

# Development of LabVIEW Based Harmonic Analysis and Mitigation Scheme with Shunt Active Filter for Power Quality Enhancement

Sindhu M.R., Manjula G. Nair, T. N. P. Nambiar

**Abstract** - Power quality issues, their modeling and mitigation techniques are become hot research topics soon after the introduction of solid state devices in power system. These nonlinear loads, power electronics based ASDs, UPSs are used in industries in large numbers for smooth operation and control. These equipment also introduce power quality issues such as harmonics, reduction in power factor, voltage unbalance, transients etc. These issues cause malfunction or damage of power system equipments. In this paper, harmonics and reactive power are considered as major issues and shunt active power filter is used for compensation. Three phase thyristor converter fed resistive load is considered as test system in this work. Different methods of harmonic analysis and mitigation techniques are surveyed by the author. In this paper, harmonic analysis of source current at the point of common coupling is done using LabVIEW based harmonic analyser, and the reactive and harmonic components of the source current are separated with the help of LabVIEW based intelligent control software. It also generates the switching signals to control voltage source inverter, used as active filter. Simulation and experimental studies using LabVIEW based control system shows the satisfactory performance.

**Index Terms**— Data acquisition system, Harmonic compensation, Intelligent controller, Power Quality, Reactive compensation, Shunt Active Filter.

## I. INTRODUCTION

Harmonics are introduced by power electronic converters, ASDs, UPS, etc. which are widely used in the industries [1]. Power Quality Monitoring systems were employed for power quality analysis in industrial, commercial and residential systems. It helps to monitor voltages and currents waveforms, transients, sags and swells, distortions, frequency deviations etc. in a given 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. Recently many power quality monitoring techniques were developed by various researchers such as real time detection and classification [3-9], embedded system based and web based monitoring based on compact microprocessor [7].

Wavelet transform based harmonic analyser [8]. But these implementations accompany errors in measurement, less execution speed, etc. Some of the methods are not suitable for time domain featured disturbances. Recently, Virtual Instrumentation based techniques [4-6] have shown the improved performance and reliability of the system. In this paper Laboratory Virtual Instrument Engineering Workbench (LabVIEW) based harmonic monitor is presented. In addition, these power quality issues lead to derating of equipment, maloperation of system, excess losses etc. Hence an effective harmonic mitigation scheme is in demand. Many options were suggested to alleviate the problems due to harmonics. Tuned L-C passive filters have traditionally been used to absorb harmonics generated by large industrial loads, primarily due to their low cost and high efficiency. However, they have many drawbacks. Supply impedance strongly influences the compensation characteristics of the passive filter, i.e., it may cause parallel or series resonance with ac line impedance which amplifies the harmonic current and voltage of the line at certain frequencies. Also the passive filters are bulky in size, cause high no load losses, detuning and tend to be susceptible to load and line switching transients. To avoid most of these problems, active filters were developed [14]. Active filters are dynamic compensators, which inject equal and opposite harmonic compensation so that distortion free currents are produced by source. Active filters can be generally classified as shunt, series and hybrid filters. Series active filters are mainly used for voltage harmonic compensation, Shunt active filters are used for current harmonic compensation and hybrid active filters are for both voltage and current harmonic compensation [10]. Shunt active filters are considered in this work. Many control algorithms were developed to control active filters such as Instantaneous reactive power theory, Synchronous detection, Synchronous reference frame theory, Icos algorithm were used by many researchers[13,14]. Akagi introduced IRPT [14], which is widely discussed because of its fast dynamic response. It is based on transformation of voltage and current signals to derive instantaneous active and reactive power. Harmonic components in active power and reactive power are extracted using low-pass and high-pass filters.

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Then, using inverse transformation, the compensating commands in terms of either currents or voltages are derived. However, the IRPT is quite complex and it gives incorrect reference currents under distorted and unbalanced source/load conditions. In the SD algorithm [14], the average real power consumed by the load with respect to the three phases gives the desired mains currents, assuming them to be balanced and in phase with the supply voltages after compensation.

The reference compensation signals are then derived as the difference between the load currents and the desired mains currents. Here the computation steps and the hardware involved are less complicated compared to the IRPT technique, but the algorithm gives distorted mains currents under distorted mains voltage conditions [14]. The DC bus voltage control algorithm [14] was a novel algorithm developed, where, the power balance in the system as reflected in DC link capacitor voltage was used to generate the reference compensation signals for the active filter. This algorithm became popular because of its simple computations and due to its capability to work well in all balanced/ unbalanced conditions. It uses PI controller which can provide only fixed compensation for varying system conditions. It does not have flexibility to tune the controller parameters with changing system conditions. In the algorithm proposed by Bhuvaneshwari and Manjula [15], the real part of fundamental load current is extracted. A combined solution for monitoring and mitigating power quality issues is still in demand.

In this paper, an intelligent controller based on LabVIEW was developed and tested for power quality monitoring and mitigating techniques to meet IEEE standards.

## II. LABVIEW BASED HARMONIC ANALYSER

In this section, improved and intelligent power quality monitoring system using LabVIEW is presented [16,17]. LabVIEW programs are generally called as virtual instruments (VI). It divides into two- front panel and block diagram. Front panel is the user interface, where controls and indicators are provided. Block diagram is graphical executable program in LabVIEW. Block diagram includes lower level VIs, built in functions, constants and control structures. Front panel objects have corresponding terminals on the block diagram so that data can pass from the user to the program and to the user.

The developed power quality monitor consists of standard Personal Computer, Data Acquisition System (NI USB 6009) and nonlinear load. The quantities required for harmonic analysis, source current and source voltage are sensed with the help of hall effect current and voltage sensors and are fed to NI USB 6009 data acquisition system. The DAQ card can read 8 analog input channels, 2 analog output channels, 12 I/O digital lines. Its sampling frequency is 48kS/s. This interfacing device helps to connect LabVIEW software with the test system. The analog signals are collected with the help of hall effect sensors by the data acquisition cards, converts to digital data and sent to computer. The hall effect voltage sensors (LEM LV 25 – P) help to measure both AC and DC voltages up to 500V, 50kHz. The hall effect current sensors help to measure current from 10Hz to 20kHz. Signal conditioning is done to convert analog signals to a suitable form. These acquired data are analysed by LabVIEW. This program estimates the parameters such as true rms values,

phase angles, voltage and current unbalances, displacement power factor, distortion power factor, net power factor, real power, reactive power, distortion power, current crest factor, voltage crest factor, and Total harmonic distortion. The LabVIEW programs for estimation of following parameters are shown in Fig.1.

i. Total Harmonic Distortion:

$$THD_I = \sqrt{\left(\frac{I_{rms}}{I_{1rms}}\right)^2 - 1}$$

$$THD_V = \sqrt{\left(\frac{V_{rms}}{V_{1rms}}\right)^2 - 1}$$

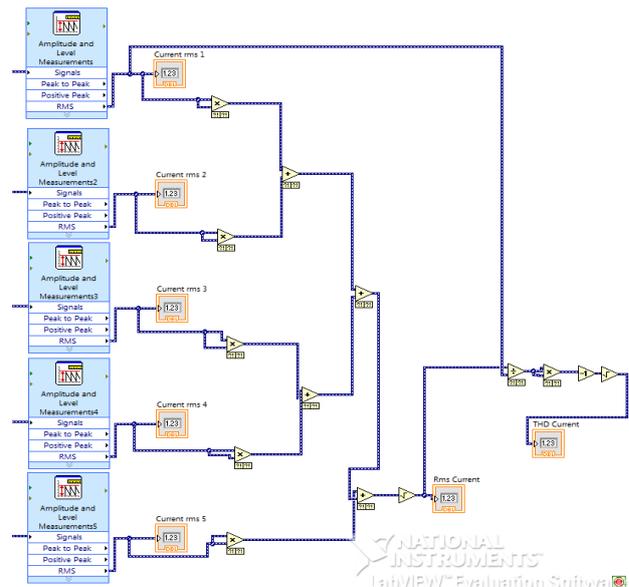


Fig. 1(a) LabVIEW program for THD measurement

i. Real Power  $P = V_{1rms} I_{1rms} \cos(\theta_1 - \phi_1) W$

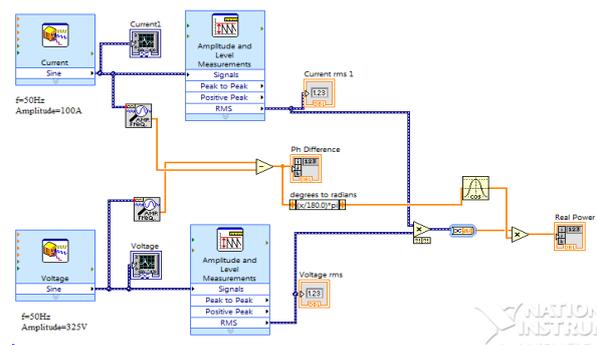


Fig. 1(b) LabVIEW program for Real Power Estimation

Reactive Power  $Q = V_{1rms} I_{1rms} \sin(\theta_h - \phi_h) VAR$

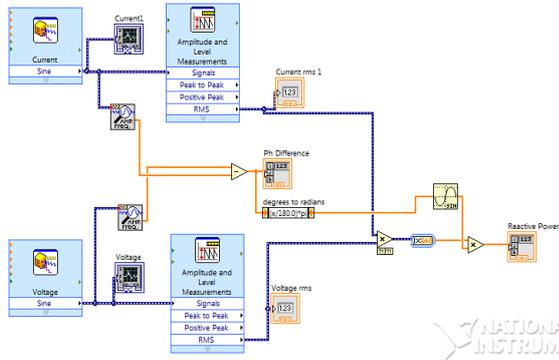


Fig. 1(c) LabVIEW program for Reactive Power

- ii. Apparent Power  $S = V_{rms} I_{rms}$  VA
- iii. Distortion Power  $D = \sqrt{S^2 - (P^2 + Q^2)}$  VAD

where S – Apparent Power,  
P – Real or Active Power,  
Q – Reactive Power

iv. Distortion Power Factor =  $\frac{V_{1rms} I_{1rms}}{V_{rms} I_{rms}} = \frac{S_1}{S}$

v. Displacement Power Factor =  $\frac{V_{1rms} I_{1rms} \cos(\theta_1 - \phi_1)}{V_{rms} I_{rms}} = \frac{P_1}{S_1}$

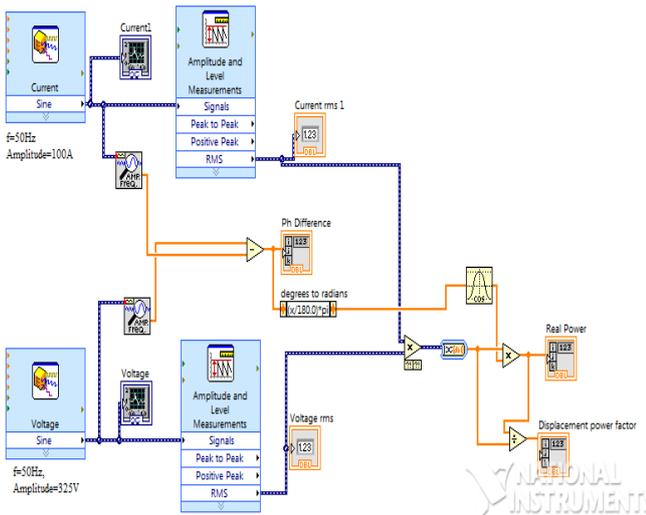


Fig. 1(d) LabVIEW program for Displacement Power Factor

vi. Voltage Crest Factor (VCF) =  $\frac{\sum_{h=2} V_h}{V_1}$

vii. Current Crest Factor (CCF) =  $\frac{\sum_{h=2} I_h}{I_1}$

$$I_{peak} = \sum_{h=1} I_h = I_1(1 + CCF)$$

$$V_{peak} = \sum_{h=1} V_h = V_1(1 + VCF)$$

**A. Selection of Test System**

A test system is selected for studying the harmonics created by nonlinear load and effect of a suitably designed active filter on source current harmonics. The most appropriate test system, the author believes, is a phase controlled three phase thyristor converter fed RL load, which is shown in Figure 2(a). 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. Hence the load inductance at 50Hz is taken about 500% of load resistance.

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. Without any filter – Harmonic Analysis Using LabVIEW**

Harmonic analysis of ac line current is made for various triggering angles of three phase thyristor converter to study the effect of variations in triggering angle on the predominant harmonics and THD. The firing angle ( $\alpha$ ) of thyristor converter is varied from  $0^\circ$  to  $60^\circ$  in steps of  $10^\circ$ .The results are given in Table 1.

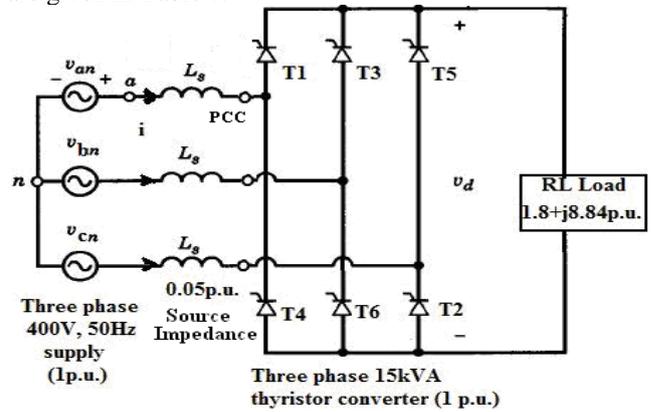


Figure 2(a) Schematic diagram of the test system I

Table 1 Harmonic analysis - Source current, Power demand, Source power factor and Harmonic spectrum of source current for 3 $\phi$  thyristor converter fed R – L load under varying triggering angles

$\alpha^\circ$	Fund Source current (p.u.)	Real Power demand (p.u.)	Reactive power demand (p.u.)	Sss supply pf	Harmonics in source current		
					h5 %	h7 %	THD %
0	0.77	0.77	0	0.98	15.9	8.6	18
10	0.76	0.75	0.13	0.96	17.5	10.	21
20	0.72	0.7	0.2	0.91	19.0	11.9	24
30	0.66	0.6	0.3	0.83	20.0	12.9	26
40	0.58	0.5	0.4	0.73	20.8	13.5	28
50	0.49	0.3	0.4	0.61	21.6	13.8	29
60	0.38	0.2	0.3	0.47	31.0	22.5	44

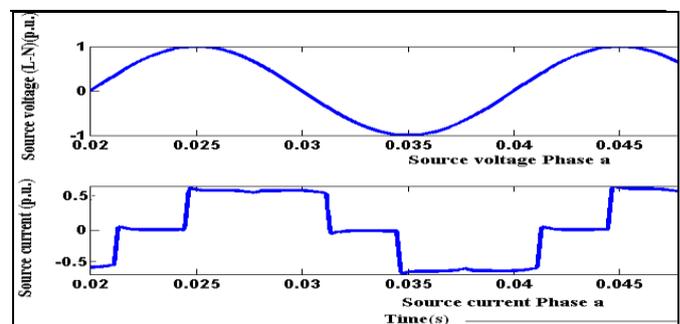


Figure 2(b) Harmonic analysis - Source voltage and Source current waveforms (phase a) for 3 $\phi$  thyristor converter ( $\alpha = 60^\circ$ )

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The source voltage and source current waveforms for a typical firing angle  $\alpha = 60^\circ$ , measured at point of common coupling PCC, are shown in Figure 2. It is clear from Table 1 that as triggering angle increases,

1. The fundamental component of source current decreases.
2. Real power demand of the load decreases.
3. Reactive power demand of the load increases to maximum and then, decreases.
4. Source power factor decreases. The source power factor is calculated as the product of displacement power factor and distortion power factor.
5. Total harmonic distortion in the source current increases ranging from 18% to 45%.
6. Fifth harmonic and seventh harmonic components are predominant in the harmonic spectra.

Harmonic analysis of the source current is carried out under balanced/unbalanced source and balanced/unbalanced load conditions.

(i) 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 18.4%.

(ii) 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:  $1.3\angle -135^\circ$ , Phase C:  $0.7\angle 135^\circ$ ) applied to the R – L Load through thyristor converter. Distortions in the three phase currents are unbalanced.

(iii) 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 R (15%), Y (5%), and B (24%) phases in parallel with nonlinear load. The % of unbalance is calculated as the deviation from the average of three phase unbalanced loads.

Fundamental component of source current and THD in source current in the three phase system for different firing angles  $\alpha = 0^\circ, 30^\circ$ , and  $60^\circ$  are obtained under above mentioned conditions. The results are shown in Table 2 – Table 4. The source currents and the load currents are one and the same. Tables 2 - 4 show this nonlinear load introduces harmonics and unbalance in source currents, which are to be compensated by suitable filter configuration. The Icos $\phi$  control algorithm based shunt active filter is used as harmonic compensator and its performance is discussed in the next section.

Table 2 Harmonic analysis – Fundamental Source current, and THD in source current for 3 $\phi$  thyristor converter load ( $\alpha = 0^\circ$ ) without any filter

Source/load	Fundamental component of source current (p.u.)			THD in source current (%)		
	Phase a	Phase b	Phase c	Phase a	Phase b	Phase c
Balanced source balanced nonlinear load	0.77	0.77	0.77	18.43	18.43	18.43

Unbalanced source balanced nonlinear load	0.51	0.75	0.32	19.23	20.9	25.4
Balanced source unbalanced nonlinear load	0.67	0.74	0.62	21.7	22.4	20.9

Table 3 Harmonic analysis – Fundamental Source current, and THD in source current for 3 $\phi$  thyristor converter load ( $\alpha = 30^\circ$ ) without any filter

Source/load	Fundamental component of source current (p.u.)			THD in source current (%)		
	Phase a	Phase b	Phase c	Phase a	Phase b	Phase c
Balanced source balanced nonlinear load	0.668	0.668	0.668	25.81	25.81	25.81
Unbalanced source balanced nonlinear load	0.382 2	0.457 3	0.243 2	26.4	27.87	32.52
Balanced source unbalanced nonlinear load	0.501 4	0.549 2	0.465 1	28.53	30.1	27.9

Table 4 Harmonic analysis – Fundamental Source current, and THD in source current for 3 $\phi$  thyristor converter load ( $\alpha = 60^\circ$ ) without any filter

Source/load	Fundamental component of source current (p.u.)			THD in source current (%)		
	Phase a	Phase b	Phase c	Phase a	Phase b	Phase c
Balanced source balanced nonlinear load	0.381	0.381	0.381	43.94	43.94	43.94
Unbalanced source balanced nonlinear load	0.1674	0.24	0.121 1	31.9	34.2	38.6
Balanced source unbalanced nonlinear load	0.24	0.27	0.21	34.61	36.2	33.4

### III. IMPLEMENTATION OF HARMONIC MITIGATION SCHEME BASED ON ICOSΦ CONTROLLER IN LABVIEW

A laboratory model of Icosφ controller based shunt active filter is set up and tested. A three phase 20kVA, 20 kHz PWM voltage source inverter assembly, which consists of a three phase IGBT based inverter along with a large DC link capacitor, is used as the shunt active filter. DC link capacitor of 1650mF / 800V is used to maintain steady DC bus voltage required by inverter. IcosΦ algorithm developed by Manjula and Bhuvanewari [15] is used in this work because of its simplicity and effectiveness. Digital controllers can operate with high flexibility, at extremely high frequencies and at very low cost. Hence, this algorithm is implemented with the help of LabVIEW software.

According to Icosφ algorithm, the source is required to supply only the real part of the fundamental component of the load current. Remaining parts of load current – i.e., reactive component and harmonics – are to be supplied by the active filter. Assuming a balanced source, the three phase instantaneous fundamental component of voltages can be represented by

$$v_a = V_m \sin \omega t \quad ; \quad v_b = V_m \sin(\omega t - 120^\circ) \quad ; \quad v_c = V_m \sin(\omega t + 120^\circ) \quad (1)$$

a, b, c = phases a, b, c, respectively

V<sub>m</sub> = peak value of the instantaneous voltage

When balanced three phase supply feeds a non-linear reactive load, the load current contains fundamental and harmonic components.

$$i_{La} = \sum_{h=1}^{\infty} I_{La,h} \sin(h\omega t - \phi_{ha})$$

$$i_{Lb} = \sum_{h=1}^{\infty} I_{Lb,h} \sin(h\omega t - 120^\circ - \phi_{hb})$$

$$i_{Lc} = \sum_{h=1}^{\infty} I_{Lc,h} \sin(h\omega t + 120^\circ - \phi_{hc}) \quad (2)$$

where, a, b, c = phases a, b, c, respectively

i<sub>L</sub> = instantaneous load current in phases a, b, c

I<sub>L, h</sub> = peak value of h<sup>th</sup> harmonic component of load current

φ<sub>h</sub> = phase angle of the h<sup>th</sup> harmonic component with respect to voltage

The fundamental component of the load current is separated with the help of biquad low pass filter. Its output is fundamental component is delayed by 90° during the filtering operation.

$$i_{Lfa} = I_{La,1} \sin(\omega t - \phi_{la} - 90^\circ)$$

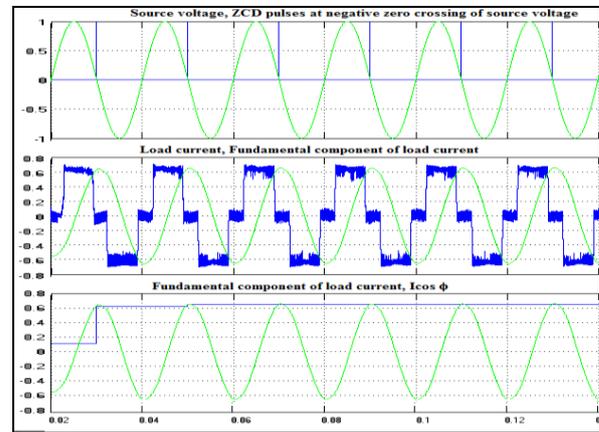
$$i_{Lfb} = I_{Lb,1} \sin(\omega t - \phi_{lb} - 120^\circ - 90^\circ)$$

$$i_{Lfc} = I_{Lc,1} \sin(\omega t - \phi_{lc} + 120^\circ - 90^\circ) \quad (3)$$

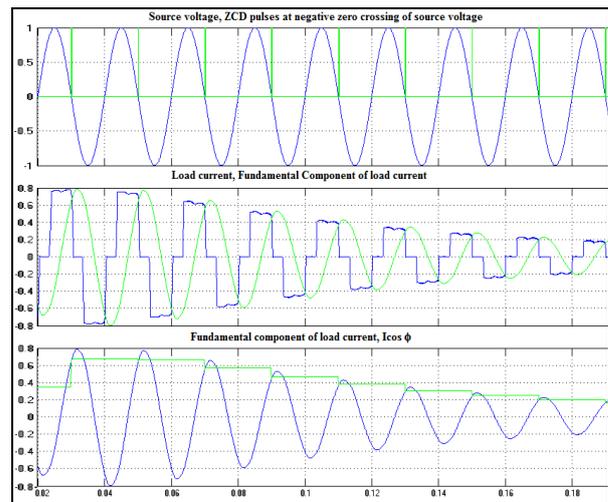
The real part of the fundamental component of load current is estimated as follows:

At the time of negative zero crossing of the input voltage of any one phase, say a phase, i.e., at ωt = nπ, instantaneous value of fundamental component of load current is the peak value of real component of the fundamental load current. Similarly, instantaneous values of fundamental components

of phase b load current at ωt = 300° and phase c load current at ωt = 60° are the respective real components. This is illustrated in Figure 3 (a) and Figure 3 (b). Figure 3(a) shows the significant parameters under steady state load conditions for three phase thyristor converter load feeding resistive load, with firing angle α = 0°. Figure 3 (b) shows the significant parameters under dynamic load conditions - for DC motor drive. The real part of fundamental component of load current is updated in every cycle.



(a) Illustration of Icosφ algorithm under static load conditions – Three phase thyristor converter fed resistive load



(b) Illustration of Icosφ algorithm under dynamic conditions – DC drive with change in load torque

Figure 3 Illustration of Icosφ algorithm – Under static and dynamic load conditions

The magnitude of the desired source current  $|I_{s(ref)}|$  is the magnitude of real part of the fundamental component of load current in the respective phases, i.e., for phase a it can be written as  $|I_{s(ref)}| = |\text{Re}(I_{La})|$ . To ensure balanced, sinusoidal, unity power factor currents to be drawn from the source, the magnitude of the desired source current can be expressed as the average of the magnitudes of the real components of the fundamental load currents in the three phases.

$$|I_{s(ref)}| = \frac{|\text{Re}(I_{La})| + |\text{Re}(I_{Lb})| + |\text{Re}(I_{Lc})|}{3} \quad (4)$$

$$= \frac{|I_{La}| \cos\phi_a + |I_{Lb}| \cos\phi_b + |I_{Lc}| \cos\phi_c}{3}$$

The voltage fluctuations in DC bus voltage of active filter are also sensed and given to PI controller, which calculates the current to be taken from the source to meet power loss in the inverter and coupling inductor. This current is added to the average value of  $|I_{s(ref)}|$  in equation (4) above. The three phase source voltages are used as templates to generate unit amplitude sine waves in phase with source voltages and they are expressed as,

$$\begin{aligned} \text{i.e. } U_a &= 1 \sin \omega t \\ U_b &= 1 \sin(\omega t - 120^\circ) \\ U_c &= 1 \sin(\omega t + 120^\circ) \end{aligned} \quad (5)$$

The desired (reference) source currents in the three phases are obtained by multiplying reference source currents with unit amplitude templates of the phase to ground source voltages in the three phases respectively.

$$\begin{aligned} i_{sa(ref)} &= |I_{s(ref)}| \times U_a = |I_{s(ref)}| \sin \omega t \\ i_{sb(ref)} &= |I_{s(ref)}| \times U_b = |I_{s(ref)}| \sin(\omega t - 120^\circ) \\ i_{sc(ref)} &= |I_{s(ref)}| \times U_c = |I_{s(ref)}| \sin(\omega t + 120^\circ) \end{aligned} \quad (6)$$

The compensation currents to be injected by the shunt active filter are the difference between the actual load currents and the desired source currents.

$$\begin{aligned} i_{a(comp)} &= i_{La} - i_{sa(ref)} \quad ; \quad i_{b(comp)} = i_{Lb} - i_{sb(ref)} \quad ; \\ i_{c(comp)} &= i_{Lc} - i_{sc(ref)} \end{aligned} \quad (7)$$

The equivalent block diagram of Icos $\phi$  algorithm is shown in Figure 4.

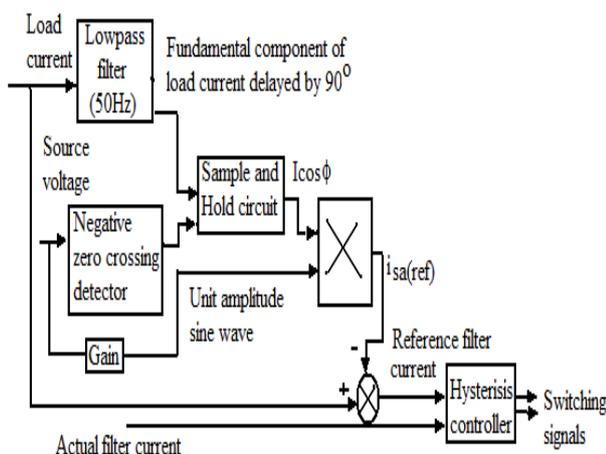


Figure 4 Block diagram showing implementation of Icos $\phi$  algorithm for a phase

The operations done by the LabVIEW controller circuit are explained below:

**Step 1: The source voltages, load currents and active filter injection currents are sensed with Hall Effect voltage and current sensors.**

Three LV-20P voltage transducers are used for sensing three phase source voltages. Six LA-25-NP current transducers are

used for sensing three phase load currents and three phase actual filter currents.

**Step 2: Detection of fundamental component of load current:**

Low pass filtering by using biquad filter is done to extract fundamental component of load current. The advantages of using biquad filter, rather than other low pass filters, are that they are easy to design, and give unity gain and exact 90° phase shift.

**Step 3: Determination of real component of load current:**

The comparator and monostable multivibrator is used for getting sharp output pulses at the negative zero crossing of the source voltage in each phase. These output pulses and output of the biquad filter are fed to a sample and hold circuit to obtain instantaneous value of fundamental component of load current at negative zero crossing of source voltage, i.e., real part of fundamental component of load current.

**Step 4: Obtaining desired source current waveforms:**

The real part of the fundamental component of load current is multiplied with unit sinusoidal waves to obtain desired source current waveforms, using AD 633 JN multiplier.

**Step 5: Derive PWM pulses to inverter:**

The reference compensation current is obtained by subtracting reference source current from load current. A comparator is used to compare reference compensation current and actual filter current. When reference filter current is more than actual filter current, output of the comparator is high and vice versa. The isolation between power circuit and controller circuit is done using an optocoupler 6N136. The output pulses are amplified using transistor amplifier BC 547.

**Step 6: Injection of compensating currents at the point of common coupling**

The compensating currents produced by three phase inverter are injected through coupling inductors at the point of common coupling. The coupling inductor is designed as follows: The maximum current gradient in the compensation current is given by [15]

$$\left(\frac{di_F}{dt}\right)_{\max} = \frac{V_C - v_s(t)}{L_F} \leq \frac{V_C + \sqrt{2}V_{seff}}{L_F}$$

where  $V_C = V_{DC}$  and

$V_{seff}$  = effective supply voltage.

$$L_F \leq \frac{V_{dc} + \sqrt{2}V_{seff}}{\left(\frac{di_F}{dt}\right)_{\max}}$$

Therefore,

$$\left(\frac{di_F}{dt}\right)_{\max} = 10A/\mu s,$$

For  $\left(\frac{di_F}{dt}\right)_{\max} = 10A/\mu s$ , the value of coupling inductor used in this work is 400V, 5A, 10mH. The model of the test system with shunt active filter is shown in Figure 5. The 10kVA three phase IGBT based VSI inverter (3 kHz switching frequency) with 24mF DC bus capacitor and 10mH coupling inductor is used as the shunt active filter. The circuit for Icos $\phi$  algorithm is simulated in LabVIEW and used to control shunt active filter as shown in Figure 6.

The three phase load currents, source voltages, and filter currents are sensed using NI USB 6009 data acquisition system.

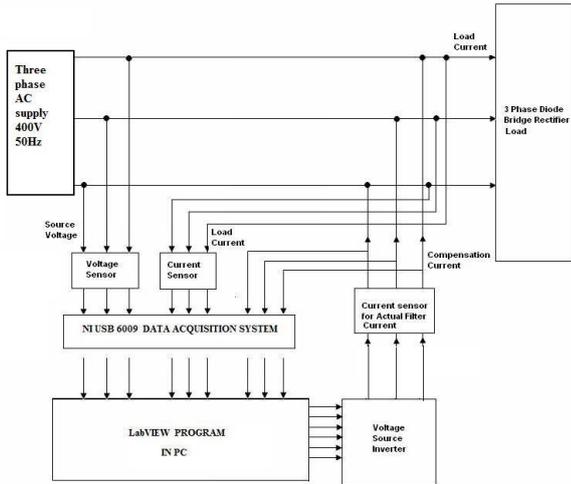


Figure 5. Layout of the complete experimental setup

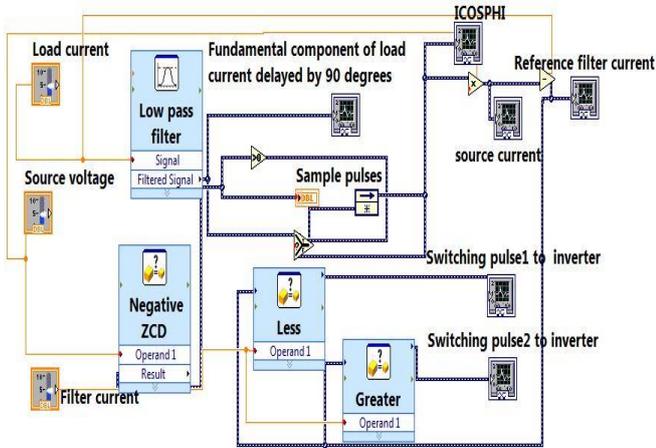


Figure 6. Equivalent controller circuit in LabVIEW

The system is simulated under balanced/unbalanced source and balanced/unbalanced nonlinear load conditions and results are as follows:

(i) balanced source balanced nonlinear load: Under the balanced source balanced nonlinear load conditions to mitigate harmonics, the shunt active filter is applied. It is found that addition of the active filter reduces the harmonics in source current and source current THD is within IEEE limits. The fundamental component of source current (p.u.) and source current THD are displayed in Table 5. However, it takes time delay up to one cycle for perfect compensation. The source voltages, distorted load currents, and reference compensation currents are shown in Figure 7.

(ii) unbalanced source and balanced nonlinear load: The unbalanced three phase source voltages are applied through thyristor converter to the R – L load. Table 5 shows that, the shunt active filter keeps the source currents balanced. Also the harmonics in source current are highly reduced and source current THD is within IEEE limits.

(iii) balanced source and unbalanced nonlinear load: The three phase balanced supply is connected to unbalanced nonlinear load conditions. Table 5 shows that the shunt active filter is capable of compensating load unbalance and source current harmonics.

Table 5 Harmonic analysis – Fundamental Source current, and THD in source current for 3 $\phi$  thyristor converter load ( $\alpha = 0^\circ$ ) with analog Icos $\phi$  controller based shunt active filter

Source/load	Fundamental component of source current (p.u.)			THD in source current (%)		
	Phase a	Phase b	Phase c	Phase a	Phase b	Phase c
Balanced source balanced nonlinear load	0.78	0.78	0.78	1.16	1.1	1.14
Unbalanced source balanced nonlinear load	0.5851	0.5851	0.585	1.46	1.47	1.45
Balanced source unbalanced nonlinear load	0.6815	0.6815	0.681	1.52	1.4	1.55

Table 6 Harmonic analysis – Fundamental Source current, and THD in source current for 3 $\phi$  thyristor converter load ( $\alpha = 30^\circ$ ) with LabVIEW based Icos $\phi$  controller for shunt active filter

Source/load	Fundamental component of source current (p.u.)			THD in source current (%)		
	Phase a	Phase b	Phase c	Phase a	Phase b	Phase c
Balanced source balanced nonlinear load	0.579	0.579	0.579	1.79	1.79	1.79
Unbalanced source balanced nonlinear load	0.2909	0.2909	0.2909	3.18	3.67	2.46

Balanced source unbalanced nonlinear load	0.4152	0.4152	0.4152	3.51	2.76	2.95
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Table 7 Harmonic analysis – Fundamental Source current, and THD in source current for 3 $\phi$  thyristor converter load ( $\alpha = 60^\circ$ ) with LabVIEW based Icos $\phi$  controller for shunt active filter

Source/load	Fundamental component of source current (p.u.)			THD in source current (%)		
	Phase a	Phase b	Phase c	Phase a	Phase b	Phase c
Balanced source balanced nonlinear load	0.19	0.19	0.19	2.36	2.36	2.36
Unbalanced source balanced nonlinear load	0.1103	0.1103	0.1103	3.18	3.67	2.46
Balanced source unbalanced nonlinear load	0.125	0.125	0.125	3.51	2.76	2.95

# Development of LabVIEW Based Harmonic Analysis and Mitigation Scheme with Shunt Active Filter for Power Quality Enhancement

Tables 6-7 show the rms values of fundamental components of the source currents and THD in source currents, after the installation of shunt active filter, for different load conditions. The above results show that with active filtering, the source voltage and source current are made in phase and sinusoidal and hence reactive and harmonic compensations are provided.

## IV. ACKNOWLEDGMENT

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## V. CONCLUSION

In modern industries, electrical power quality problems are becoming the matter of serious concern, as modern equipments are prone to even small variations of PQ indices. This paper presents an effective monitoring and control system for active filter which enable practical digital implementation of shunt active filter for harmonic and reactive power compensation. LabVIEW platform is a good solution for implementing power quality monitor and harmonic mitigation as it is less costly, versatile, flexible and reliable. Here, the analog signals are sensed from the test system with hall effect sensors and given to PC through NI USB 6009 data acquisition card. specific interfacing devices. Then this raw data is processed and analyzed by using VI software, LabVIEW. It is powerful VI software, which can acquire, analyze and present any electrical signal efficiently. This is very helpful for studying, measuring, analyzing and controlling of power system harmonics. The effectiveness of the control method is verified using simulations and is further validated with results from an experimental setup. The results show that the LabVIEW package based controller can satisfactorily compensate for balanced and unbalanced nonlinear load currents and also adapt itself to compensate for variations in nonlinear load currents.

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