I J C T A, 8(5), 2015, pp. 2021-2028

Simplified Control Algorithm for Power Quality Improvement in Industrial Applications

Sindhu S.*, Divya Dananjayan, and M.R. Sindhu*****

Abstract: This paper deals with the design and development of a control strategy for improving the power quality in the grid. The proposed control algorithm aims at eliminating the harmonics, compensation of the reactive power and power factor correction thereby enhancing the performance of system. The overall system is designed, developed, operated in MATLAB-SIMULINK and system performance is validated by simulation results.

Keywords: Power quality, Reactive Power Compensation, Harmonic distortions, Active filter

1. INTRODUCTION

Most of the industrial and commercial loads are having non-linear characteristics such as electric drives, computer loads, ballasts, switched mode power supply etc. These loads introduce power quality issues such as current distortions, voltage distortions, reactive power demand, low power factor, imbalance, excess neutral current, etc[1]. Due to severity of the effects of power quality issues, various power quality standards IEEE-519 [2], IEC-61000 [3] were set up by technical committees. To meet the specified standard limits, different harmonic filters were suggested [4]. Numerous topologies of active filter were implemented by various researches[5][6]. Shunt active filter configuration is preferred as the reduction in current distortion may lead to reduction in voltage distortions also. The shunt active filter is usually controlled to provide reactive and harmonic compensation [7].The system discussed in this paper includes real power sharing controller in addition to harmonic and reactive compensation.

This paper explains the industrial test system and deals with the performance analysis of the selected non-linear system. The proposed control strategy design is discussed in detail and simulation of the system with shunt active filter connected for harmonic and reactive power compensation is done using MATAB/Simulink.

2. SYSTEM DESCRIPTION

Many industrial applications like electroplating, plasma processes which are non-linear in nature causes many power quality issues which affects the system as whole and reduces the efficiency. This non-linear load is modelled as a three-phase thyristor converter fed resistive load in laboratory. Initially, the power quality issues when the non-linear system is connected to the grid are studied. A shunt active filter is connected to the system to rectify the power quality issues. A new control strategy is proposed which generates pulses for the Shunt active filter and thus it compensates for the harmonics and reactive power. Fig.1 shows the block diagram of the system.

---

* Dept of Electrical and Electronics Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Amrita University, India, Email: *sindhus2478@gmail.com*

** Dept of Electrical and Electronics Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Amrita University, India, Email: *divya.dananjayan@gmail.com*

*** Dept of Electrical and Electronics Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Amrita University, India, Email: *sindhumadassery@gmail.com*

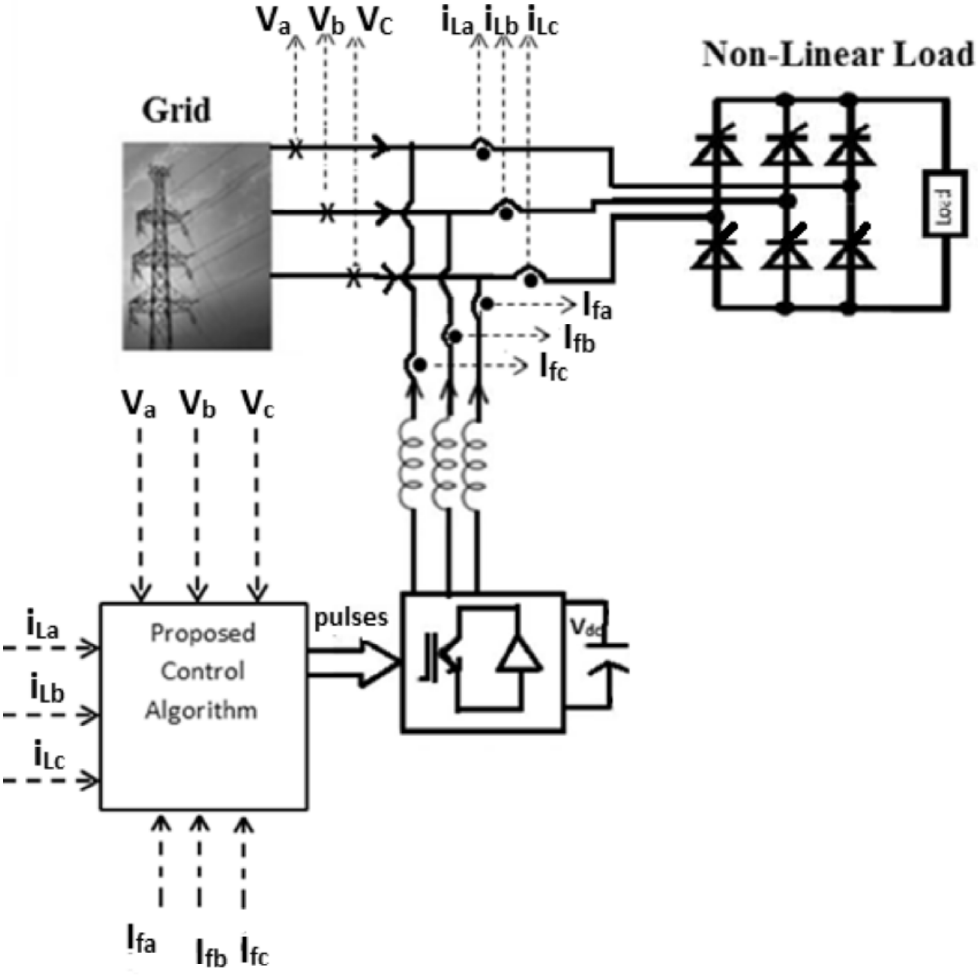


Figure 1: Block Diagram of the System

3. SYSTEM OPERATION

3.1. Grid connected system without compensation

Initially the power quality issues are studied when the system is connected to the grid. Fig.2 represents the system when connected to the grid. Fig. 2 shows the simulation results obtained for each phase when the non-linear load is connected to the three phase supply. From the waveforms it is clear that the source current is non-sinusoidal which is due to the presence of harmonics and reactive power. Table 1 shows the results obtained for various system parameters of non-linear system

Table 1 depicts the presence of harmonics and reactive power caused by the non-linear system. This demands compensation of harmonics and reactive power in order to improve the power quality.

Table 1
System Parameters obtained without compensation

Alpha	*Load current, Irms (A)*	*THD_I (%)*	*P(kW)*	*Q(kVA)*	*Power factor*
0	8.2	15.6	4.9	0	0.96
15	8.06	18.4	4.8	1.41	0.9
30	7.32	22.2	4.3	2.46	0.8
45	6.06	25.43	2.87	2.87	0.6
0	4.35	28.06	1.44	1.44	0.4

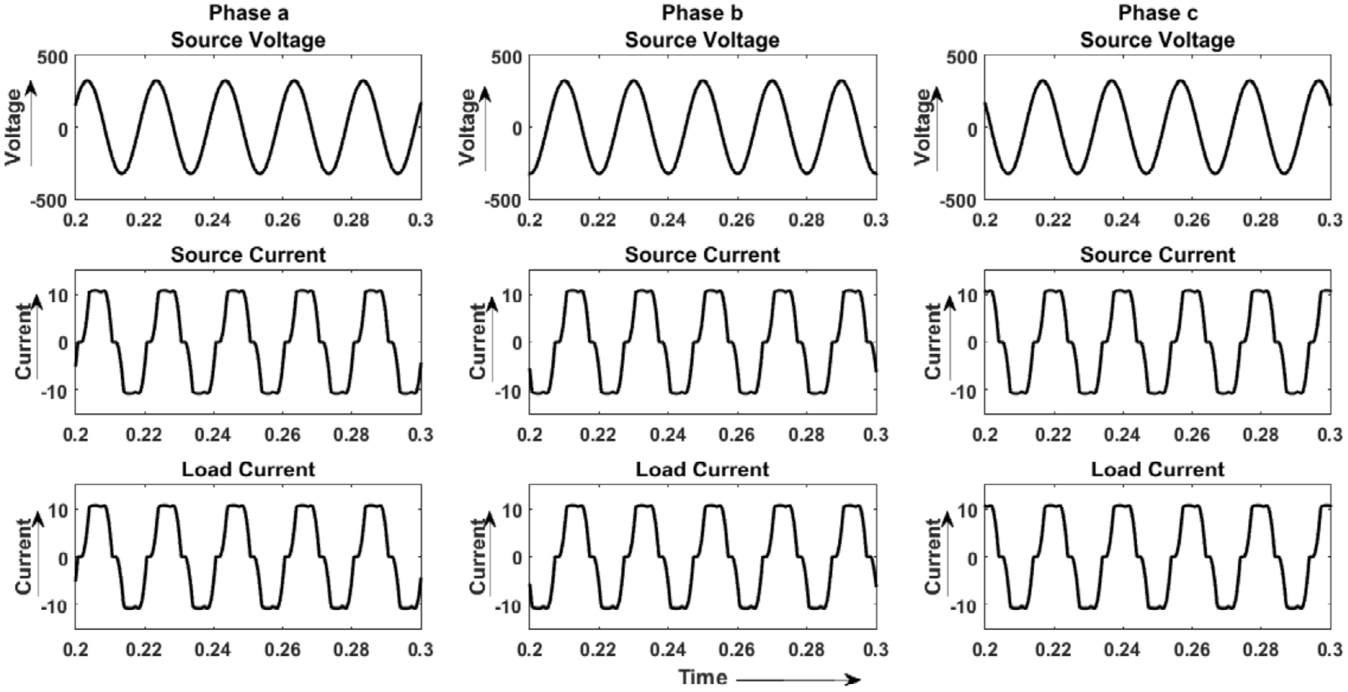


Figure 2: Simulation results obtained when the filter is not connected

4. PROPOSED CONTROL STRATEGY

Details shown in Table 1 and Fig.2 clearly depicts the need for Shunt active filter for the compensation of harmonics and reactive power. There are different methods in which the shunt active filter can be controlled. Various algorithms and strategies have been proposed, tested and implemented in order to generate pulses to control the filter. Some of the established control strategy are Instantaneous Reactive Power Control Technique, Synchronous detection algorithm, Icosf algorithm [5]-[9] etc. A new control algorithm is proposed and developed which aims in elimination of the current harmonics and compensation of the reactive power. The existing control algorithm uses Zero crossing detectors, sample and hold techniques which is inefficient to produce the accurate results at zero crossing and in unbalanced conditions. The proposed control algorithm uses simple mathematical principles to provide accurate results. This also works efficiently in unbalanced conditions.

According to the control algorithm, the real power component of the load current will be supplied by the source while the reactive and harmonic components are provided by the shunt active filter. The three phase nonlinear load currents are composition of fundamental and harmonics [10][11].The real component and reactive components of the sensed load currents are separated with a second order biquad filter, which has three portions-low pass filter, high pass filter and a band pass filter[12].

The fundamental component is extracted with the low-pass filter which has a cut off frequency of 50Hz. It has an inherent phase delay in each phase of 90 degrees. The currents obtained from the low-pass filter are given as

$$\begin{aligned} i_{La(LPF)} &= I_{La}\sin(\omega t-\phi_a-90^{\circ}) = -I_{La}\cos(\omega t-\phi_a); \\ i_{Lb(LPF)} &= I_{Lb}\sin(\omega t-2\pi/3-\phi_b-90^{\circ}) = -I_{Lb}\cos(\omega t-2\pi/3-\phi_b) \\ i_{Lc(LPF)} &= I_{Lc}\sin(\omega t+2\pi/3-\phi_c-90^{\circ}) = -I_{Lc}\cos(\omega t+2\pi/3-\phi_c) \end{aligned} \tag{1}$$

The low-pass filter output currents are inverted to obtain real part of fundamental component of load current. The output of band-pass filter with cutoff frequency of 49.9Hz and 50.1 Hz is the fundamental component of load current and expressed as

$$\begin{aligned} &i_{La(BPF)} = I_{La}\sin(\omega t-\phi_a); i_{Lb(BPF)} = I_{Lb}\sin(\omega t-2\pi/3-\phi_b); \\ &i_{Lc(BPF)} = I_{Lc}\sin(\omega t+2\pi/3-\phi_c) \end{aligned} \tag{2}$$

The load currents are passed through a peak detector. The output of both low-pass filter and band-pass filter of each phase are divided by magnitude of fundamental peak load currents to extract out the sine and cosine terms only.

$$\begin{aligned} &i_{La(LPF)} = \cos(\omega t-\phi_a); i_{Lb(LPF)} = \cos(\omega t-2\pi/3-\phi_b); \\ &i_{Lc(LPF)} = \cos(\omega t+2\pi/3-\phi_c) \\ &i_{La(BPF)} = \sin(\omega t-\phi_a); i_{Lb(BPF)} = \sin(\omega t-2\pi/3-\phi_b); \\ &i_{Lc(BPF)} = \sin(\omega t+2\pi/3-\phi_c) \end{aligned} \tag{3}$$

The unit template waveform is passed through a low pass filter of cut off frequency 50Hz and band-pass filters with cut off frequency between 49.9Hz and 50.1Hz. The outputs of low pass filter and band-pass filter are as in equation (4)

$$\begin{aligned} &U_{a(LPF)} = \cos(\omega t); U_{b(LPF)} = \cos(\omega t-2\pi/3) \\ &U_{c(LPF)} = \cos(\omega t+2\pi/3) \\ &U_{a(BPF)} = \sin(\omega t); U_{b(BPF)} = \sin(\omega t-2\pi/3) \\ &U_{c(BPF)} = \sin(\omega t+2\pi/3) \end{aligned} \tag{4}$$

On multiplying the filter outputs of each phase in equation (4) by filter outputs of each phase in equation (3), based on trigonometrical identities, the outputs obtained are shown in equations (5).

$$\begin{aligned} &U_{a(LPF)}.i_{La(LPF)} = \frac{1}{2}[\cos\phi_a + \cos(2\omega t-\phi_a)] \\ &U_{b(LPF)}.i_{Lb(LPF)} = \frac{1}{2}[\cos\phi_b + \cos(2(\omega t-2\pi/3)-\phi_b)] \\ &U_{c(LPF)}.i_{Lc(LPF)} = \frac{1}{2}[\cos\phi_c + \cos(2(\omega t+2\pi/3)-\phi_c)] \end{aligned}$$

$$\begin{aligned} &U_{a(BPF)}.i_{La(BPF)} = \frac{1}{2}[\cos\phi_a - \cos(2\omega t-\phi_a)] \\ &U_{b(BPF)}.i_{Lb(BPF)} = \frac{1}{2}[\cos\phi_b - \cos(2(\omega t-2\pi/3)-\phi_b)] \\ &U_{c(BPF)}.i_{Lc(BPF)} = \frac{1}{2}[\cos\phi_c - \cos(2(\omega t+2\pi/3)-\phi_c)] \end{aligned} \tag{5}$$

The displacement power factor of each phase is obtained by adding equations in (5)

$$\cos\phi_a = \frac{1}{2}[\cos\phi_a - \cos(2\omega t-\phi_a)] + \frac{1}{2}[\cos\phi_a - \cos(2\omega t-\phi_a)] \tag{6}$$

To maintain balanced source currents, displacement power factor and peak value of reference source currents are obtained as average values of three phases and the average of the load current of each phase is taken so as to remove any unbalance in any of the phases.

$$\cos\phi = \frac{\cos\phi_a + \cos\phi_b + \cos\phi_c}{3} \tag{7}$$

The magnitude of the desired source current is expressed as

$$I_{sref} = I_{Lavg}\cos\phi \tag{8}$$

The reference source currents for each phase is given as

$$I_{sa(ref)} = |I_{sref}|u_a; I_{sb(ref)} = |I_{sref}|u_b; I_{sc(ref)} = |I_{sref}|u_c \tag{9}$$

The compensation currents are obtained as the difference between the actual load current and the source reference currents i.e.

$$i_{abc(comp)} = i_{Labc} - i_{sabc(ref)} \tag{10}$$

The inverter losses are also met with active power drawn from AC mains. The error signal obtained by comparing the actual capacitor voltage with a reference dc value is processed using a Proportional Integral controller. The required main currents are obtained with the help of PI Controller. The loss component of mains current is obtained as the output of the PI controller iswl multiplied by the unit sine wave. The compensation currents to meet switching losses are calculated as

$$i_{abc(swl)} = i_{swl} \cdot u_{abc} \tag{11}$$

The reference currents generated using an exponential composition algorithm are obtained as

$$i_{ref\_abc} = i_{abc(comp)} - i_{abc(swl)} \tag{12}$$

The switching pulses for the shunt filter are obtained by the comparison of the reference and actual filter currents in a hysteresis controller.

5. SHUNT ACTIVE FILTER COMPENSATION

Thus the comparison of the reference and the actual filter current generates switching pulses for the filter and thus the compensating current is injected to the system to remove harmonics and for compensating the reactive power thereby improving the power quality[11]. Fig 3(a) and Fig 3(b) shows the outputs obtained at different stages of the proposed control strategy. The filter outputs are shown in Fig 3(a) and the power factor obtained is shown in Fig 3(b).

Thus from the above simulation results it is very clear that the proposed control strategy is efficient enough to improve the power factor and harmonics. The proposed control algorithm is then implemented to generate pulses to the shunt active filter.

The shunt active filter connected at the PCC of the system injects the current required for the compensation to remove harmonics and the reactive power at point of common coupling Fig. 4 shows the simulation results of the reference current obtained from the proposed control algorithm, actual compensation current, and finally the sinusoidal source current in phase with the source voltage.

Table 2 shows the results obtained for the shunt active filter connected system. The table clearly depicts the compensation of reactive power, harmonics compensation and also power factor correction.

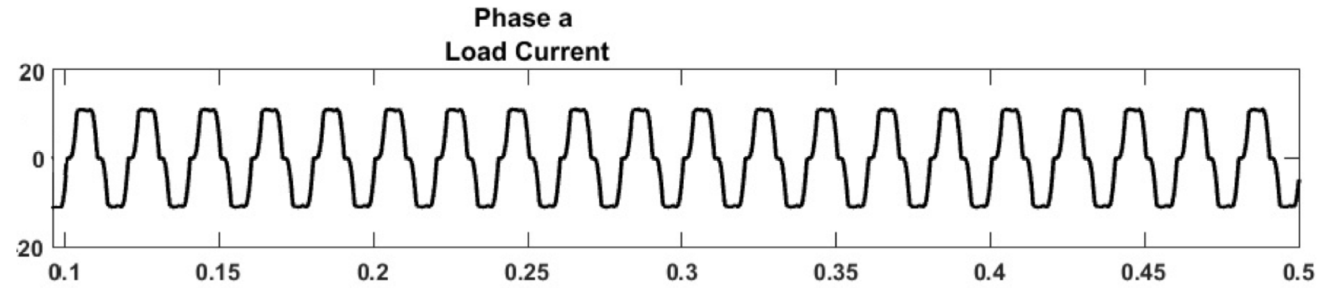
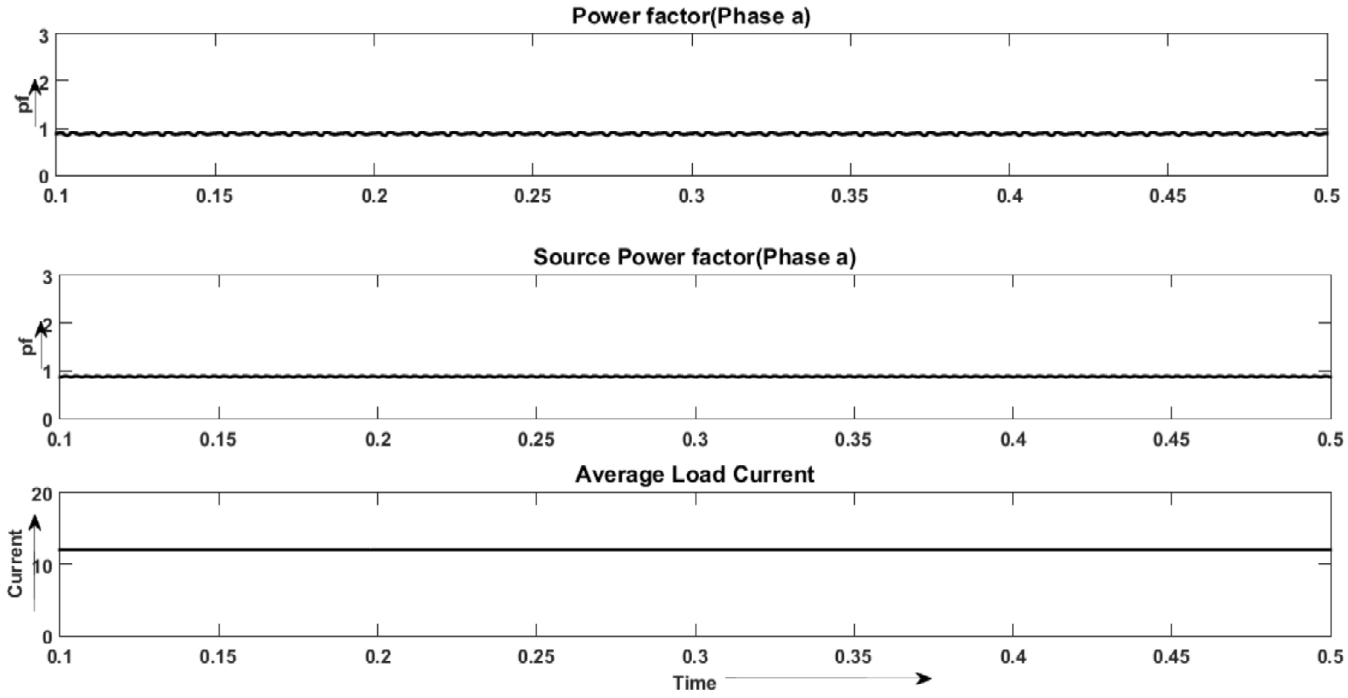


Figure 3: (a) Output obtained at different stages of proposed control strategy



(b) Output obtained at different stages of proposed control strategy

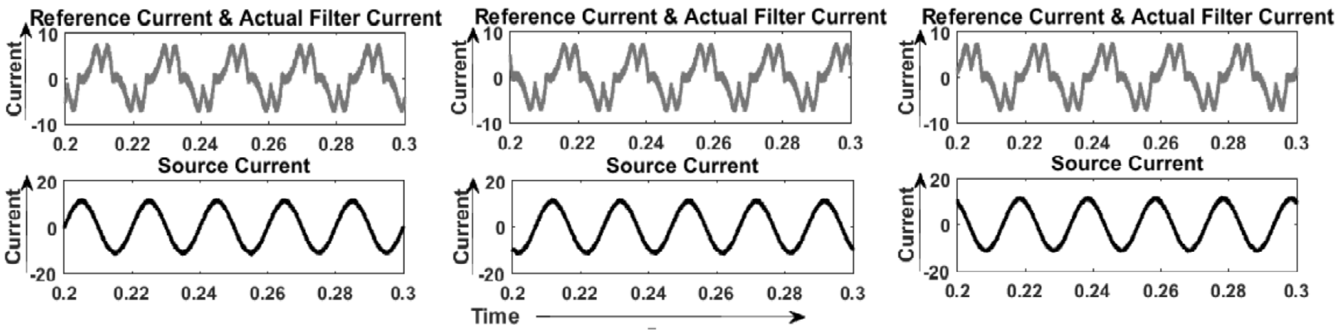


Figure 4: Waveforms obtained for reference current, actual filter current and source current

Table 2
System Parameters obtained with compensation

Alpha	*Load current, Irms*	*THD_I (%)*	*P(kW)*	*Q(kVA)*	*Power factor*
0	7.4	0.9	4.9	0	0.99
15	7.8	1.1	4.8	0	0.99
30	6.1	1.8	4.3	0	0.99
45	4.3	2.8	2.87	0	0.99
60	2.4	4.2	1.44	0	0.99

The above simulation results clearly depict the reference current generated by the control algorithm and the actual compensation current are equal. This current is fed by the shunt active filter which makes the source current sinusoidal removing harmonics and compensates for the reactive power.

6. DISCUSSION

The power quality issues in an industrial application when connected to the grid led to the proposal of an effective control algorithm in order to improve the power quality. The simulation results depict the effectiveness and efficiency of the proposed control strategy. The power quality factors such as Current Harmonics were eliminated, Reactive Power was compensated and Power factor was improved.

7. CONCLUSION

Many industrial application like electroplating leads to power quality issues when connected to the grid. In this paper the power quality issues when a non-linear load connected to the load were studied. A control strategy was designed and simulated which generates pulses to the shunt active filter thereby improving the power quality issues. The simulation results are shown which clearly depicts the compensation of reactive power, harmonics and also power factor correction.

Acknowledgment

The authors would like to thank Amrita Vishwa Vidyapeetham and Department of Science and technology for the support in carrying out this project work.

References

[1] Aiswarya, M.; Ilango, K.; Manitha, P.V.; Nair, M.G., “Simulation analysis of modified DC bus voltage control algorithm for power quality improvement on distributed generation systems,” in *Power and Energy Systems Conference: Towards Sustainable Energy, 2014* , Vol., No., March 2014

[2] Rakhee Panigrahi, Bidyadhar Subudhi, Prafulla Chandra Panda “A Robust LQG Servo Control Strategy of Shunt-Active Power Filter for Power Quality Enhancement,” *IEEE Trans. onPower Electron.*, vol. 31, no. 4, April 2016, pp. 2860-2869.

[3] Parag Kanjiya, Vinod Khadkikar, Hatem H. Zeineldin, “Optimal Control of Shunt Active Power Filter to Meet IEEE Std. 519 Current Harmonic Constraints Under Nonideal Supply Condition,” *IEEE Trans. ON Industrial Electronics*, vol. 62, no. 2, February 2015, pp. 724-734

[4] IEEE 519-1992 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

[5] Bhuvaneswari, G.; Nair, M.G, “Design, Simulation, and Analog Circuit Implementation of a Three-Phase Shunt Active Filter Using the Icos Algorithm,” *IEEE Transactions on Power Delivery*, Vol. 23, Issue 2, April 2008, pp. 1222-1235.

[6] Bhuvaneswari, G. Nair, M.G. Kumar Reddy, S., “Comparison of Synchronous Detection and Icosf Shunt Active Filtering Algorithms,” Proceedings of International Conference on Power Electronics, Drives and Energy Systems, Dec.12-15, 2006, pp. 1-5.

[7] Singh, Bhim, Kamal Al-Haddad, and Ambrish Chandra. “A review of active filters for power quality improvement. Industrial Electronics,” *IEEE Transactions* on 46.5 1999, p. 960-971

[8] Surasmi N. L., M. R. Sindhu “Optimum Allocation of Active Filters In A 4-Bus System Using Genetic Algorithm”, International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459), Volume 2, Issue 4, April 2012.

[9] Sindhu. M. R**,** Manjula. G. Nair, T. N. P. Nambiar, “An ANN based Digital Controller with three phase Shunt Active Power Filter for power quality improvement,” International Review of Electrical Engineering Special issue on Power quality in smart grids, December 2011.(1.6)

[10] Asha Jos, Sindhu S, Sindhu M R, T N P Nambiar, “Design and simulation of an improved algorithm for three phase

shunt active filter", International Journal of Applied Engineering Research, ISSN 0973-4562 Vol. 10 No. 1 (2015) pp. 844-849.

[11] Sindhu. S, M. R. Sindhu, T.N.P. Nambiar, "An Exponential Composition Algorithm Based UPQC for Power Quality Enhancement", *Elsevier Procedia Technology*, Vol. 21, pp-415-422, Nov.2015

[12] Arjun R, Sindhu S, Sindhu M R, T N P Nambiar, "Power Quality Compensation for an Induction Motor Drive with UPQC**",** International Journal of Applied Engineering Research, ISSN 0973-4562 Vol. 10 No. 20 (2015) pp. 15227-15231.