problems such as power factor reduction, harmonics, voltage unbalance etc. This paper focuses harmonic distortion to be the major factor for power quality issues because of its harmful effect on power system network. Different methods of harmonic analysis and mitigation procedure are surveyed and with the help of MATLAB based harmonic analyser, harmonics of source current is inspected for different types of source and load. A very new platform for enhancing power quality using shunt Active Filter with LabVIEW based intelligent control software is initiated. Lab VIEW based controller can efficiently compensate for both balanced and unbalanced nonlinear load currents and also make itself comfortable to compensate for variations in nonlinear load currents. In this paper, a standard power system taken from reference and is designed in Simulink to find the harmonics level. A shunt active filter is designed in labview and is tested.

Keywords: Harmonic compensation, Intelligent controller, MATLAB, Power Quality, Reactive compensation, Shunt Active Filter.

Introduction

The increasing use of sensitive and non-linear loads, the deregulation of utilities, and the increased interconnections in power systems has led to an increased need to solve and prevent power quality problems. This power quality is defined as "Any power problem manifested in voltage, current, or frequency deviations that results in failure or malfunction of customer equipment." [1]. These problems, if not mitigated would cause heavy economic as well as technical disturbances. These Power quality problems are of many types such as transients, sags and swells, distortions, frequency deviations, harmonics, inter-harmonics. Harmonics are introduced by power electronic converters, ASDs, UPS, etc. which are widely used in the industries [3]. Power Quality diagnostic tools were employed for power quality analysis in industrial, commercial and residential systems to detect any abnormal condition in system. Best power quality monitoring technique with reduced cost and capable of remote data processing are necessary to ensure good power quality at different distribution points. In earlier days, power quality is monitored by power meter, signal analysers such as distortion analyser, frequency meter etc [2]. But they do not have ability to store data for future analysis or for feedback to system. Recently power quality monitoring techniques such as real time detection and classification, embedded system based and web based monitoring based on compact microprocessor [4-10] have been designed. But they have assumed their devices to be balanced and in phase with the supply voltages after compensation which may not be the case. We have fluke meter, yokogowa meter and hioki meter as power quality problem detector in existing market; but these devices come up fixed vendor defined functionality and specification and again these also don't have any memory for future reference. Here we have used LabView to design the power quality detection mitigation scheme as it is easier to use and modify because of digital system. It has broader range and association is not fixed so we can change it according to our requirement.

LabVIEW is a National Instrument development software that allows rapidly and cost-effectively interface with measurement and control hardware, data analyses, share results, and distribute systems. It is based on graphical programming techniques that allow programming with visual expressions, spatial arrangements of text and graphic symbols. In MATLAB we can design the circuit using virtual instruments using Simulink and can implement any algorithm using function block. These modern technology uses advance methods for measurement and recording of the power quality parameters. The most important parameters such as voltage, current, power are recorded into text files which can further used for future data analysis. LabVIEW provides two panel i.e. block diagram and front panel for graphical program development and graphic interface formed by switches and panels intended for user interaction respectively, whereas in MATLAB there is only one panel for block diagram and to check the signal we have to use scopes. In this experiment the type of filter used is Low Pass Butterworth IIR/FIR Filter of Order 3 having cut off 100 Hz which depends only on the current and past inputs. Because the filter does not depend on past outputs, the impulse response decays to zero in a finite amount of time. Because FIR filters return a linear phase response, use FIR filters for

applications that require linear phase responses and IIR filter is a digital filter with impulse responses that can theoretically be infinite in length or duration.

The frequency response of the Butterworth Filter approximation function is also often referred to as “maximally flat” (no ripples) response because the pass band is designed to have a frequency response which is as flat as mathematically possible from 0Hz (DC) until the cut-off frequency at -3dB with no ripples. Higher frequencies beyond the cut-off point rolls-off down to zero in the stop band at 20dB/decade or 6dB/octave. This is because it has a “quality factor”, “Q” of just 0.707. And Order causes the transition between the pass band and the stop band to become steeper. However, as the value of Order increases, the processing speed becomes slower, and the number of distorted points at the start of the signal increases. The order of IIR filter is often by default taken to be 3.

We can utilize LabVIEW software for the data acquisitions and treatment of the electrical signals of a mini electrical power system. It also analyses the waveform of the signals and its harmonics level and defines the phasor graph of all the current and tension signals at the same time [11]. virtual software is easy to program, as it is visual and has an interface that allows the visualization of how the data propagate during signal acquisition and treatment. The sensors that measure current or tension signals are of the Hall-effect type, which in itself assures galvanic insulation of the signals. There is a board from National Instruments that conditions the signals for the analogue/digital conversion board, which has 16 analogue inputs converting analogue signals in the range between 0 and 10 V to digital values. For this feature it becomes very easy to process the signals using any algorithm in practical system.

Various parameters of power

Apparent Power = $S = V_{rms} I_{rms}$ VA

Real Power = $P = V_{rms} I_{rms} \cos(\theta_1 - \phi_1)$ W

Reactive Power = $Q = V_{rms} I_{rms} \sin(\theta_1 - \phi_1)$ VAR

Distortion Power = $D = \sqrt{S^2 - (P^2 - Q^2)}$ VA

The Displacement power factor = $P/S = \cos(\theta_1 - \phi_1) = \frac{V_{rms} I_{rms} \cos(\theta_1 - \phi_1)}{V_{rms} I_{rms}}$

Distortion Power Factor = $\frac{V_{rms} I_{rms}}{V_{rms} I_{rms}} = \frac{S_1}{S}$

THD = $I_{rms} \div I_{s1}$

Where

$I_{rms} = \sqrt{(I_2^2 + I_3^2 + \dots + I_n^2)}$

I_n^2 Denotes n^{th} harmonics in source current

I_{s1} Denotes fundamental source current

Harmonic Modelling and mitigation technique

Harmonic modelling is a mathematical way of predicting harmonic distortion levels and potential resonances based on available power system data. All but the simplest of systems will require a computer to perform this analysis. Components such as transformers, capacitors, motors, and the utility system impedance are taken into account, and non-linear loads are represented by multiple frequency harmonic current sources. Such a modelling study will indicate if harmonic levels will fall within IEEE or utility limits.

A. Analysis by matlab

Here we have adopted a standard test system(Fig. 1) to study the harmonics created by nonlinear load. The analysis part is completed, but mitigation part in MATLAB could not be completed for time and resource constraints. However both part is completed using LabView which will be discussed later in next subsection.

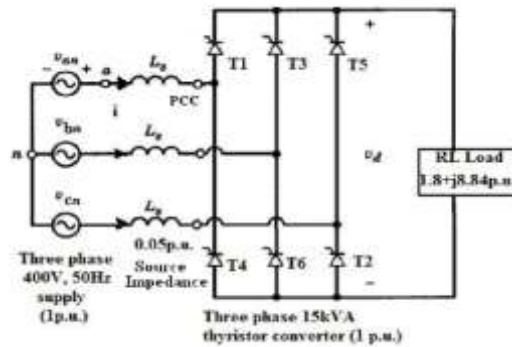


Figure 1. standard test system to study the harmonics created by nonlinear load

The inductance of the load circuit has to be sufficiently large in order to provide steady DC current through the load and rectangular current pulses in the ac side. The three phase balanced 400V, 50Hz supply connected through three phase 6 pulse thyristor converter to 3kW resistive Load (Base V = 400V, Base kVA=15kVA).

B. Balanced source and balanced nonlinear load

The test system is operated under three phase 400V, 50Hz balanced source and balanced nonlinear load impedance conditions. The three phase source currents are distorted in equal amounts and THD is 21%.

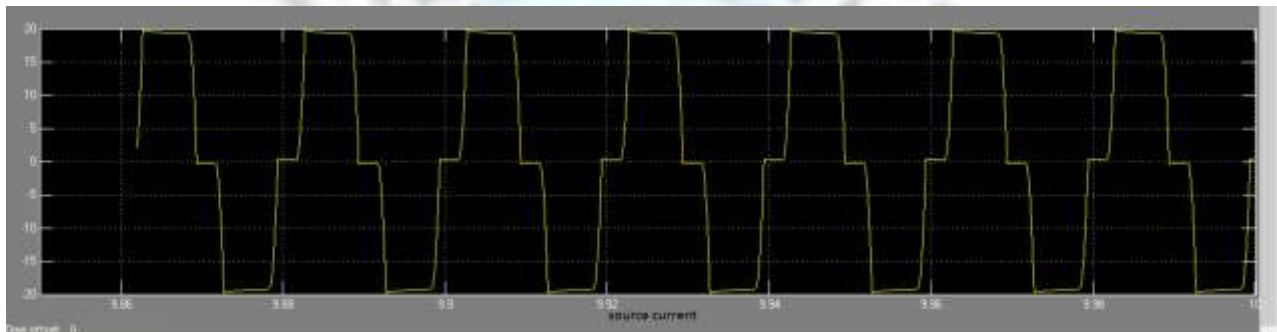


Figure 2. Source Current

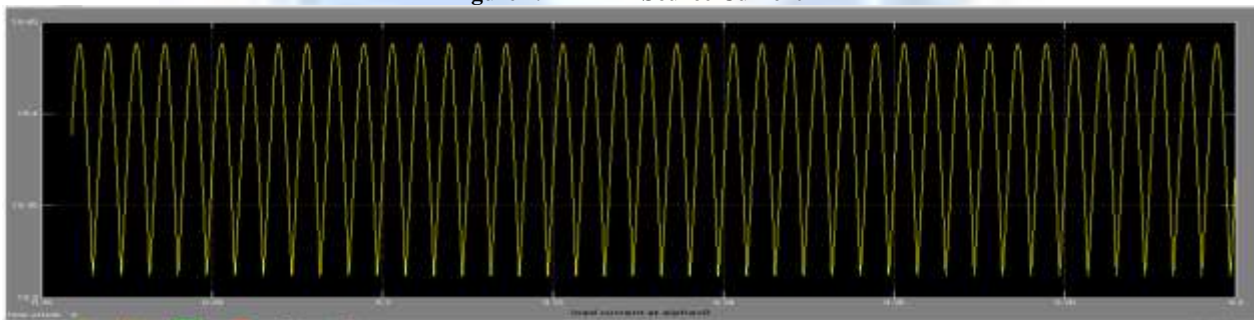


Figure 3. Load Current

C. Unbalanced source and balanced nonlinear load

The system is operated under unbalanced source and balanced nonlinear load conditions. A three-phase unbalanced voltage (Phase A: $1\angle 0^\circ$, Phase B: $0.7\angle 135^\circ$, Phase C: $1.3\angle -135^\circ$) applied to the R – L Load through thyristor converter. Distortions in the three phase currents are unbalanced.

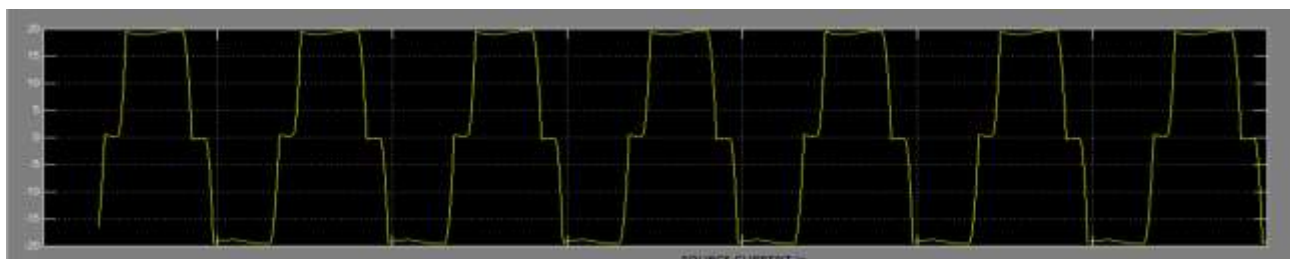


Figure 4. Source Current

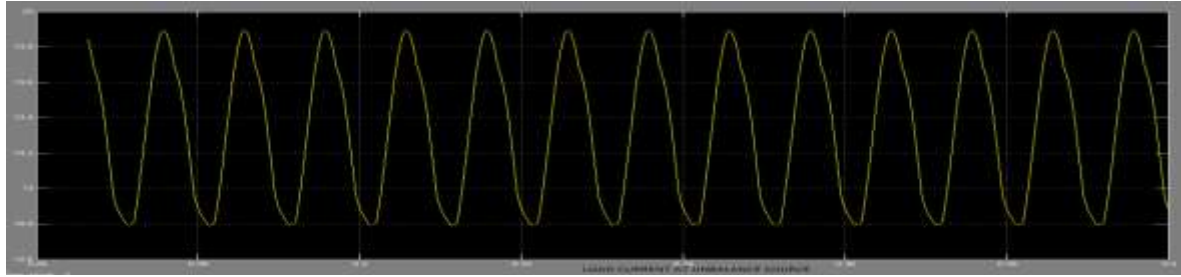


Figure 5. Load Current

D. Balanced source and unbalanced nonlinear load:

The system is operated under balanced source and unbalanced nonlinear load conditions. Unbalanced nonlinear load is introduced in the three phases by adding additional star connected load in A (20%), B (10%), and C (18%) phases in parallel with nonlinear load. The % of unbalance is calculated as the deviation from the average of three phase unbalanced loads.



Figure 6. Source Current

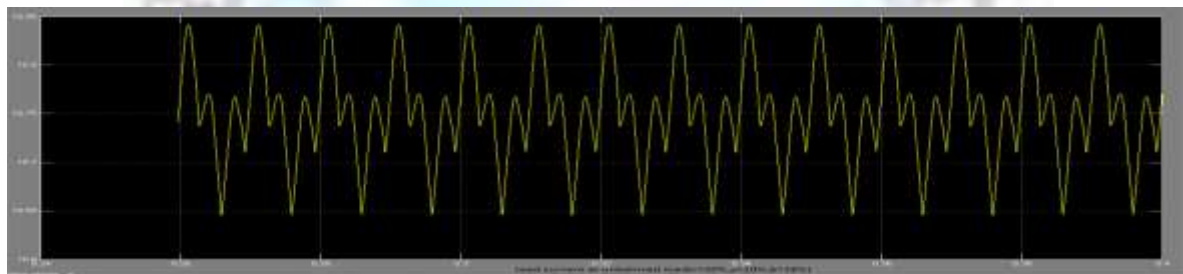


Figure 7. Load Current

Data obtained:

Fundamental component of source current and THD in source current in the three phase system for different firing angles $\alpha = 10^\circ, 20^\circ, 40^\circ$ and 50° are obtained under above mentioned conditions. The results are shown in Table 1 – Table 4. The source current of different phases have similar waveform but all have 120° phase difference to each other.

Table 1: For firing angle $\alpha = 10^\circ$

FOR $\alpha = 10^\circ$						
SOURCE/LOAD	FUNDAMENTAL COMPONENT OF SOURCE CURRENT IN PU			THD IN SOURCE CURRENT		
	PHASE A	PHASE B	PHASE C	PHASE A	PHASE B	PHASE C
BALANCED SOURCE AND BALANCED NON-LINEAR LOAD	0.76	0.76	0.76	21	21	21
UNBALANCED SOURCE AND BALANCED NON-LINEAR LOAD	0.52	0.75	0.33	22.57	29.33	33.2
BALANCED SOURCE AND UNBALANCED NON-LINEAR LOAD	0.63	0.72	0.61	23	31.4	22.5

Table 2: For firing angle $\alpha = 20^\circ$

FOR $\alpha = 20^\circ$						
SOURCE/LOAD	FUNDAMENTAL COMPONENT OF SOURCE CURRENT IN PU			THD IN SOURCE CURRENT		
	PHASE A	PHASE B	PHASE C	PHASE A	PHASE B	PHASE C
BALANCED SOURCE AND BALANCED NON-LINEAR LOAD	0.72	0.72	0.72	24	24	24
UNBALANCED SOURCE AND BALANCED NON-LINEAR LOAD	0.56	0.71	0.31	25.7	33.2	37.4
BALANCED SOURCE AND UNBALANCED NON-LINEAR LOAD	0.61	0.68	0.63	26.1	34.7	25.4

Table 3: For firing angle $\alpha = 40^\circ$

FOR $\alpha = 40^\circ$						
SOURCE/LOAD	FUNDAMENTAL COMPONENT OF SOURCE CURRENT IN PU			THD IN SOURCE CURRENT		
	PHASE A	PHASE B	PHASE C	PHASE A	PHASE B	PHASE C
BALANCED SOURCE AND BALANCED NON-LINEAR LOAD	0.58	0.58	0.58	28	28	28
UNBALANCED SOURCE AND BALANCED NON-LINEAR LOAD	0.36	0.51	0.32	16.3	19.4	23.8
BALANCED SOURCE AND UNBALANCED NON-LINEAR LOAD	0.42	0.45	0.39	19.3	21.5	18.7

Table 5: For firing angle $\alpha = 50^\circ$

FOR $\alpha = 50^\circ$						
SOURCE/LOAD	FUNDAMENTAL COMPONENT OF SOURCE CURRENT IN PU			THD IN SOURCE CURRENT IN %		
	PHASE A	PHASE B	PHASE C	PHASE A	PHASE B	PHASE C
BALANCED SOURCE AND BALANCED NON-LINEAR LOAD	0.49	0.49	0.49	29	29	29
UNBALANCED SOURCE AND BALANCED NON-LINEAR LOAD	0.26	0.47	0.21	17.2	20.4	24.7
BALANCED SOURCE AND UNBALANCED NON-LINEAR LOAD	0.33	0.38	0.26	20.3	22.8	19.2

This shows that this nonlinear load introduces harmonics and unbalance in source currents, which are to be compensated by suitable filter configuration.

ANALYSIS BY LabView

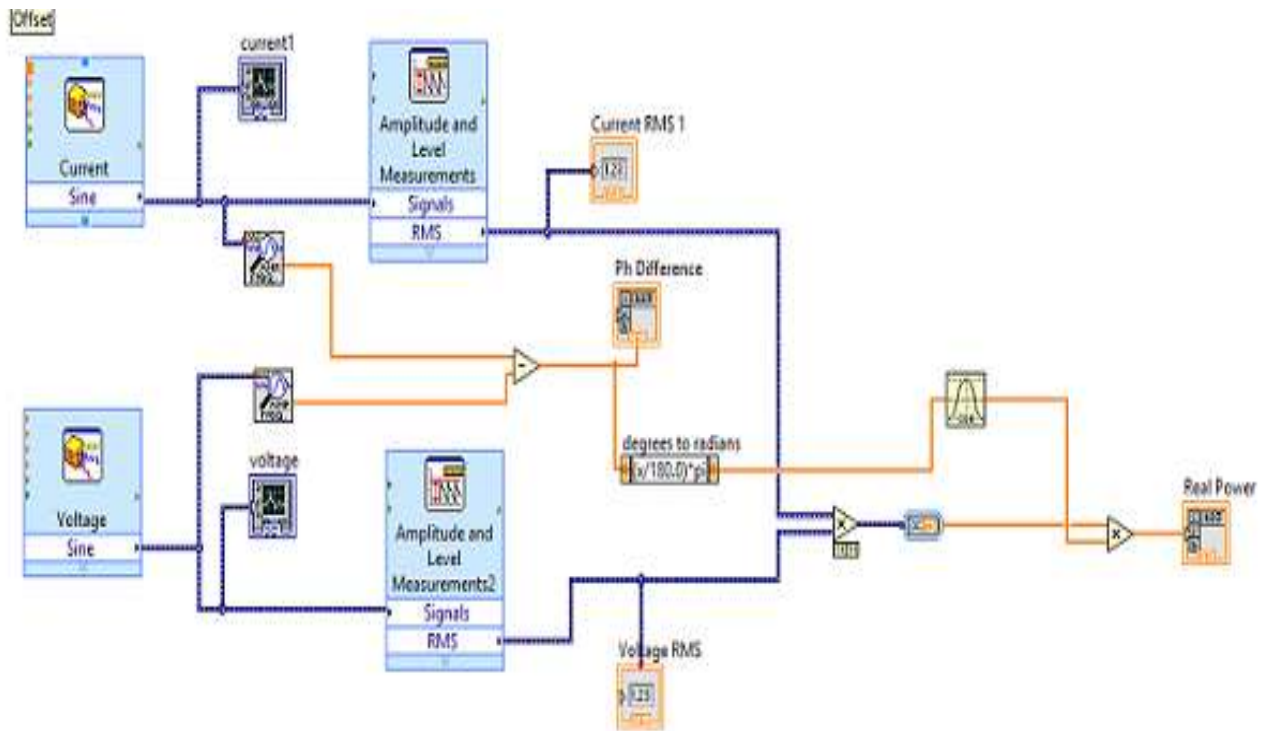


Figure 8. Lab View algorithm for real power (P).

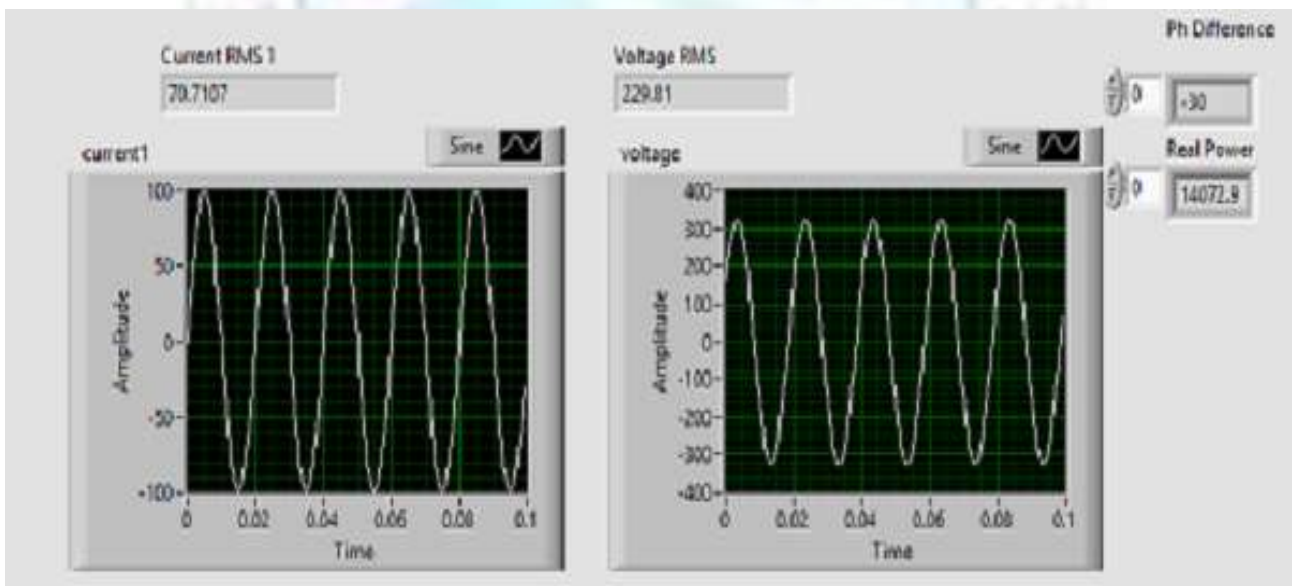


Figure 9. Waveform for Real Power Output Voltage and Current

This is the block diagram and output waveform of real power calculation. There are other factors present in this system but the important factors like voltage, current, phase difference and the actual value of real power are shown. The values of voltages and current are rms. Real power is calculated according to them. Both voltage and current are given by using signal simulator. There are waveform detectors connected to both current and voltage block which shows the waveforms in the output panel.

Here the value of current is 70.7107 A and voltage is 229.81 V. Phase difference is -30 degree and the real power calculated is 14072.9 W.

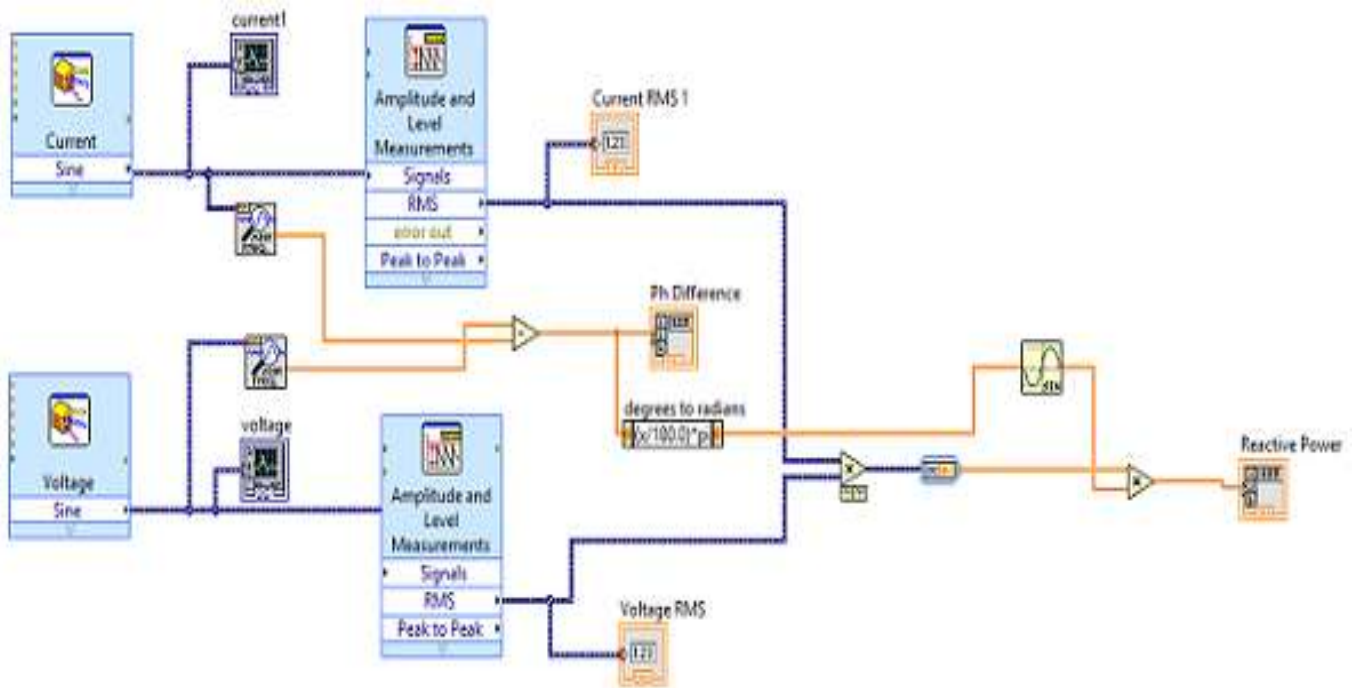


Figure 10. Block Diagram for Reactive Power (Q)

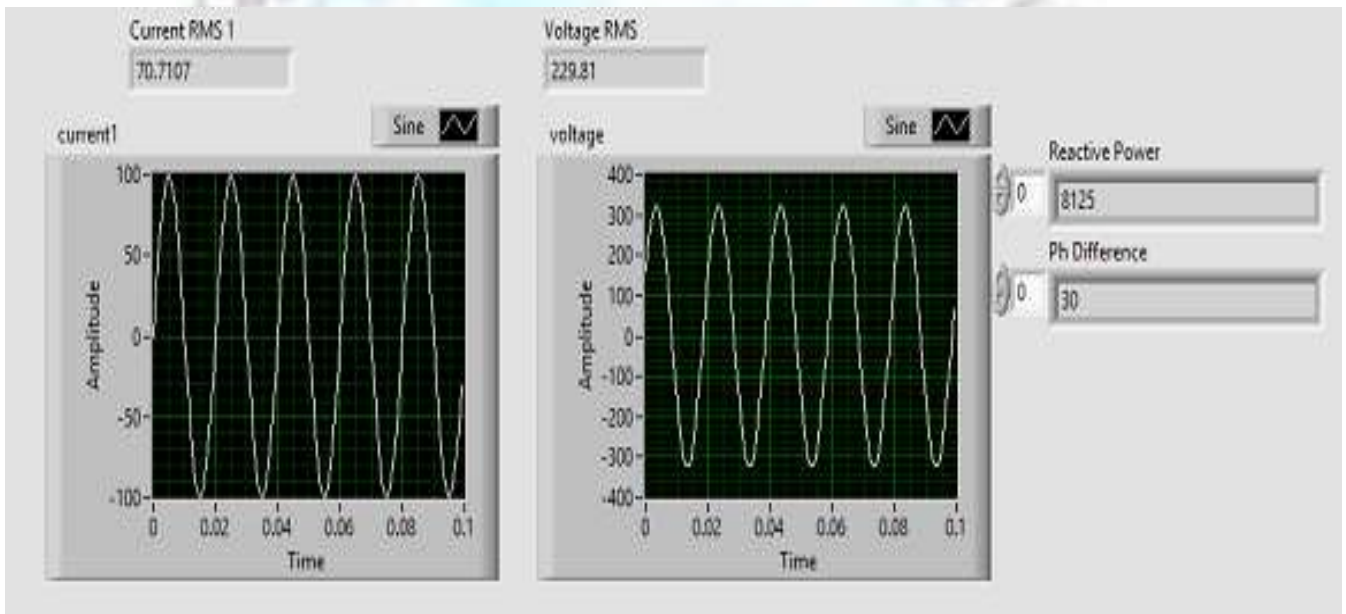


Figure 11. Waveform for Reactive Power Voltage and Current

This is the block diagram and output waveform of reactive power calculation. The values of voltages and current are rms. Reactive power is calculated according to them. Formula for theoretical calculation of reactive power is given above in the section of used formulae. We can compare both the theoretical calculation and LABVIEW output. Here also waveform detectors connected to both current and voltage block which shows the waveforms in the output panel. Here the value of current is 70.7107 A and voltage is 229.81 V. Phase difference is 30 degree and the reactive power calculated is 8125.

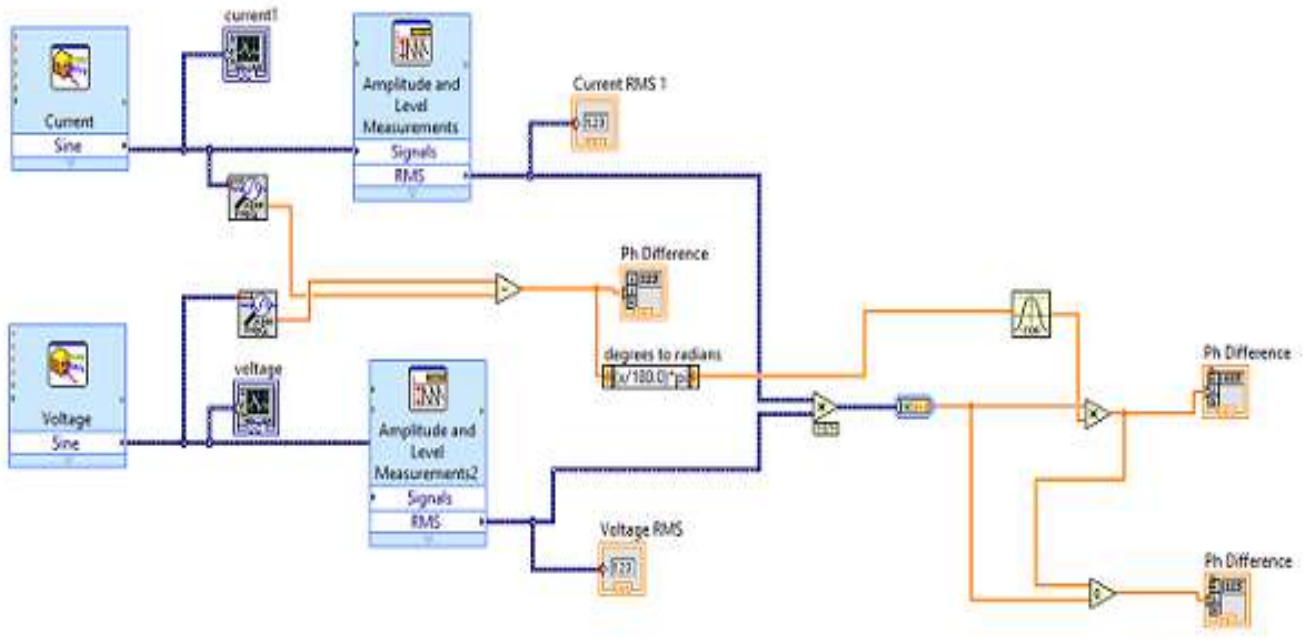


Figure 12. Block Diagram for Displacement Power factor

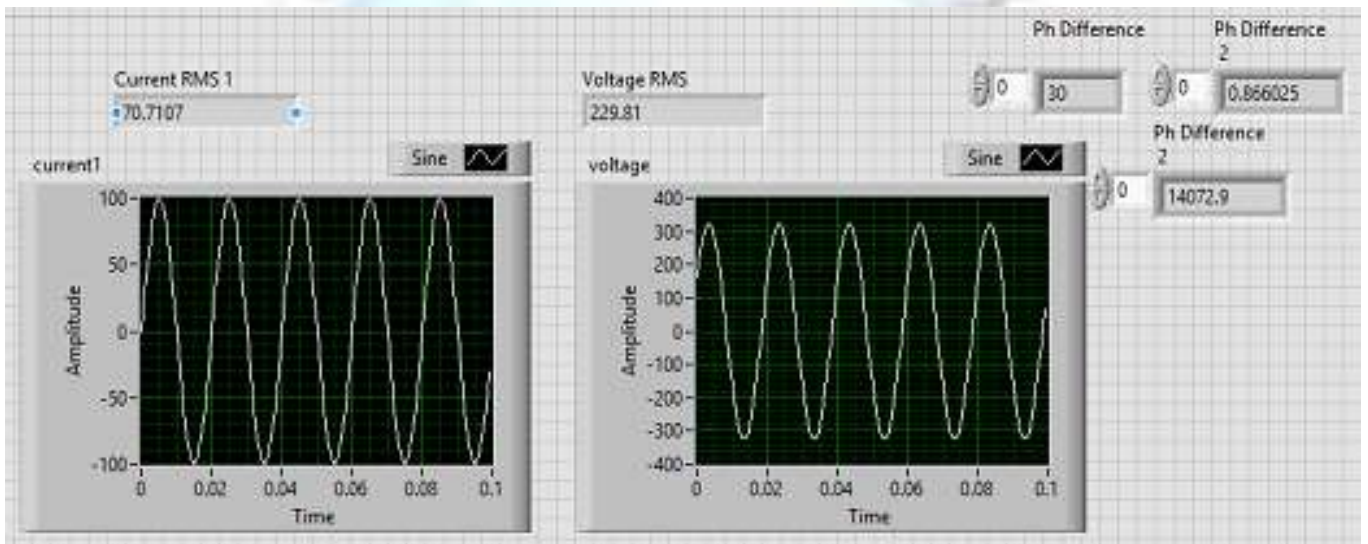


Figure 13. Waveform for displacement power factor current and voltage

Displacement power factor is caused by presence of reactive component in the load. If there is an inductive component in the load, then there will be an inductive current flowing in the resistive circuit. The inductive current lags the voltage waveform by 90 degrees. Likewise a capacitive component causes a capacitive current that leads the voltage waveform by 90 degrees. The displacement power factor value is the cosine of the angle between the voltage waveform and the resultant current waveform. For sinusoidal (non-distorted) currents, the displacement power factor is the same as the apparent power factor.

MITIGATION BY LabVIEW

Here we used one fundamental signal having frequency $f = 50$ Hz and amplitude = 1. Three harmonic components are used here i.e. 3rd harmonics, 5th harmonics and 7th harmonics. Other higher order harmonics will be reduced automatically by the circuit. They are negligible as compared to the lower order harmonics. Lower order harmonics are very dangerous for the circuit. Here 3rd order harmonic has frequency $f = 150$ Hz and amplitude 5% or 0.05. 5th order harmonic has frequency $f = 250$ Hz and amplitude 10%. 7th order harmonic has frequency $f = 350$ Hz and amplitude 15%. The simulation diagram for only phase is given below.

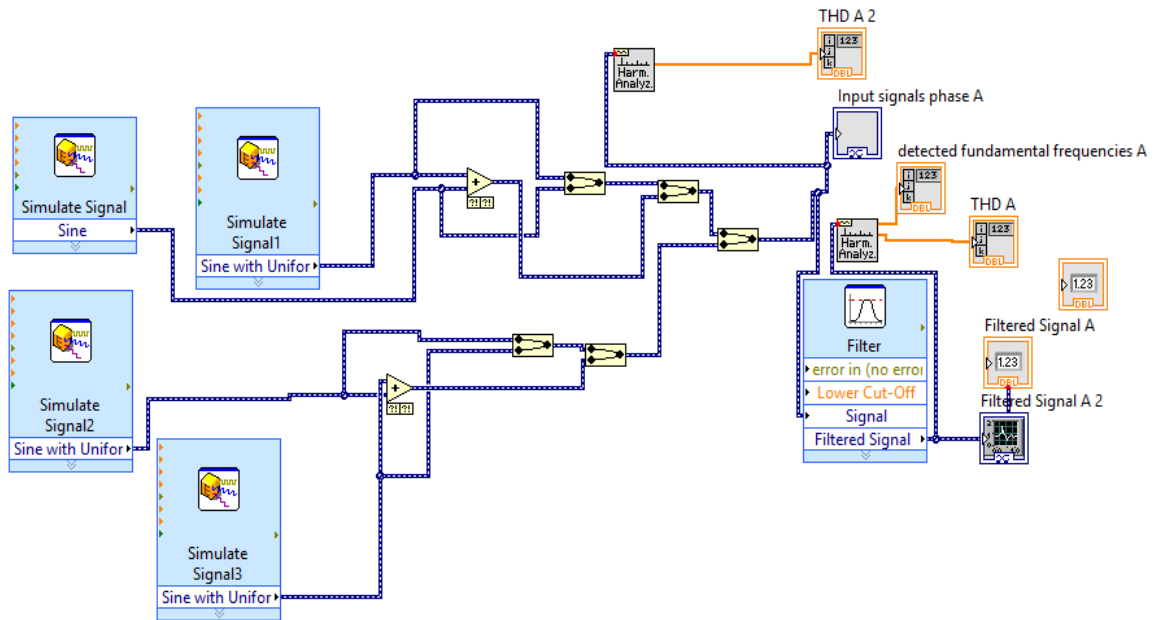


Figure 14. Block diagram for phase A.

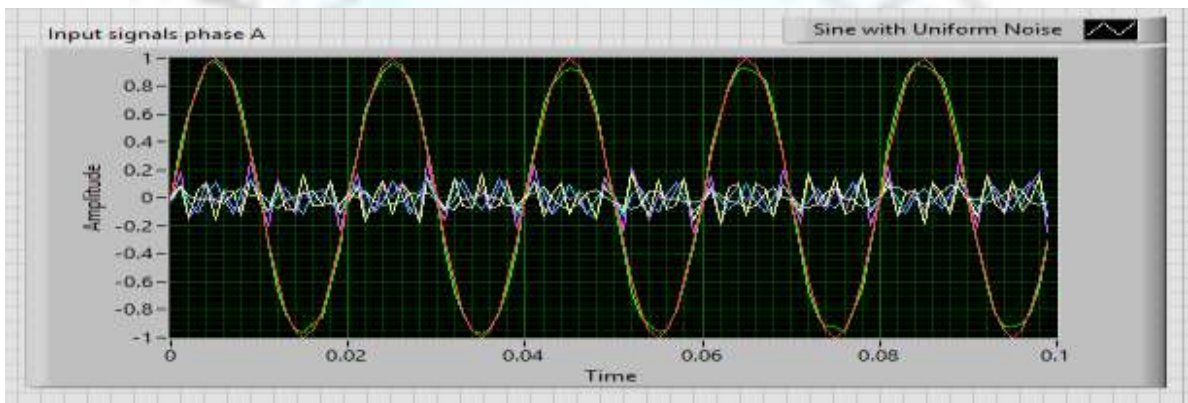


Figure 15. Input signal before filtering of only one phase i.e. Phase A

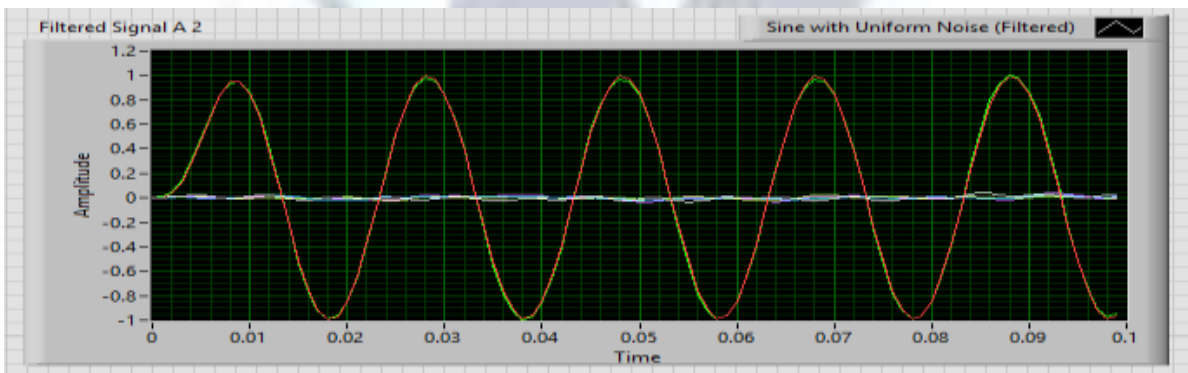


Figure 16. The signal after filtering, This is for only one phase

THD A2 13.54m	THD B2 3.89m	THD C2 12.58m
THD A 260.75m	THD B 136.51m	THD C 172.34m

Figure 17. THD after filtering result

From the data it is seen that THD A 2 i.e. signal before filtering have value 260.75m and after filtering THD A is 13.54m . So there is a clear result of harmonic reduction by filter. For phase A the reduction in total harmonic distortion is 94.78%. Similarly for phase B and phase C by considering THD B, THD B 2 and THD C, THD C 2 the reduction of harmonics is obtained to be 95.74% and 89.71 %.

Table 6: THD value after filtering for firing angle $\alpha = 0^\circ, 20^\circ, 40^\circ, 60^\circ$

α°	Fundamental Source Current (P.U)	Real power demand (P.U)	Reactive power demand (P.U)	Supply PF	5 th Harmonics (In %)	7 th Harmonics (In %)	THD (before filtering)	THD (after filtering)
0 ⁰	0.77	0.77	0	0.98	15	8	558.3m	1.15m
20 ⁰	0.72	0.7	0.2	0.91	19	11	769.38m	1.27m
40 ⁰	0.58	0.5	0.4	0.73	20	13	810.21m	1.39m
60 ⁰	0.38	0.2	0.3	0.67	31	22	1082.64m	1.78m

Conclusion

This project presents an innovative technology management by critical analysing about power quality problems, issues and their effect in life and the corrective measures using different means. However it becomes an serious issue as modern equipment are prone to even small variations of PQ indices. An effective mitigation and control method for active shunt filter for reducing the harmonics and reactive power compensation by using smart LabVIEW software technology is presented. This platform makes it easy and flexible to monitor and mitigate both power and harmonics. This also comes with many advantages w.r.t. ordinary power analyser e.g. user friendly, more accurate, broad working range. This can be modified depending on the system and can be accessed from a different place. Most important characteristics is that it can be improved whenever a better algorithm is developed.

Due to uncontrollable growth of both balanced and unbalanced nonlinear loads with the growth of population and urbanisation power system faces new power quality issues every day. As LabVIEW technology is of less cost, versatile, more reliable and flexible it can be used to detect power quality problems in practical power system efficiently. Its effectiveness of control method can be verified using simulation and further validated with results from an experimental set up. Due to some unexpected challenges we have not completed the mitigation using MATLAB. We are still trying our level best to complete our target and we expect to complete in near future.

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