Reducing Harmonics in Micro Grid Distribution System by Implementing Six Pulse SAPF with PI Controller

C.S Sharma[1] Vaishali Dubey[2]
[1]Associate Professor [2]PG Student
[1,2]Department of Electrical Engineering
[1,2]Samrat Ashok Technological Institute Vidisha, Madhya Pradesh

Abstract— In last few decades power quality improvement has been major research topic. This is due to wide use of semiconductor and non-linear devices. The power quality of any source is measured by some indexes set by internationally such harmonics factor, and telephonic interference level etc. Employing several harmonic compensation methods. We are able to meet those index limits set by international bodies. This is very essential in reference to performance & economy of operation. Power filters are extensively employed in modern electrical power distribution system to remove harmonics associated with the system. Shunt active power filter (SAPF) is one of the power filters which have better dynamic performance. SAPF required accurate control technique which provides robust performance under source & load unbalance. Control methods are responsible for generating reference currents which is employed to trigger Voltage Source Inverter. Hence, compensation of harmonics depends largely on technique used. For any Shunt APF system there is many way of implementing control blocks whose output is given to gate of the voltage source inverter.

Key words: Voltage Disturbances, Nonlinear Loads, PCC, Power Quality, Shunt Active Power Filter (SAPF), PWM

I. INTRODUCTION

Now a days in distribution systems, the load sometimes suddenly increase or decreases and similar as nonlinear loads draws non-sinusoidal currents from the AC mains and which causes the load harmonics and reactive power, and excessive neutral currents gives pollution in power systems. Most pollution problems arrives in power systems are due to then on linear characteristics and also fast switching of power electronic devices. The increased use of power electronic controlled devices and non-linear electronic devices in power systems has given rise to certain distortions in voltage and current waveform called as “harmonics”. It highly affects the other consumers. Hence it is required to overcome these inexpedient features. The shunt passive filters, which consist of tuned LC filters and high passive filters are used to lower down the affect of harmonics to the system. The power capacitors are employed to improve the power factor of the system. But they have certain limitations of fixed compensation, bearing large size and can also deport resonance conditions. So active power filters are now a days seen as a best option over the normal passive filters, to compensate harmonics and reactive power need of the non-linear loads. There are various topologies of active power filters have been done so far. The shunt active power filter which is based on current controlled voltage source type Pulse Width Modulation type converter has been proved to be efficient even when the load is highly nonlinear. An instantaneous volt ampere compensator which is reactive and also harmonic suppressor system is proposed without the use of voltage sensors but require very costly and complex hardware for the current reference generator.

II. POWER FILTER TOPOLOGIES

The harmonic filter connected to AC system has two objectives

- To minimize the effect of harmonic voltage and current in the power system below an acceptable level
- To compensate the reactive power required by the loads.

Two type of filters used for the above purposes which are:

1) Passive filter
2) Active power filter

Depending on the application system or electrical problem to be solved, active power filters can be implemented as series type, shunt type, or a combination of both filters. And these filters can be also combined with passive filters to create some hybrid power filters.

The shunt-connected active power filter also shows similar characteristics to STATCOM which is reactive power compensator of power system when used with a self-controlled dc bus. The shunt active power filters, also acts as a current source, injects harmonic compensating current of shifted in phase by 180° but same magnitude as the load current harmonics and thus load current harmonics compensates.

The series connected filter mainly compensates sags/swell from the supply and thus protects users from inadequate voltage quality voltage in unbalances. These are useful in low power applications. These filters can be used in place of UPS with comparatively very cheap cost as none of the energy storing element like battery is used.

The series active filters work as mixed filter topologies with passive LC filters. In case of passive LC filters are generally connected in parallel to the load then series power filter works as a harmonic isolator and forces load current harmonics to circulate from the passive filter and not from the power distribution system.

In a series-shunt active filter the shunt active filter is generally located at the load side and can be used to compensate the reactive power, load harmonics, and unbalances of load current. And series filter is at the source side and acts as a harmonic blocking filter. This particular filter topology has been called the Unified Power Quality conditioner.

Multilevel inverters are generally based on hybrid AC filter and used for active filter based topologies. These 3- ϕ four wire inverters are becoming very much popular for mostly inverter applications like power factor compensators and machine drives. The good use of multilevel converters is that they can decreases the harmonic content produced by the active filters, because multilevel converters can also produce more levels of voltage than any other converters.

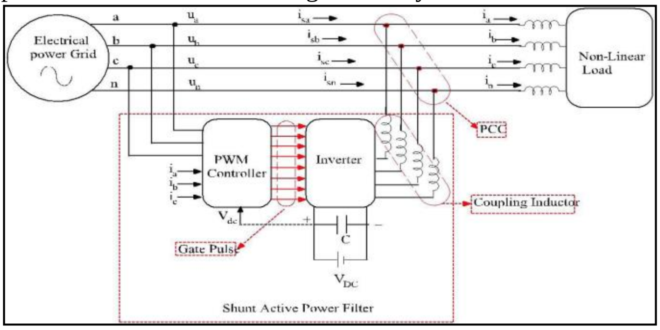

Fig. 1: Shunt Active Power Filters Topology

III. VOLTAGE SOURCE CONVERTERS

The active power filter topologies generally use voltage source converters. This topology, shown in Figure 1, converts a dc voltage into an ac voltage by gating the power semiconductor switches. A single pulse for each half cycle can be applied to synthesize an ac voltage. For such purposes most applications require dynamic performance, pulse width modulation is the most commonly used for active filter. The PWM techniques applied to control the VSI for consist of dc bus voltage chopped to produce an ac voltage of an arbitrary waveform.

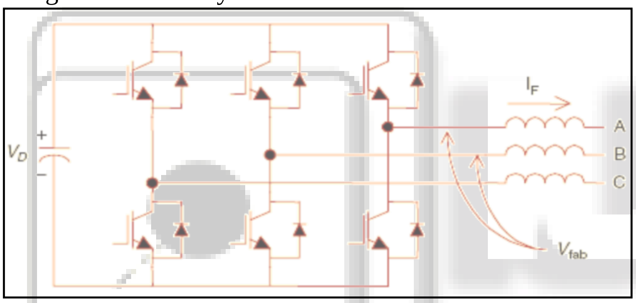

Fig. 2: Voltage source converter topology for active filters

Voltage source converters are more preferred over current source converter because it has higher efficiency than the current source converters and lower starting cost.

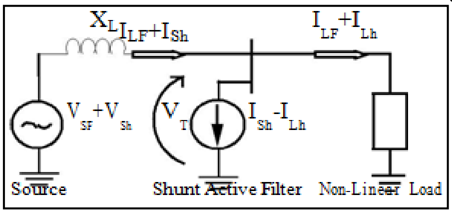

Fig. 3: Principle of Shunt Current Compensation

They can be readily expanded in parallel to increase their combined rating and also their switching rate can also increases if they are carefully controlled so that their individual switching times won't coincide. Thus, higher-order harmonics can be removed with use of converters and converter switching rates will not be increased individually. Because of this nonlinear load current will have harmonics, so load current will becomes the sum of fundamental and all remaining harmonics, all harmonics will be integral multiple of fundamental frequency. Load current can be written as:

$$i_L(t) = \sum_{n=1}^{\infty} In \sin(n\omega t + \Phi n)$$

$$= I_1 \sin(\omega t + \Phi l) + \sum_{n=2}^{\infty} InSin(n\omega t + \Phi n) \quad (1)$$

Instantaneous Load can be written as:

$$p_L(t) = v_s(t) \times i_L(t) \quad (2)$$

Putting value of $i_L(t)$ from equation (1) in equation (2)

$$P_A(t) + p_R(t) + p_H(t) \quad (3)$$

Here is active or fundamental power. Only fundamental component of voltage, current can give power to the load and reactive power. So real or active power which given by the load from the source is:

$$p_A(t) = v_m i_1 \sin^2\omega t \times \cos\varphi_1 = v_s(t) \times i_s(t) \quad (4)$$

Therefore, current(source) after compensation will be as by equation (5)

$$i_s(t) = {}^{pA(t)}/_{Vs(t)} = i_1\cos\varphi 1 \times \sin\omega t\ i_m \sin\omega t \quad (5)$$

Where $i_m = i_1\cos\varphi_1$

In a practical converter, there are switching, and capacitor and conducting leakage losses. So that these losses must be supplied through the supply or by the grid . So total current supplied by supply will be given as:

$$i_{SP} = i_m + i_{slo} \quad (6)$$

Where I_{sp} = peak current supplied by source.

Where I_{slo} = converter loss current supplied by the source.

If overal total harmonic as well as reactive power of the load is supplied, by the Active Power Filter then there will be no such harmonic in source current and also source current will be with in phase with the source voltage. Thus, the total source current including losses will be given as $i_s^*(t) = i_{SP}\text{Sin}\omega t$. So compensating current will be given as:

$$i_c(t) = i_L(t) - i_s^*(t) \quad (7)$$

It is obvious from the discussion that for instantaneous compensation of reactive power, harmonic power, source (grid) should be able to supply current $i_s^*(t)$. Therefore, it is necessary to find $i_s^*(t)$ which is known as reference current.

IV. CALCULATION OF REFERENCE CURRENT

Instantaneous currents can be given as:

$$i_s(t) = i_l(t) - i_c(t) \quad (8)$$

Source voltage is given by:

$$v_s(t) = v_m \sin\omega t \quad (9)$$

If a non-linear load is given, then load current will have a fundamental component and thus harmonic components which can be represented as:

$$i_L = \sum_{n=1}^{\infty} In \sin(n\omega t + \Phi n)$$

$$= I_n \sin(n\omega t + \Phi 1) + \sum_{n-2}^{\infty} \sin(n\omega t \Phi n) \quad (10)$$

The instantaneous load power can be written as:

$$P_L(t) = v_s(t) \times i_L(t)$$

$$= V_m I_1 \sin^2\omega t \times \cos\varphi_1 + v_m I_1 \text{Sin}\omega t \times \cos\omega t \times \sin\Phi_1 + V_m \sin\omega t \sum_{n-2}^{\infty} InSin(n\omega t\Phi n) \quad (11)$$

$$= p_f(t) + p_r(t) + p(t) \quad (12)$$

$$= p_f(t) + p_c(t)$$

In the expressions (11) and (12)

$p_f(t)$ is the real power

$p_r(t)$ denotes reactive power &

$p_h(t)$ denotes harmonic power drawn by load

From (11), the real (fundamental) power drawn by the load is:

$$P_f(t) = V_m I_1 \sin^2\omega t \times \cos\varphi_1 = v_s(t) \times i_s(t) \quad (13)$$

From (13), the source current provided by the source, after compensation is:

$$I_s(t) = p_f(t)/v_s(t) = I_1 \cos\varphi_1 \sin\omega t = I_m \sin\omega t$$

Where $I_{sm} = I_1 \cos\Phi_1$

There is also some kind of switching losses in the PWM converter, and thus utility must also supply a small fraction overhead for the converter switching losses and capacitor leakage and with addition to the real power of the load. The total peak current given by the source is therefore:

$$I_{sp} = I_{s1} + I_{sm} \qquad (14)$$

If the active filter provides the total harmonic and reactive power, then $i_{s(t)}$ would be similar in phase with the utility voltage and purely sinusoidal. At this moment, the active filter should provide the compensation current:

$$i_c(t) = i_L(t) - i_s(t) \qquad (15)$$

Hence, for instantaneous and accurate compensation of reactive and harmonic power it is important to estimate, the fundamental part of the load current will be the reference current. The power circuit design includes three main parameters: L_c, V_{dcref} and C_{dc}.

A. *Selection of L_c, V_{dcref} and C_{dc}*

The design of these components is based on the following assumptions:

- The source voltage of AC side is sinusoidal.
- For design of L_c, the AC side line current distortion is assumed to be 5%.
- Fixed compensation of reactive power of the active filter applied.
- The pwm converter is assumed to operate in the linear modulation (i.e. $0 \le ma \le 1$) mode.

According to the compensation principle, the filter adjusts the current i_{c1} to compensate the reactive power of load side. If the active filter compensates all the fundamental power (reactive) of the load, i_{s1} should be in phase and i_{c1} should be perpendicular to V_S. The three-phase reactive power delivered from the filter can be given from a vector diagram:

i. e. the active filter can compensate the reactive power from the load only when the situation $V_{c1} > V_S$. If the PWM converter is assumed to operate in the linear modulation (i.e. $0 \le m_a \le 1$) mode, the modulation factor amplitude ma is:

$$m_a = v_m/(V_{dc}/2)$$

Where $m_a = 1$, $v_m = \sqrt{2}\, V_c$ and hence $V_{dc} = 2\sqrt{2}\, V_{c1}$

Filter inductor (L_c) is applied to filter the ripples of the converter current, and hence the design of inductor is based on the harmonic current principle of reduction. The ripple current of the PWM converter can be given as the maximum voltage(harmonic) occurs at the frequency $m_f\omega$:

$$I_{ch\,(mfw)} = \frac{Vch(mfw)}{mf\,\omega Lc} \qquad (17)$$

By solving (16) and (17) simultaneously, the value of L_C, and V_{C1} can be calculated. V_{c1}, and hence V_{dcref}, must be set according to the capacity requirement of the system (i.e. $V_S \le V_{C1} \le 2V_S$). As the switching frequency is not fixed with the hysteresis controller a practically value of 10 kHz assumed. The design of the DC side capacitor is based on the law of instantaneous power flow. The choosing of C_{DC} can be governed by reducing the voltage ripple [2]. According the specification of the peak to peak voltage ripple ($V_{dc}p\text{-}p(max)$) and rated filter current ($I_{c1},rated$), the DC side capacitor C_{dc} can be

$$C_{dc} = \frac{\pi \times Ic1,rated}{\sqrt{3}\,\omega Vdc,p-p(max)} \qquad (18)$$

V. PWM TECHNIQUE TOPOLOGY

The performance of a Shunt Active PF is affected by the selection of certain current control techniques. To compensate distorted current drawn by these no-linear loads, the Filter must have the ability to track sudden slope variations into current reference given to very high di/dt which makes the design of the control and the practical implementation of filter very critical. Hence the choice and implementation of the current regulator is more important for the achievement of satisfactory performance level. One of these techniques is current hysteresis control. The basic principle of these methods that the switching signals are derived from the comparison of the reference signal with the inverter output currents giving a hysteresis band.

Pulse width modulation (PWM) is the most commonly used by today. PWM techniques are given to a VSI consist of chopping the dc bus voltage to produce an ac voltage of the waveform. There are a number of PWM techniques present to attain sinusoidal patterns or any certain pattern. PWM techniques, the output of ac of the filter control as a current or voltage source device. Shows the way PWM works by means of one of the simplest and most commonly used techniques the triangular technique. It obliges the o/p voltage v_a over a switching cycle, defined by the carrier period of V_{car}, to be same to the average amplitude of the wave V_a ref.

VI. PI CONTROL SCHEME

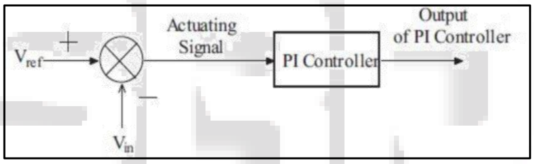

Fig. 4: APF Control Scheme with PI controller

The error signal is given to PI controller. The o/p of PI controller has been considered as peak value of the ref. current. It is further than multiplied by the unit sine vectors which are (u_a, u_b, and u_c) which are in phase with the voltages(source) to obtain the ref. currents (i_{sa}*, i_{sb}*, and i_{sc}*). Such reference currents and existing currents are given to a hysteresis based, carrier less current controller(PWM) to generate switching signals of PWM converter. The difference of ref. current template and actual current decide the operation of switches. These signals after proper isolation and also amplification are than given to the switching devices.

VII. SIMULINK MODEL

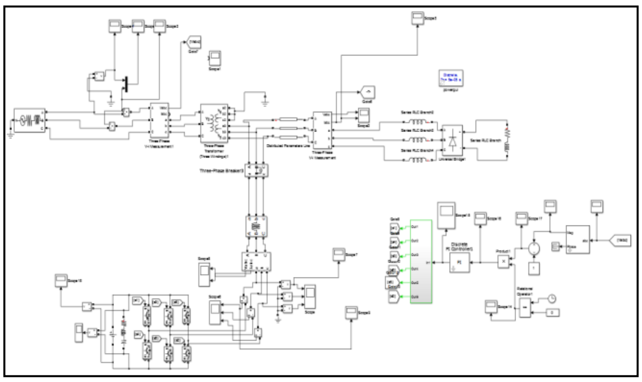

Fig. 5: Simulink Model

A. *Subsystem used for Producing 6 Pulses of Inverter*

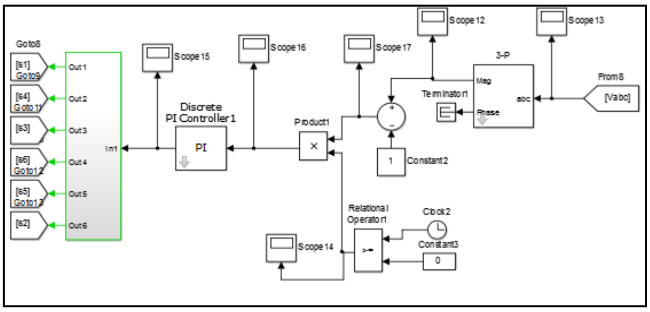

Fig. 6: Subsystem used for Producing 6 Pulses of Inverter

VIII. SIMULATION RESULTS

In this part simulation results of three phase shunt active power filter are shown. The results indicate a well-defined harmonic Spectrum of input current and a significant reduction in the total harmonic distortion (THD) of input current for instantaneous power control in closed loop control strategy. The Simulations are performed using MATLAB. A comparison of results with or without filter is also shown. The main improvement is found in current waveforms.

Phase voltage and frequency V	60 V, 50 Hz
line inductance, resistance	7mH, .8 Ω
Coupling inductance	2mH
For VS Type Load resistance, load capacitance	26.66 Ω, 50µF
For CS Type Load resistance, load inductance	26.66 Ω, 10mH
For CS Single phase b/w c and n	36.66 Ω,10mH
Single phase linear load b/w a and n	60 Ω,10mH
Inverter DC (bus voltage and capacitance	90 V, 3000µF
Controller Parameter	Kp=0.5, Ki=10, Kp=0.8, Ki=12,

Table 1: System Parameters for Simulation Study

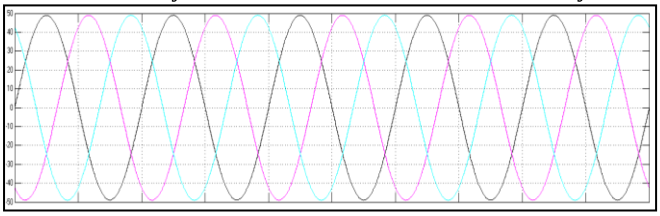
Fig. 7: source voltage waveform of the system

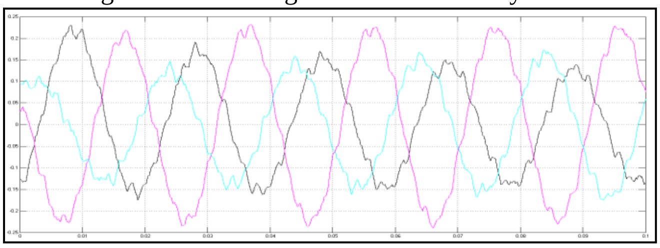
Fig. 8: Source Current Waveform of the system

The compensator is switched ON at t=0.5s and the integral time square error (ITSE) performance index is used for optimizing the and coefficients of the PI controller. The optimum values (K_p and K_i) are found to be 0.8 and 12, respectively, which corresponds to the minimum value of ITSE. The source currents for PI controllers are shown in Figs.8, respectively. Compensating currents of PI controllers are shown in figures 9. The DC side capacitor voltage during switch on response is shown in figures 10 of PI and controllers.

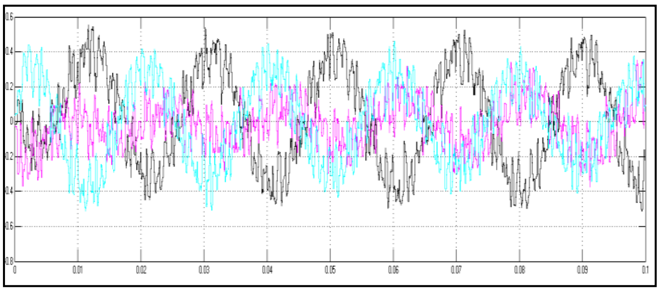
Fig. 9: Compensating current of PI controller

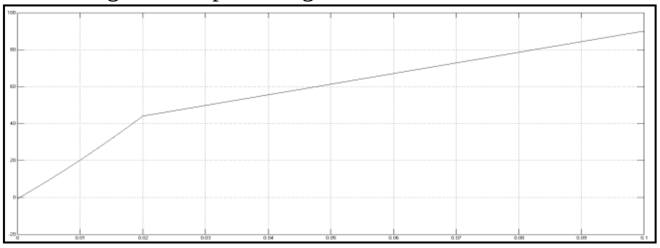
Fig. 10: DC Capacitor Voltage During Switch-on Response with PI Controller

From the wave forms it is clear that harmonic distortion is reduced after connecting compensator. The system parameters selected for simulation study are given in table 1. Figures 11-14 shows the simulation results of the implemented system with PI controller. The source voltage waveform of the reference phase only is shown in figure 4. A diode rectifier with R-L load is taken as non-linear load. The THD of the load current is 42.84%. The optimum values (Kp and Ki) are found to be 0.5 and 10 respectively.

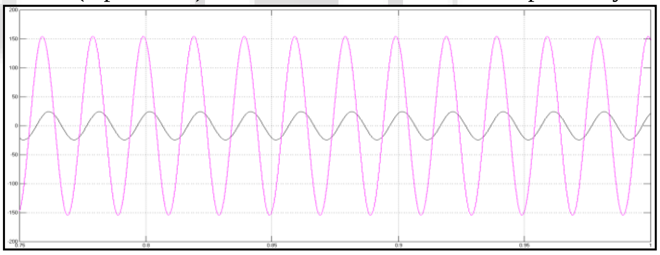
Fig. 11: Voltage and Current are in Phase Using PI Controller

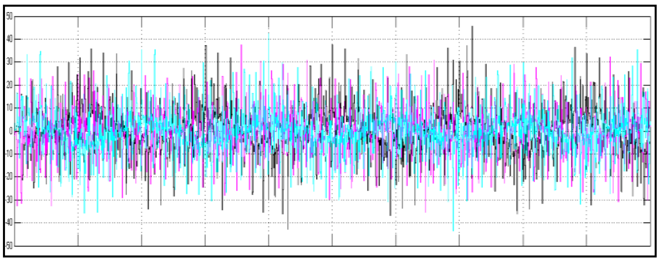
Fig. 12: Inverter Currents using PI Controller

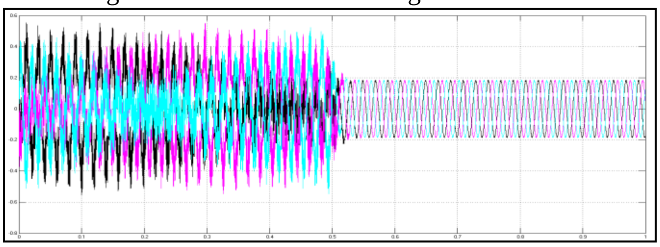
Fig. 13: source current waveform after sapf connected

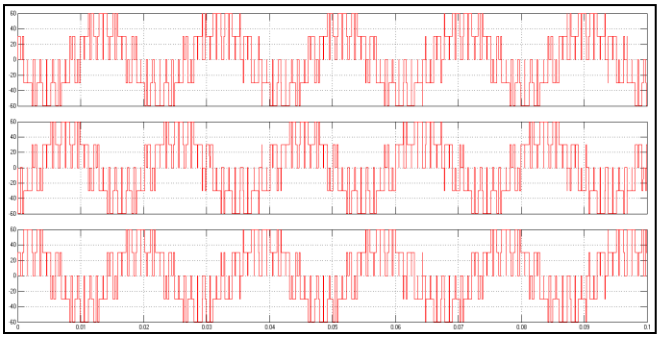

Fig. 14: Three phase Voltage Generated by APF

The settling time required by the PI controller is approximately 8 cycles. The source current THD is reduced near to 2.02% with PI compensation which is below IEEE standard with both the controllers.

IX. CONCLUSION

In this paper the comparative analysis is done for three phase distribution network feeding from SAPF After analyzing the performance of both the system we are come to the conclusion that the distribution network with SAPF have less amount of harmonic distortion in source current. Thus the performance of system is improved and THD is reduced up to large extent and are in the permissible limit of IEEE standard. PI controller based SAPF simulated in MATLAB are implemented for harmonic and reactive power compensation of the non-linear load at PCC. It is found from the simulation results that shunt active power filter improves power quality of the distribution system by eliminating harmonics and reactive power compensation of non-linear load. It is found from simulation results that shunt active power filter improves power quality of the power system by eliminating harmonics and reactive current of the load current, which makes the load current sinusoidal and in phase with the source voltage. The THD of the source current is below 5% according to simulation result and it is in permissible limit of IEEE standard.

SYSTEM	THD (%)
Without filter	42.84
With six pulse SAPF	2.02

Table 2: Comparative THD results

A. Future Work

Power systems are evolved from remote generators feed their loads to enormous interconnected systems which are spread across many the country. Interconnected systems are more reliable systems, since in case of disruption in different parts like one part of the system, power can flow from alternate paths & thus can maintain continuity of the system. Though, harmonic distortions which are introduced by the nonlinear loads will propagate throughout. These issue may be solved by installing certain types of filters of suitably designed ratings at best possible locations in the interconnected power system. The optimal allocation & rating of these shunt active filters can be determined with help of evolutionary algorithms.

Sustainable expansion in the power system it is necessary to make use of the renewable energy resources like Wind, Biomass, Hydal power, Co-generation, etc. The addition of renewable energy into the obtainable power system also generates and affects power quality gives such as sudden voltage transients, instability, etc. Induction generator is useful as wind power generator; it requires reactive power for magnetization. When the generated active power generated by APF of an induction generator is varied due to wind velocity, the absorbed reactive powers & terminal voltages of an induction generator are hugely affected. A proper controlled scheme in wind energy generation system is necessary under the normal operating condition to let allow the correct control over the active power production. Generally Shunt Active Hybrid Filters are suggested for better improving of power quality issues, when generation rapidly changes with wind velocity.

REFERENCE

[1] Pradeep Anjana, Vikas Gupta, Harpal Tiwari "Reducing Harmonics in Micro Grid Distribution System Using APF with PI Controller" published in T&D Conference and Exposition, 2014 IEEE PES DOI: 10.1109/TDC.2014.6863500
[2] C.-S. Lam, M.-C. Wong Y.-D. Han, "Hysteresis current control of hybrid active power filters" Published in IET Power Electronics, doi: 10.1049/iet-pel.2011.0300
[3] S. Orts-Grau, F. J. Gimeno-Sales, A. Abellán-García, S. Seguí- Chilet, and J. C. Alfonso-Gil, "Improved Shunt Active Power Compensator for IEEE Standard 1459 Compliance" IEEETransactions on Power Delivery, Vol. 25, No. 4, October 2010
[4] Akashkumar Chavada, pushprajsinh Thakor2, Bipinkumar Nanecha3, " Simulation And Analysis Of Shunt Active Power Filter" published in International Research Journal of Engineering and Technology (IRJET) Volume: 03 Issue: 05 | May-2016
[5] Mrs.Chhaya S Bandgar , Ms.Shama B Patil "Mitigation of harmonics using shunt active filter" Journal of Electronicsl and Communication Engineering (IOSR-JECE) ISSN: 2278-2834-, ISBN: 2278-8735, PP: 44-54
[6] Reyes S. Herrera and Patricio Salmerón, "Instantaneous Reactive Power Theory: A Comparative Evaluation of DifferentFormulations" IEEE Transactions On Power Delivery, Vol. 22,No. 1, January 2007
[7] Reyes S. Herrera, Patricio Salmerón, and Hyosung Kim,"Instantaneous Reactive Power Theory Applied to Active Power Filter Compensation: Different Approaches, Assessment, and Experimental Results" IEEE Transactions On Industrial Electronics, Vol. 55, No. 1, January 2008
[8] Yunwei Li, D. Mahinda Vilathgamuwa and Poh Chiang Loh, "Microgrid Power Quality Enhancement Using a Three-Phase Four-Wire Grid-Interfacing Compensator" IEEE Transactions On Industry Applications, Vol. 41, No. 6, November/December 2005
[9] A.Elmitwally, SAbdelkader and M.EI-Kateb, "Neural network controlled three-phase four-wire shunt active power filter" IEE Power Generation & transmission Vol. 147, N0.2 March 2000
[10] J. A. Barrado, R. Griñó and H. Valderrama-Blavi, "Power-Quality Improvement of a Stand-Alone Induction Generator Using a STATCOM With Battery Energy Storage System" IEEE Transactions On Power Delivery, Vol. 25, No. 4, October 2010

[11] Rade M. Ciric, Antonio Padilha Feltrin, and Luis F. Ochoa,"Power Flow in Four-Wire Distribution Networks—General Approach" IEEE Transactions On Power Systems , Vol. 18, No. 4,November 2003
[12] P. Salmerón, J. C. Montaño, J. R. Vázquez, J. Prieto, and A. Pérez, "Compensation in Nonsinusoidal, Unbalanced Three-Phase Four- Wire Systems With Active Power-Line Conditioner" IEEE Transactions On Power Delivery, Vol. 19, No. 4, October 2004
[13] Ning-Yi Dai, Man-Chung Wong, and Ying-Duo Han, Seni, "Application of a Three-level NPC Inverter as a Three-Phase Four-Wire Power Quality Compensator by Generalized 3DSVM" IEEE Transactions On Power Electronics, Vol. 21, No. 2, March 2006.