International Journal of Engineering & Technology, 7 (2.8) (2018) 543-549

SPC

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research Paper

Power quality improvement and reactive power compensation using enhanced sliding mode controller based shunt active power filter and static VAR compensator

T. Rajesh[1*], S. Rajeswari[2]

[1]Professor, [2]Associate Professor, [1,2]Department of Electrical and Electronics Engineering
[1]INFO Institute of Engineering,Tamil Nadu, [2]Karpagam Academy of Higher Education,Tamil Nadu
[*]Corresponding Author E-mail: rajeshpradha@gmail.com

Abstract

The power quality is the challenging criteria in all equipment's at all levels comprise industrial sectors and consumer places. Some parameters are very sensitive which may affect and disturb the power quality. These parameters are harmonic current, power compensation and voltage sag. Providing the source without these parameters with efficient power quality is essential. Hence by selecting proper device the power output may reach without any interruption along with linear, non-linear and unbalanced loads. This paper introduces a Sliding Mode Controller (SMC), a very effective controller implemented with Shunt active filter and Static VAR Compensator (SVC) FACTS device which increases the reactive power compensation and suppresses the harmonic to enhance the system performance with high reliability.

Keywords: *Power Quality, Reactive Power, Sliding Mode Controller, Non-linear load*

1. Introduction

Power quality plays a vital role in industrialization using power electronic devices because of rapid growth of Power Systems and in house hold equipments. There is necessary in distributing the energy to all levels with improved power quality. Power quality may affect by voltage sag [3], power factor [4], harmonic current and reactive power. These parameters degrade the performance and power quality of the power system. Moreover power electronics utilization is increased widely these constraints [7] must be suppressed to improve the power quality [14] in power system. FACTS device [13], [15] is the best method to reduce the above mentioned constraints. These devices are economic and control the power flow to improve the stability. Another important constraint that affects the power quality is harmonic (disturbance) [9] or ripples. Many research works are going on this field to predict the harmonics. This may affect the system behavior critically and tunes performance of the system vigorously [9]. Ripples are unwanted variance generated and dominant in direct voltage output from input alternating voltage. These unwanted ripples or harmonics are caused by non-linear a load which is a combination of harmonic and unbalanced load connected in power system. Therefore, it must be eliminated or reduced and is achieved by Passive and active filters connected at the load to improve the power flow. Many passive and active shunt filters [5] are present to improve power quality [1]. Hence to improve the power quality in power systems there is a need for reactive power [6] compensation by power electronic devices. There are different types of controllers like PI controller [12], PID controller, Fuzzy logic controller [11], Power Electronic converter [9] and space vector modulation technique [8] to eliminate harmonics under non-linear load. Adaptive controller [10] compensates power for harmonic distortion under load. In this paper FACTS device SVC and shunt active filter is utilized.

The proposed method, Sliding Mode Control is to control shunt active filter for harmonic suppression and FACTS device is the best device to improve reactive power. Because of its fast response, system stability and robustness SMC has been widely utilized.This paper is organized as follows. Section II deals with related work. Section III walks through proposed methodology. Section IV discuss about the results. Section V concludes the paper.

2. Related Work

L. H. Tey et al proposed an artificial neural network (ANN) technique to improve power quality and reactive power by suppressing harmonic currents for shunt active filter with nonlinear load.This technique used two signals for hysteresis control, one in three phase IGBT and another in voltage source inverter which speeds up the system by extracting the harmonics and reduced the time cycle to 1 cycle instead of 2 or 3 cycles.

Adil M. Al-Zamil and David A. Torrey (2001) has developed a hybrid series passive shunt active power filter system with space vector pulse width modulation control based on dead beat control model which reduced the complexity, shunt active filter bandwidth and system cost. The proposed controller utilized a 16 bit microcontroller, Motorola MC68HC16Z1.

A. A. Valdez et al has proposed a current loop controller for reactive power compensation, to improve stability of the system due to harmonic current distortion caused between line and load impedance which brings power factor close to unity.

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Wen Li and Yoichi Hori illustrates about vibration suppression using a combination FO-DOB and neuron based PI fuzzy controller, in which former is to estimate disturbance and to generate compensation signal and later is used to realize the outer loop.

PichaiJintakosonwit et al has discussed about automatic gain adjustment when it detects voltage harmonic at its installation bus without considering circuit parameters, moreover it reduce losses, current compensation and avoid over-damping performance in active filter.

Ying Xiao, Y. H. Song and Y. Z. Sun, 2002 has developed a flexible steady state power flow control of FACTS device based on active and reactive power injection model and optimal power flow model. This approach was implemented with Jacobian matrix which is independent of physical models and different control parameters of FACTS devices.

Chien-Hung Liu and Yuan-Yih Hsu in 2010 has designed a self-tuning PI controller which adapt the controller gains for STATCOM under all load conditions and disturbances using particle swarm optimization algorithm. Real time measurements were derived with an efficient formula to estimate system load impedance.

3. Proposed Methodology

Among various types of filters such as active, passive filters [1] with series, shunt or combination of series and shunt configurations, shunt active filter is preferred under linear, non-linear load and unbalanced load conditions. Shunt active filter is employed to control the inverter pulses. Sliding mode controller is proposed in this paper, which is a non-linear control method to suppress harmonics [16] and reactive power compensation to improve power quality [2]. Shunt active filter with SVC FACTS devices implemented using Sliding Mode Controller (SMC) is shown in Figure 1.

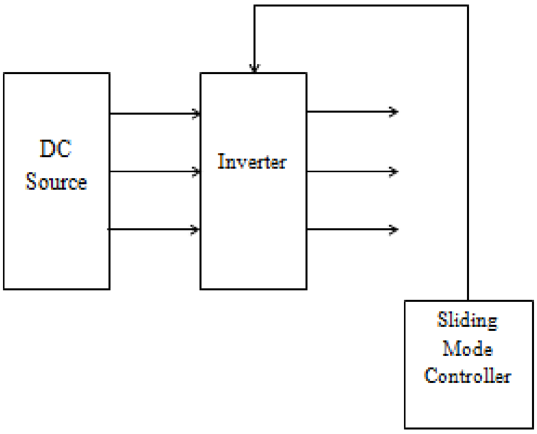


Fig. 1: Shunt Active Filter with Static VAR Compensator and Sliding Mode Controller

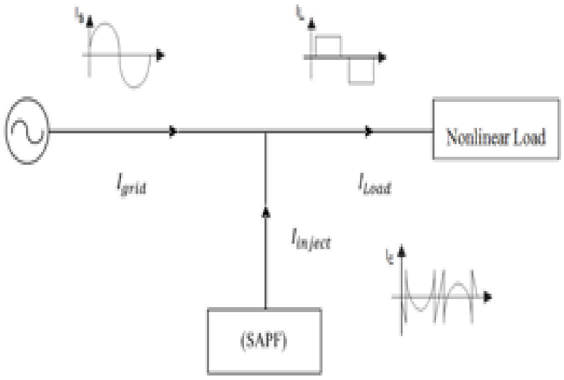


Fig. 2: Configuration of Shunt Active Filter

Power system and power electronic engineers have been intended to design/develop a solution for power quality problems due to increased harmonic pollution severity in ac network with non-linear loads. One such device is active power filter used since 1970's to suppress harmonics to increase voltage balance.

a) Shunt active filter

Active power filters are classified according to topology such as series, shunt or combination of both. Shunt active filter is widely used to eliminate unbalanced current, harmonic current of higher order and reactive power compensation in the three phase transmission line. Mostly it is connected at load end to inject compensating current in opposite phase of non-linear load current. In this paper shunt active filter as shown in Figure 2, acts as controlled current source which injects load generated harmonic generated by load with phase shift of 180°.

b) DC link capacitor

DC link capacitor in shunt active filter is supplied by solar energy. Its main contribution is

- to maintain almost constant DC voltage
- serves as energy storage unit to supply actual power difference between load and power source

Real power by source and load are equal in steady state to compensate the loss. Under load, the real power will be disturbed and also the DC link voltage. This difference in real power is compensated by DC link capacitor. To maintain steady state operation, the tracked peak value of the shunt active filter must be proportionately adjusted with the actual power drawn from the source. Thus the consumption of actual power by load is compensated by capacitor's charged or discharged current and also loss.

c) Static VAR Compensator

Static VAR Compensator (SVC) is used for voltage stability in power system network to improve power quality, inwhich the inverter pulses are controlled by Sliding Mode Controller (SMC). SVC is one of the FACTS device which regulates the voltage, harmonics, power factor correction (brings the power factor near to 1) and stabilizes the system. SVC is mainly connected near load end in large industrial sectors to improve power quality and also to regulatetransmission voltage when connected to power system. Reactive power compensation is done by this FACTS device in transmission line system and is improved by controlling the power factor. If power factor becomes low, current in transmission line will be high.

Due to this high current

- Copper loss will be high
- Machine will produce large KVAR which, in turn increases the size of the machine and cost of themachine.
- Voltage drop will be increased
- Produce low efficiency

Hence power factor must be improved. Maintaining the power factor greater than 0.95 will reduce reactive power loss and voltage-drop in the transmission line at the point of common coupling (PCC). The power factor improvement brings active power current same as the circuit current.

d) Sliding mode controller

Sliding Mode Controller is one among non-linear control method. Sliding Mode Converter replaces the Power converters [9] because of its robustness, steady state response and inelastic structure.The sliding mode controller design consists of

A) Switching function
B) Control law

This control law makes the switching function to the system state and can either be continuous or discontinuous. Let the nonlinear system form be

$$\dot{A} = f\ (a, u) \tag{1}$$

Due to discontinuity forced on surface control side

$$\sigma\ (a) = 0 \tag{2}$$

Where, A is the system error and u is the control issued by the corrector with variable structure. The system will take either (3) or (4) depending on the application of order.

$$A = f^{-}(A, U^{-})\text{if}\sigma\ (A) < 0 \tag{3}$$
$$A = f^{+}(A, U^{+})\text{if}\sigma\ (A) > 0 \tag{4}$$

Case (i) Non-linear system

A nonlinear system is given interms of differential equation as below

$$\dot{A} = f(A, t) + g(A, t). U \tag{5}$$

Where,

$$A\ \in\ S^{n}, U\ \in\ S^{m}, f(A, t) \in\ S^{n}, g(A, t)\ \in\ S^{nXm}$$

Initially, switching surface of desired dynamics $\sigma(a) = 0$ is defined. Second, the control function$u(a, t)$is synthesized. This is done to check whether any state outside and inside the switching surface joined. A sliding mode occurs once it is attained and hence equilibrium point reaches.
The sliding surface is given by

$$\sigma(a) = Cx =\ 0 \tag{6}$$
$$\sigma(a) = \sum_{i=1}^{n} c_i a_i \tag{7}$$

Case (ii) Multivariable
It is represented as

$$\dot{A} = f(A, t) + g\ (A, t). U \tag{8}$$

Where,

$$A\ \in\ S^{n}, U\ \in\ S^{m}, f(A, t) \in\ S^{n}, g(A, t)\ \in\ S^{nXm}$$

The switching surfaces $(\sigma_1 \sigma_2 \sigma_3 \dots \dots . \sigma_m)$ makes the problem more complex. At the intersection of these surface only sliding modes occurs. The switching surfaces are

$$\sigma(a) = Cx \tag{9}$$
$$\sigma(a) = [\sigma_1(a), \sigma_2(a), \sigma_m(a)]^{T} = 0 \tag{10}$$
$$C = [c_1, c_2, \dots . c_n] \tag{11}$$

The switching surface of dimension “m” and $\sigma_i(a)$ is the ith switching surface.
Case (iii) Mono-variable
It is represented as

$$\dot{A} = f(A, t) + g\ (A, t). U \tag{12}$$

Where,

$$A\ \in\ S^{n}, U\ \in\ S^{m}, f(A, t) \in\ S^{n}, g(A, t)\ \in\ S^{nXm}$$

The condition of sliding mode:

$$\left[\left(\frac{\partial\sigma}{\partial a}\right)^{T} g(a, t)\right]^{-1} \neq 0 \tag{13}$$

The average value of the control is represented as
$\text{Min}\{U\hat{}\ -\ (a, t), U\hat{}\ +\ (a, t)\} < u\_eq < max\{U\hat{}\ -\ (a, t), U\hat{}\ +\ (a, t)\}$(14)
The sufficient and necessary condition for sliding mode is given by

$$U_{min} = \min\{U^{-}(a, t), U^{+}(a, t)\} \tag{15}$$
$$U_{max} = \max\{U^{-}(a, t), U^{+}(a, t)\} \tag{16}$$

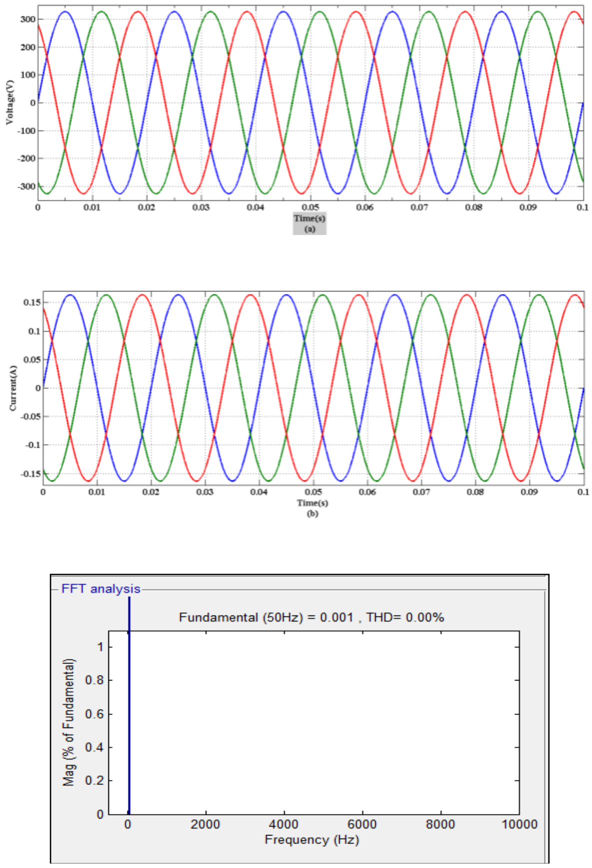
The harmonic currents and components are identified. The proposed method injects the reactive and harmonic current.

4. Results and Discussion

The simulation of a proposed Sliding Mode Controller designed with Shunt Active Filter, non-linear load and SVC has been carried out with MATLAB Simulink tool. The parameters of the system are source voltage, source frequency, line inductance for 3 phase and 1 phase, DC link voltage and capacitor, AC filter inductance, filter resistor, filter capacitor and switching frequency for Shunt active power filter. The waveforms for various combinations are analyzed for with balanced load, unbalanced load and combination of both with and without filter and SVC. The entire simulation work was carried out in MATLAB/Simulink and the parameters of the proposed system is given in Table 2.

a. Balanced load

The simulated waveforms of the system when connected with balanced linear load and its FFT analysis are shown in Figure 3. In this case there is no need of SAPF since, the load is purely linear in nature and is free from harmonics. It is observed from Figure 3(b) , that the grid current is undistorted, sinusoidal with equal magnitude in phases. Since the grid current is sinusoidal the THD level is zero, which is shown in Figure 3(c)



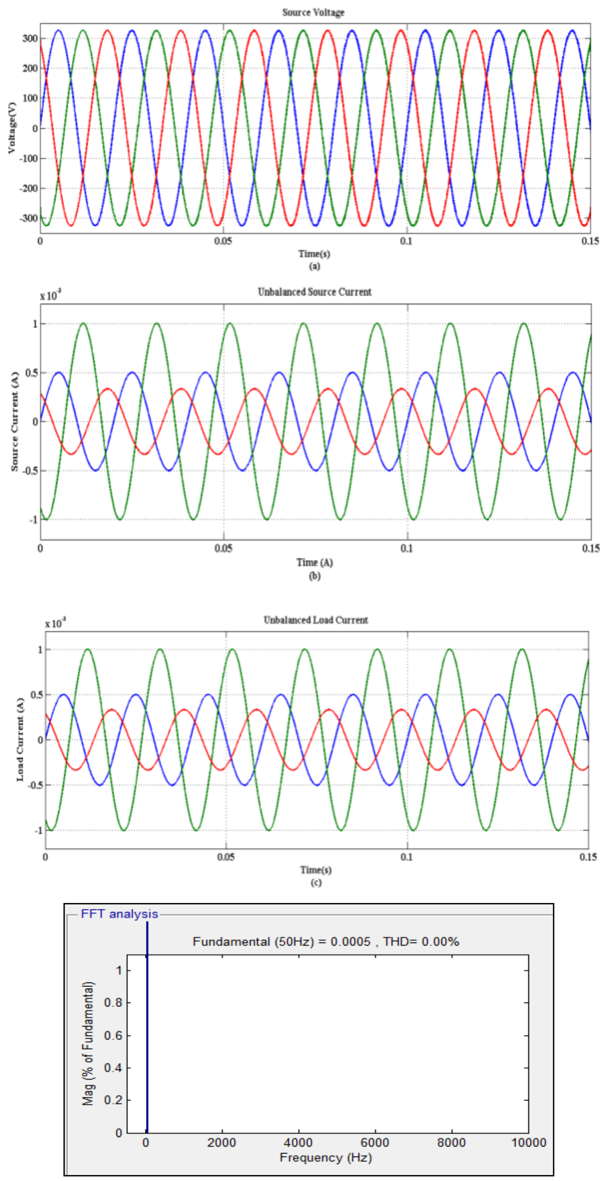
(c)

Fig.3: System performance under balanced linear load conditions (a): Load voltage waveform for the system connected with balanced load (b): Load current waveform for the system connected with balanced load (c): THD analysis for system with balanced load

b. Unbalanced load

The simulated waveforms of the system when connected with unbalanced linear load and its FFT analysis are shown in Figure 4.

In this case also there is no need of SAPF since, the load is purely linear in nature and is free from harmonics. It is observed from Figure 4(b) , that the grid current is undistorted, sinusoidal with unequal magnitude in phases due to the unbalance nature of the load. Since the grid current is sinusoidal the THD level is zero, which is shown in Figure 4(d).

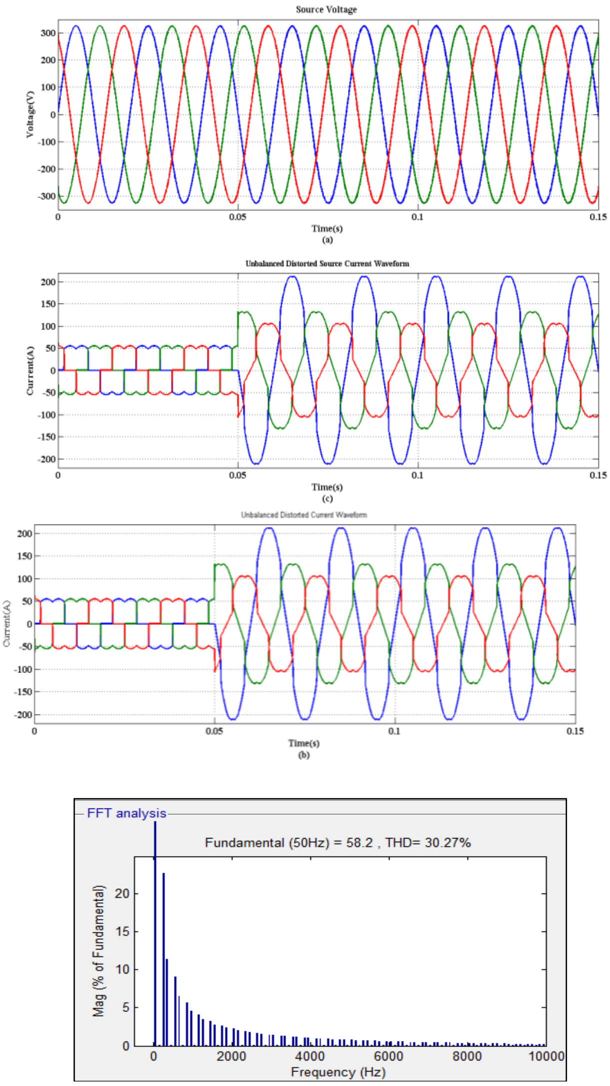


(d)

Fig.4: Performance under unbalanced linear load conditions (a) Load voltage waveform for the system connected with unbalanced load (b) Source current for system with unbalanced load (c) Load current waveform for the system connected with unbalanced load (d) THD for system with unbalanced load

c. Unbalanced and Distorted load

The performance of the system is evaluated with distorted and unbalanced load, one after the other. Parameters such as source voltage, source current, load current are evaluated to demonstrated its proper functioning. Moreover THD of the line current is analysed for determining power quality at AC mains. Figure 5 illustrates the waveform of the system which supplying distorted and unbalance load.



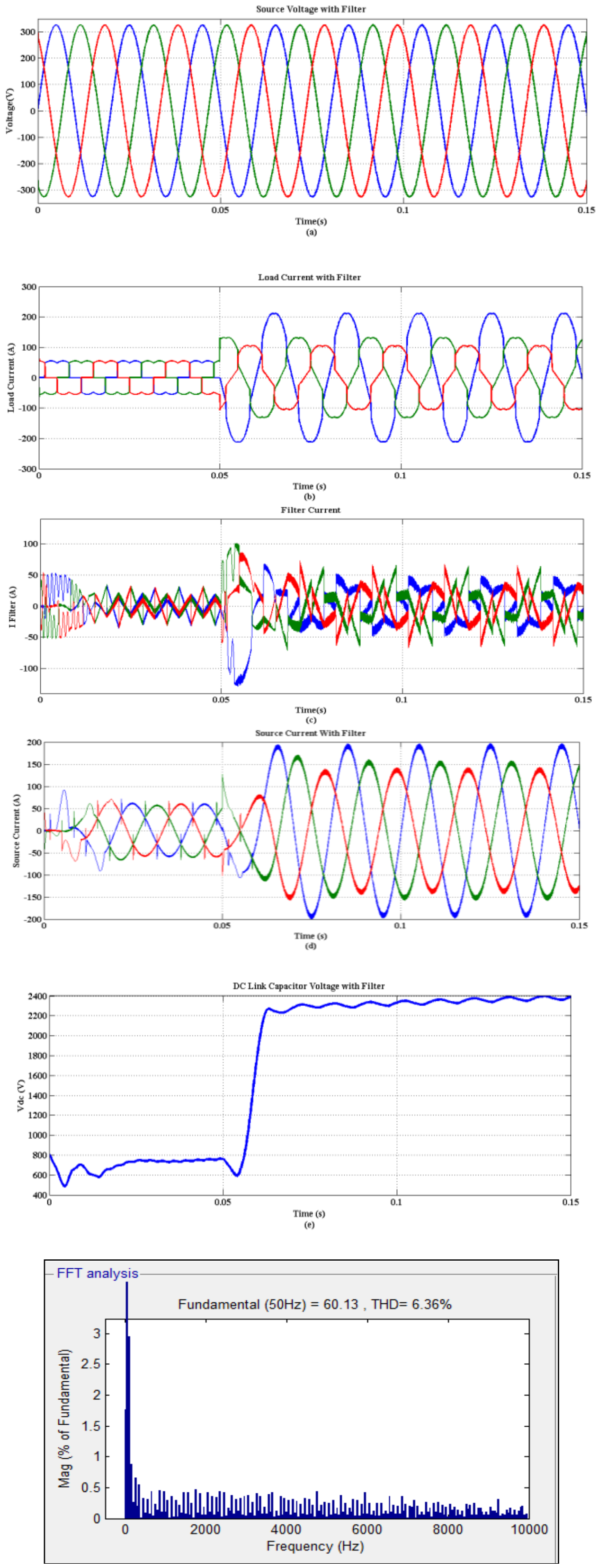
(d)

Fig. 5: Performance under unbalanced and distorted loads conditions (a) Load voltage waveform (b) Source current (c) Load current waveform(d)THD for system with unbalanced load

Initially a nonlinear load is connected in the system which is 40% of the rated load till 0.05 s. At the instant of 0.05 s, for analysing the dynamic nature of the system, an unbalanced load is also connected. It is observed from the simulated waveforms shown in Figure 5(b) and 5(c), that there is sudden change in magnitude of current at the instant of 0.05 s due to the addition of the new load which is unbalanced in nature and the THD is found to be 30.27% which is shown in Figure 5(d). The nonlinear nature of the load contributes for the increased THD. The THD level can further be reduced by installing a superior quality power filter.

d. System connected with filter

SAPF is employed with the aim of improving the performance of the system. The performance of the system is evaluated with SAPF. Parameters such as source voltage, load current, filter current, source current, dc link capacitor voltage (V_{dc}) and THD are evaluated to demonstrate the working of the filter. Figure 6 illustrates the simulated output waveforms of the system when connected with SAPF.



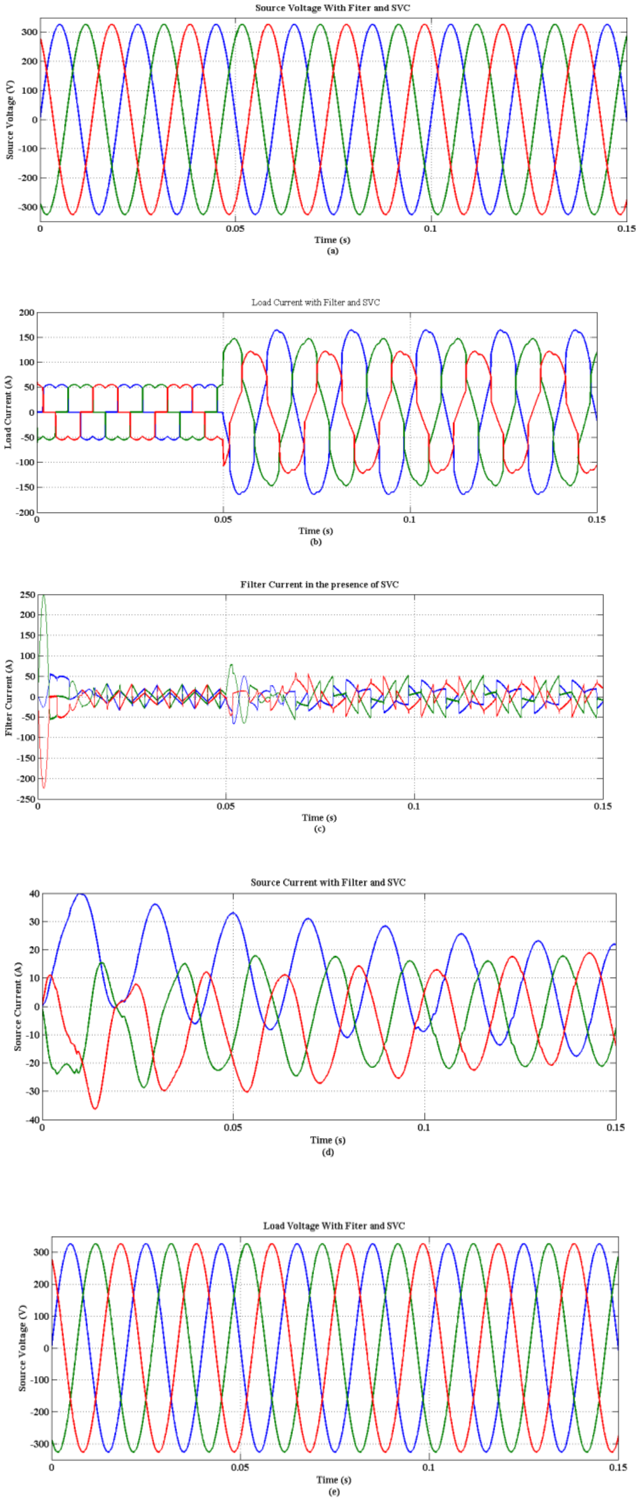
(f)

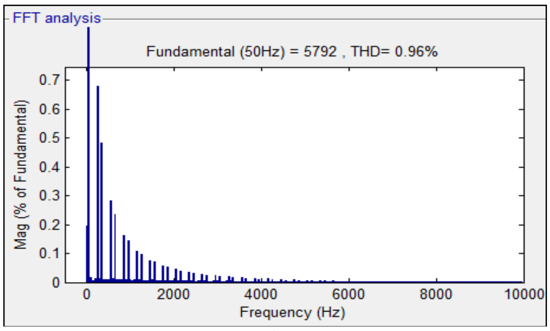
Fig. 6: Performance under unbalanced and distorted loads conditions with SAPF (a) Source Voltage (b) Load Current (c) Filter Current (d) Source Current (e) V_{dc} Regulation (f) THD for system with SAF

Initially only the nonlinear load is connected and at the instant of 0.05 s an unbalanced load is connected which is reflected in Figure 6(b) and 6(d). Based on the requirement of the load, SAPF injects negative harmonic filter current at PCC which is shown in Figure 6(c). It is observed that, initially there are transients in the filter current when the load changeover takes place (i.e., from 0.05 s onwards) and the transients dies out immediately after few millisecond. It is evident from Figure 6(d) that the source current is sinusoidal and free from harmonics and THD level is further reduced to a lower value of 6.39% as shown in Figure 6(F). Still the THD level is marginally high which is due to the unbalance nature of the load and insufficient reactive power compensation.

e. System with filter and SVC

The system is connected with shunt active filter and FACTS device SVC to suppress the harmonic and to improve the reactive power compensation. The reactive power is compensated by injecting the compensating current to utilize the real power by the system. The Figure 7 shows the waveform of the system when connected with filter and SVC.

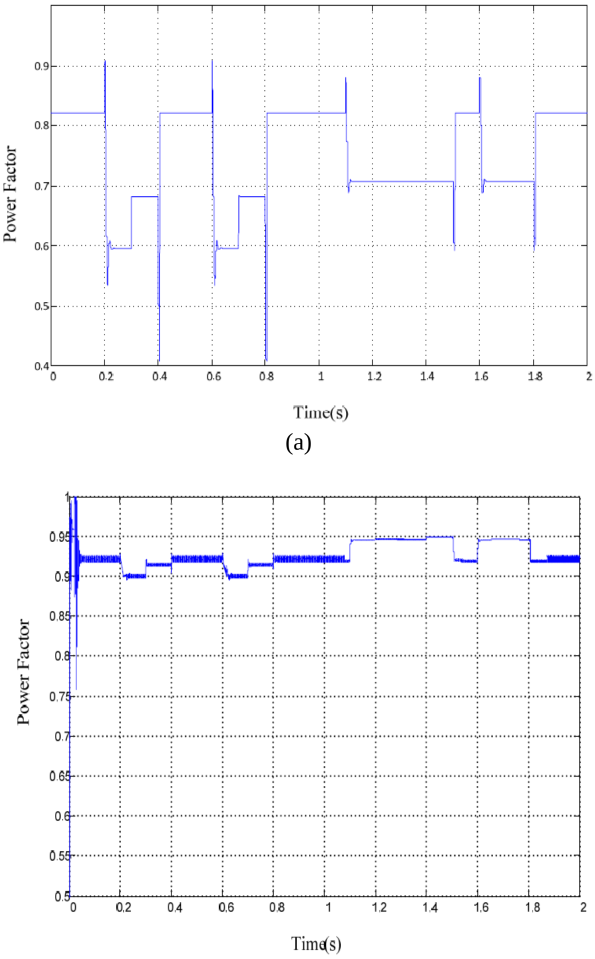




(f)

Fig. 7: Performance under unbalanced and distorted loads conditions with SAPF and SVC (a) Source Voltage (b) Load Current (c) Filter Current (d) Source Current (e) Load Voltage (f) THD for system with SAF and SVC

It is observed from Figure 7(f) that the THD level is 0.96% is very low which is reflected in the source current waveform. Thus it is clear that power quality is increased by connecting both the devices to three phase system at the load end.SVC has a place with shunt associated FACTS controllers. Its basic role is to compensate low power factor, to control the reactive power and to enhance voltage quality at PCC.



(a)

(b)

Fig. 8: (a) Power factor of the system with fault without SVC (b) Power factor of the faulted system with SVC

In Figure 8(a) when fault occurs, power factor of the system varies between 0.6 and 0.8 and it is not constant when load is changed. For tackling this issue SVC with a PI controller is used. When SVC is not connected to system, power factor is 0.8, when it is connected to the system; power factor is increased to 0.96 Figure 8(b) shows power factor of system when SVC is connected to the system. Table 1 shows the power factor levels in the presence and absence of SVC respectively.

Table 1: Power factor of the system with and without SVC

Description	Power Factor
System with SAF and without SVC	0.8
System with SAF and SVC	0.96

Table 2: Simulation Parameters

	PARAMETER	SPECIFICATION	VALUE
SOURCE	Voltage	VSabc	415 V_{rms}
	Frequency	f	50 Hz
LOAD	3 Phase AC Line Inductance	L_{Labc}	3 mH
	1 Phase AC Line Inductance	L_{La1}	1.5mH
	3 Phase Inductance	L_{da3}	13 mH
	3 Phase Resistor	R_{da3}	19Ω
	1 Phase Resistor	R_{da1}	60.5 Ω
	1 Phase Capacitor	C_{da1}	240µF
DC LINK	Voltage	VDA	500V
	Capacitor	C1C1	1000µF
SAPF	AC Line Inductance	L_{Cabc}	4.2mH
	Filter Resistor	R_{Cabc}	8 Ω
	Filter Capacitor	C_{abc}	16 µF
	Switching frequency	f_{pwm}	19KHz

Table 2 gives the detail about the simulation parameters. Table 3 provides the THD analysis for the system under different load conditions.

Table 3: Analysis of THD under different load condition

Determination	Load	THD (%)
Without SAF and SVC	Balanced	0
	Unbalanced	0
	Balanced and unbalanced	30.27
With SAF and without SVC	Balanced and unbalanced	6.36
With SAF and SVC	Balanced and unbalanced	0.96

5. Conclusion

Power quality is the major criteria in distribution system. Power quality is improved by injecting compensating current at the load end to utilize the real power maximum by the system. In this paper, Shunt active power filter (SAPF) is employed to reduce the harmonics and to compensate the reactive power. FACTS device Static VAR Compensator (SVC) is utilized to improve the power quality and power factor of the system. The experimental results for various combinations of load are connected with the system and are implemented inMATLAB . Thepower factor is 0.96 which is nearer to unity with the system connected with SAF and SVC and the power factor is 0.8 when the system connected without SVC. The THD value is 30.27%, 6.36% and 0.96% for the system connected without SAF and SVC, with SAF and without SVC, and with SAF and SVC. Therefore by using SVC the stability of the system is improved while the load of the system varies. The proposed system not only mitigates harmonics but also regulates the power factor in the power system. It states that the proposed method improves the power quality and enhances the KVAR compensation of the system.

References

[1] Adil M. Al-Zamiland David A. Torrey, “A Passive Series, Active Shunt Filter for High Power Applications”, IEEE Transactions on Power Electronics, vol. 16, no. 1, January 2001

[2] L. H. Tey, P. L. So and Y. C. Chu, “Improvement of Power Quality Using Adaptive Shunt Active Filter” IEEE Transactions on Power Delivery, vol. 20, no. 2, April2005

[3] Pichai Jintakosonwit, Hideaki Fujita and Hirofumi Akagi, “Control and Performance of a Fully-Digital-Controlled Shunt Active Filter for Installation on a Power Distribution System” IEEE Transactions on Power Electronics, vol. 17, no. 1, January 2002

[4] Hirofumi Akagi, Hideaki Fujita and Keiji Wada, “A Shunt Active Filter Based on Voltage Detection for Harmonic Termination of a Radial Power Distribution Line” IEEE Transactions on Industry Applications, vol. 35, no. 3, May/June 1999

[5] PichaiJintakosonwit, Hirofumi Akagi, Hideaki Fujita and Satoshi Ogasawara, “Implementation and Performance of Automatic Gain Adjustment in a Shunt Active Filter for Harmonic Damping throughout a Power Distribution System” IEEE Transactions on Power Electronics, vol. 17, no. 3, May 2002

[6] Hideaki Fujita and Hirofumi Akagi, “Voltage-Regulation Performance of a Shunt Active Filter Intended for Installation on a Power Distribution System” IEEE Transactions on Power Electronics, vol. 22, no. 3, May 2007

[7] Ambrish Chandra, Bhim Singh, B. N. Singh and Kamal Al-Haddad, “An Improved Control Algorithm of Shunt Active Filter for Voltage Regulation, Harmonic Elimination, Power-Factor Correction, and Balancing of Nonlinear Loads” IEEE Transactions on Power Electronics, vol. 15, no. 3, May 2000

[8] Ahmed M. Massoud, Stephen J. Finney, Andrew J. Cruden, and Barry W. Williams, “Three-Phase, Three-Wire, Five-Level Cascaded Shunt Active Filter for Power Conditioning, Using Two Different Space Vector Modulation Techniques” IEEE Transactions on Power Delivery, vol. 22, no. 4, October 2007

[9] ShaikAffijulla and SushilChauhan, “Elimination of Resonant Internal Harmonics in Power Electronic Converters” International Journal of Advances in Engineering Sciences Vol.1, Issue 1, Jan, 2011

[10] A. A. Valdez, G. Escobar and R. Ortega, “An Adaptive Controller for the Shunt Active Filter Considering a Dynamic Load and the Line Impedance” IEEE Transactions on Control Systems Technology, vol. 17, no. 2, March 2009

[11] Salman Mohagheghi, Ganesh K. Venayagamoorthy, SatishRajagopalan and Ronald G. Harley, “Hardware Implementation of a Mamdani Fuzzy Logic Controller for a Static Compensator in a Multi machine Power System” IEEE Transactions on Industry Applications, vol. 45, no. 4, pp 1535-1544July/August 2009

[12] Chien-Hung Liu and Yuan-Yih Hsu, “Design of a Self-Tuning PI Controller for a STATCOM Using Particle Swarm Optimization” IEEE Transactions on Industrial Electronics, vol. 57, no. 2, pp February 2010

[13] EsmaeilGhahremani and Innocent Kamwa, “Optimal Placement of Multiple-Type FACTS Devices to Maximize Power System Loadability Using a Generic Graphical User Interface” IEEE Transactions on Power Systems, vol. 28, no. 2, pp 764-778 May 2013

[14] PragtiJyotishi, Proff. Deeparamchandani, “Mitigate Voltage Sag/Swell Condition and Power Quality Improvement in Distribution Line Using D-STATCOM” Int. Journal of Engineering Research and Applications, ISSN: 2248-9622, Vol. 3, Issue 6, Nov-Dec 2013, pp.667-674

[15] Ying Xiao, Y. H. Song and Y. Z. Sun, “Power Flow Control Approach to Power Systems with Embedded FACTS Devices” IEEE Transactions on Power Systems, vol. 17, no. 4, pp 943-950, November 2002

[16] Wen Li and Yoichi Hori, “Vibration Suppression Using Single Neuron-Based PI Fuzzy Controller and Fractional-Order Disturbance Observer” IEEE Transactions on Industrial Electronics, vol. 54, no. 1, pp 117-126 February 2007