Comparison of Control Strategies for Shunt Active Power Filter in Distribution Systems

M.V.S.Sivakrishna, K.S.S.Prasad Raju

Abstract**:** ***In this paper different control schemes for shunt active power filter were discussed for theharmonic mitigation in distribution systems. Shunt active power filters are connected in distribution systems, to supply excessive real and reactive powers. Shunt Active filter is used for the compensation of harmonics from nonlinear loads by injecting equal and opposing harmonic current which gives sinusoidal wave on supply side. Harmonics on load side can be eliminated by using filters with proper control strategies. These control strategies are used for the estimation of reference currents on supply side. Triggering pulses to the converter will be generated as per the difference between the reference current and the actual current on supply side. Here Instantaneous P-Q Theory, Synchronous reference frame (D-Q) Theory, Synchronous Detection method, Perfect Harmonic Cancellation strategies are applied to the filter for elimination of harmonics. In this case we are using a 3-level Neutral Point Clamped Converter as filter and Diode Bridge rectifier connected load.***

Index Terms**:** ***Shunt Active Power Filter, Harmonic Currents, Instantaneous P-Q Theory, Synchronous Reference Frame (D-Q) Theory, Synchronous Detection Method, Perfect Harmonic Cancellation, 3-level Neutral Point Clamped Converter.***

I. INTRODUCTION

Harmonic distortion is a major power quality issue in power systems. Now a day's distribution power systems are highly using power electronic equipment which results in higher harmonic contents on load side, which also affects supply side current wave forms. Due to this harmonic distortion increases on supply side [3] [11]. We are using different techniques to overcome these distorted waveforms. By using line reactors, passive filters, pulse converters, active filters we can reduce harmonic distortion on supply side [3]. But apart from active filters, all other techniques not giving results up to the requirements.

The line reactors are better for small correction of Total Harmonic Distortion (THD) of supply current. Passive filters will gives better results than line reactor but not sufficient. Pulse converters gives best results than line reactor and passive filter. But this method is also not sufficient to meet the IEEE-519 standard where the THD of 5% only acceptable [3] [12].

So for harmonic mitigation an active filter is the perfect solution. In this case we are using shunt active filter (SAF) for the mitigation of harmonics [3]. Shunt active filters uses fast switching transistors (IGBT). SAFs working is mainly depends on triggering pulses that are given to transistors [3] [11].

Shunt Active Power filters are used for the compensation of harmonics from nonlinear loads by injecting equal and opposing harmonic current which gives sinusoidal wave on supply side. Triggering pulses are generated according to the variations in compensating currents. In order to find compensating currents we have find reference currents on supply side (which are having less harmonic content). The difference between reference and actual currents on supply side will gives compensating currents [3] [11]. The equation for compensating current is shown in eq (1).

$$I_c = I_l - I_r \qquad (1)$$

Ic=Compensating current

I_l=Actual current on supply side

I_r=Reference currents on supply side.

To find reference currents we are using different control strategies [4] [10].

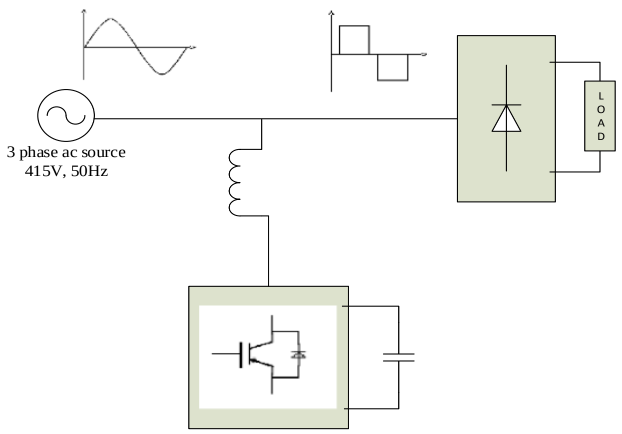

Fig.1 Shunt Active Power Filter

II. CONTROL METHODS FOR SHUNT ACTIVE FILTER

Shunt active filters requires control methods to obtain compensating currents. Here a 3-level NPC converter is used as Voltage Source Inverter (VSI) which acts like a shunt active power filter in this case. This paper discussing four different controlling schemes for shunt active power filters [4] [10].

A. *Instantaneous P-Q theory*

This is one of the famous control Strategy for shunt active filters [1] [2] [5]. In this Case triggering pulses to the

Revised Manuscript Received on June 01, 2019.

M.V.S.Sivakrishna, Department of Electrical and Electronics Engineering, S.R.K.R. Engineering College, Bhimavaram, India.Email:siva444krishna@gmail.com.

K.S.S.Prasad Raju, Department of Electrical and Electronics Engineering S.R.K.R. Engineering College, Bhimavaram, India

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

filter generated according to the real and reactive powers for every instant. Instantaneous P-Q theory uses Clark's transformation in the calculation of real and reactive powers. Here we uses positive sequence voltage detector for the measurement of positive sequence voltages. Equation for Clark's transformation is as shown eq (2), (3).

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (3)$$

In this case V_0, I_0 are equivalent to zero sequence components and are neglected. Since we are considering 3 phase 3 wire system, there was no presence of neutral wire. Zero sequence currents are flows through neutral wire only. Therefore zero sequence components are neglected because of the neutral wire absence and so V_0, I_0 also neglected.

In this method triggering pulses to converter are generated as per the time to time variations in active and reactive powers. So for switching of filter we have to find time to time variations of active and reactive powers. These are calculated from components of voltages and currents. Equations for instantaneous values of active and reactive powers shown in eq (4), (5) [1] [2] [5].

Active power $\quad P_{cal} = V_\alpha . I_\alpha + V_\beta . I_\beta \quad (4)$

Reactive power $\quad Q_{cal} = V_\alpha . I_\beta - V_\beta . I_\alpha \quad (5)$

Here V and I are supply side voltages and load side currents. After finding P_{cal} and Q_{cal} we have to find reference currents (Ir) i.e. Ir_α ,Ir_β . The reference currents equations are shown in eq (6).

$$\begin{bmatrix} I_{r\alpha} \\ I_{r\beta} \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix} \quad (6)$$

Here $\quad p = P_{avg} - P_{cal} + P_{loss}$ (7)

$$q = -Q_{cal} \quad (8)$$

P_{avg}=Average real power(from low paas filter)
P_{loss}=power loss due to variation in V_{dc}.

Such that reference currents in α-β frame are calculated. Then inverse Clark's transformation can be applied to get a, b, c reference currents.

$$\begin{bmatrix} I_{ra} \\ I_{rb} \\ I_{rc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} . \begin{bmatrix} I_{r\alpha} \\ I_{r\beta} \end{bmatrix} \quad (9)$$

It is a well-known and simple method for harmonic mitigation in distribution systems. This method gives THD of the supply current below 5% which is as per IEEE-519 standard. But this method not effective when system supply voltages are distorted and imbalanced.

B. *Synchronous Reference Frame (D-Q) theory*

This method overcomes the drawbacks of instantaneous P-Q theory [4] [6] [8]. In this method triggering pulses to the filter are generated according to the variations in load currents time to time. In Synchronous Reference Frame (SRF) Theory Park's transformation is used. This transformation is a conversion of a-b-c stationary reference frame to d-q-0 rotating reference frame. The equation for park's transformation shown in eq (10).

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(wt) & \sin(wt - \frac{2}{3}pi) & \sin(wt + \frac{2}{3}pi) \\ \cos(wt) & \cos(wt - \frac{2}{3}pi) & \cos(wt + \frac{2}{3}pi) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (10)$$

'wt' value can be obtained from Phase Locked Loop(PLL). Average values of I_d, I_q are determined by passing through low pass filter and variation of V_{dc} gives I_{loss} component, then the reference currents equations are as shown in eq (11) ,(12) [4] [6] [8].

$$I_{rd} = I_d - I_{davg} - I_{loss} \quad (11)$$

$$I_{rq} = I_q - I_{qavg} \quad (12)$$

Then components are converted to a-b-c components by means of Inverse Park's transformation as shown in eq (13).

$$\begin{bmatrix} I_a \\ I_b \\ I_0 \end{bmatrix} = \begin{bmatrix} \cos(wt) & -\sin(wt - \frac{2}{3}pi) & 1 \\ \cos(wt - \frac{2}{3}pi) & -\sin(wt - \frac{2}{3}pi) & 1 \\ \cos(wt + \frac{2}{3}pi) & -\sin(wt + \frac{2}{3}pi) & 1 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} \quad (13)$$

This is also one of the simple method for harmonic mitigation in distribution systems. It also gives THD under 5%, and can improves the transient behavior of the system. But this method is also not completely effective when it is applied to systems with distorted and imbalanced supply voltages [4] [8].

C. *Synchronous Detection Method (SDM)*

This method is similar to instantaneous p-q theory [9] [10]. It is suitable for three-phase, three wire systems only. Synchronous detection method assumed that after compensation three-phase supply currents are balanced. Because of the balanced currents average power will be divided equally between three phases.

In this method we have to find the amplitude of three-phase supply currents.

Calculation of instantaneous power [9] [10]

$$P(t) = \begin{bmatrix} V_a(t) & V_b(t) & V_c(t) \end{bmatrix} \begin{bmatrix} I_a(t) \\ I_b(t) \\ I_c(t) \end{bmatrix} \quad (14)$$

(V(t),I(t) are instantaneous quantities)
P_{dc} is the average power which is acquired by passing P(t)

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

through a low pass filter [9] [10].

$$P_a = P_{dc} \times \frac{V_{sa}}{V_{sa} + V_{sb} + V_{sc}} \quad (15)$$

$$P_b = P_{dc} \times \frac{V_{sa}}{V_{sa} + V_{sb} + V_{sc}} \quad (16)$$

$$P_c = P_{dc} \times \frac{V_{sc}}{V_{sa} + V_{sb} + V_{sc}} \quad (17)$$

(whereVs is the root mean square quantity, V is the peak quantity)

But $P_a = V_{sa} \times I_{sa} = \frac{V_a}{\sqrt{2}} \times \frac{I_a}{\sqrt{2}} = \frac{V_a \times I_a}{2}$ andso

$$I_a = 2 \times \frac{P_a}{V_a} \quad (18)$$

andReference currents are

$$I_{ra}(t) = \frac{2 \times V_a(t) \times P_a}{V_a^2} \quad (19)$$

$$I_{rb}(t) = \frac{2 \times V_b(t) \times P_b}{V_b^2} \quad (20)$$

$$I_{rc}(t) = \frac{2 \times V_c(t) \times P_c}{V_c^2} \quad (21)$$

Even though this technique implementation is easy, it can be easily effected by harmonics in supply voltages and it has slower performance compared to P-Q theory [9] [10].

D. *Perfect Harmonic Cancellation Method (PHC)*

This method is the improved version of previous control strategies [4] [7] [8]. This method objective is the compensation of different harmonic currents in distribution systems. It also supplies fundamental reactive power requirements of load and eliminates imbalance. This method assumes that, after compensation the current on supply side is in phase to positive sequence component of fundamental voltage on supply side [4] [7] [8].

This method also uses Clark's transformation

In this $I_{sref} = K * V_p$ (22)

Where V_p is positive sequence voltage of the supply

Power delivered to load

$$P_s = V * I_{sref} = V * K * V_p = K * (V_\alpha * V_{p\alpha} + V_\beta * V_{p\beta}) \quad (23)$$

K is the constant which is determined with a condition that the source power is equal to the dc component of instantaneous demand of active power by the load [4] [7] [8].

$$P_{l\alpha\beta} = V_\alpha . I_\alpha + V_\beta . I_\beta \quad (24)$$

$$P_{l0} = V_0 . I_0 \quad (25)$$

$$K = \frac{P_{l\alpha\beta} + P_{l0}}{(V_{1p0}^2) + (V_{1p\alpha}^2) + (V_{1p\beta}^2)} \quad (26)$$

$$I_{sref} = K * V_p = \frac{P_{l\alpha\beta} + P_{l0}}{(V_{1p0}^2) + (V_{1p\alpha}^2) + (V_{1p\beta}^2)} \begin{bmatrix} V_{1p0} \\ V_{1p\alpha} \\ V_{1p\beta} \end{bmatrix}$$

(27)

Where V1p=fundamental positive sequence voltage

This method is considering fundamental and constant components of voltage and currents only.

III. SIMULATION RESULTS

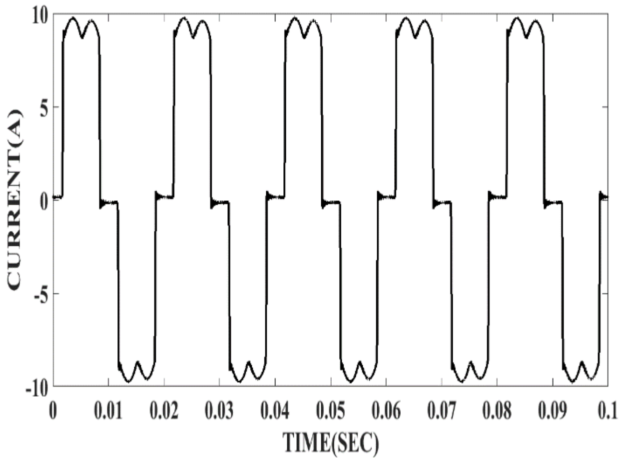

Fig.2Simulation of Current Harmonics due to the presence of Nonlinear Loads

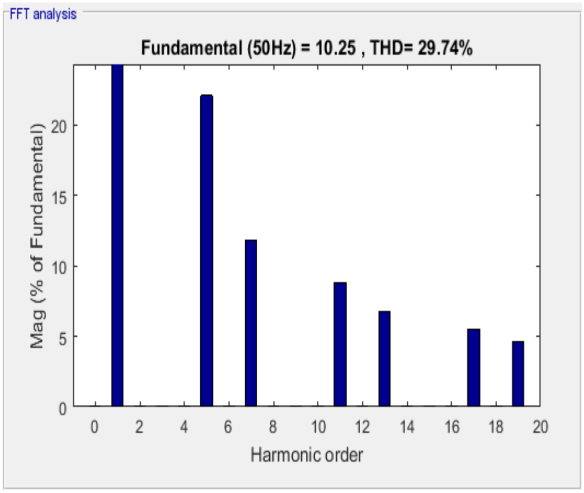

Fig.3 THD Analysis of Current Harmonics due to the presence of Nonlinear Loads

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

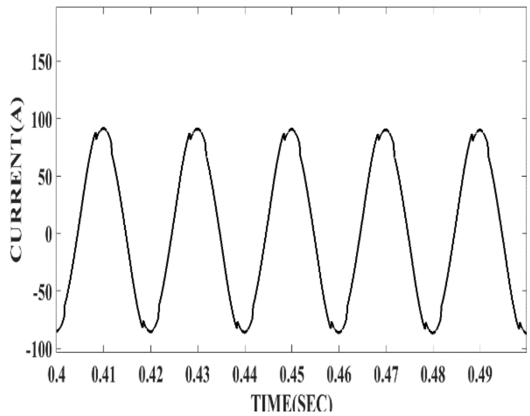

Fig.4 Simulation Result of instantaneous P-Q Theory Based Shunt Active Power Filter

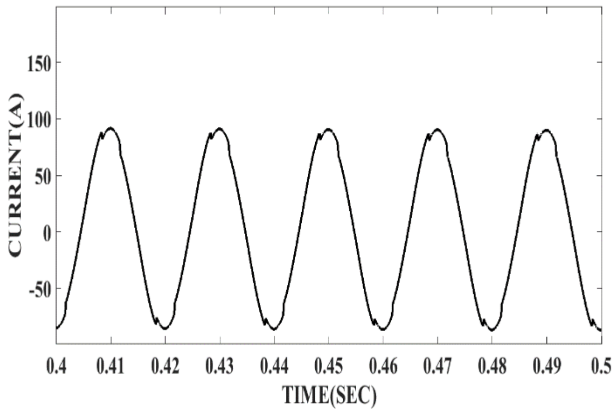

Fig.7 Simulation Result of D-Q Theory Based Shunt Active Power Filter

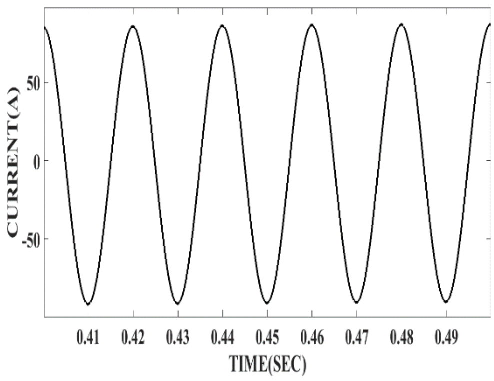

Fig.5 Injected currents in Instantaneous P-Q theory

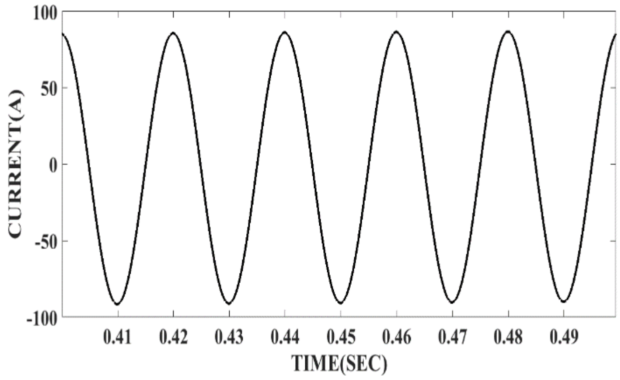

Fig.8 Injected currents in D-Q theory

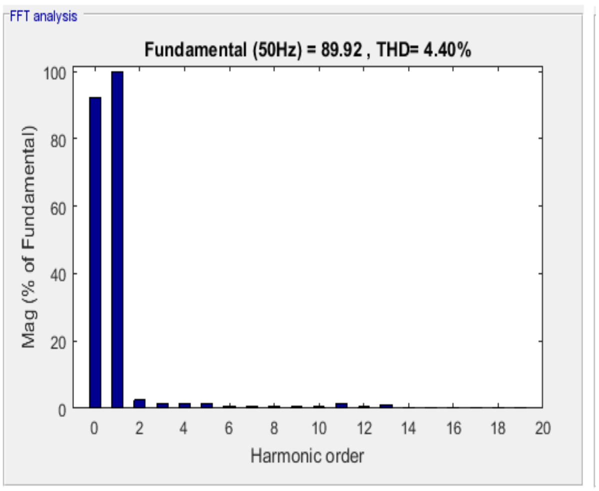

Fig.6 THD analysis of Instantaneous P-Q theory based Shunt Active Power Filter

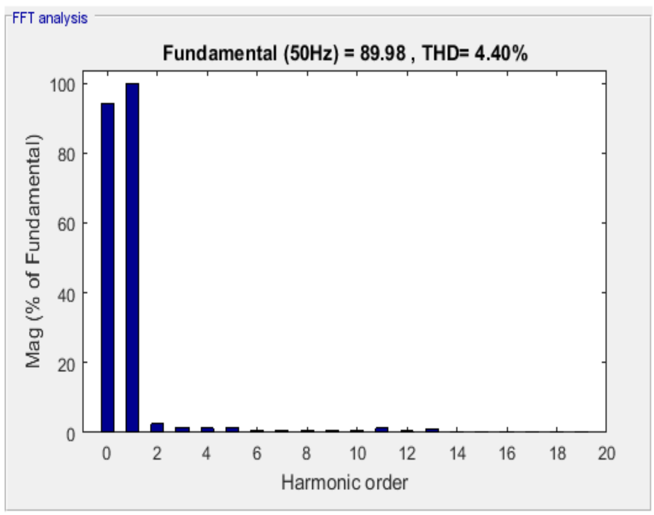

Fig.9 THD Analysis of D-Q Theory Based Shunt Active Power Filter

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

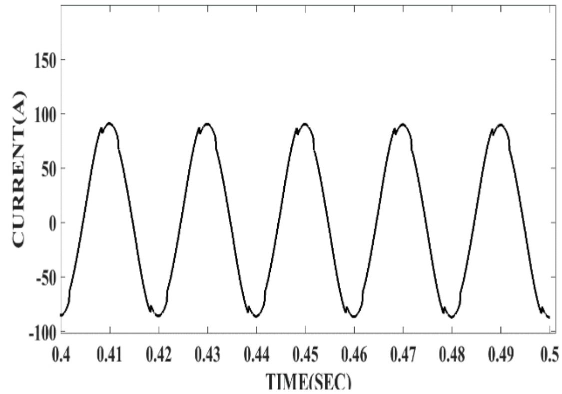

Fig.10 Simulation Result of SDM Based Shunt Active Power Filter

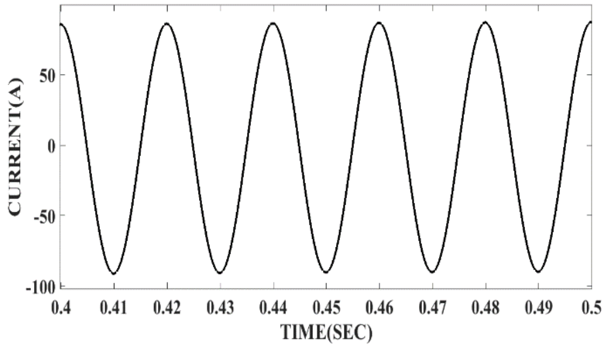

Fig.11 Injected currents in SDM technique

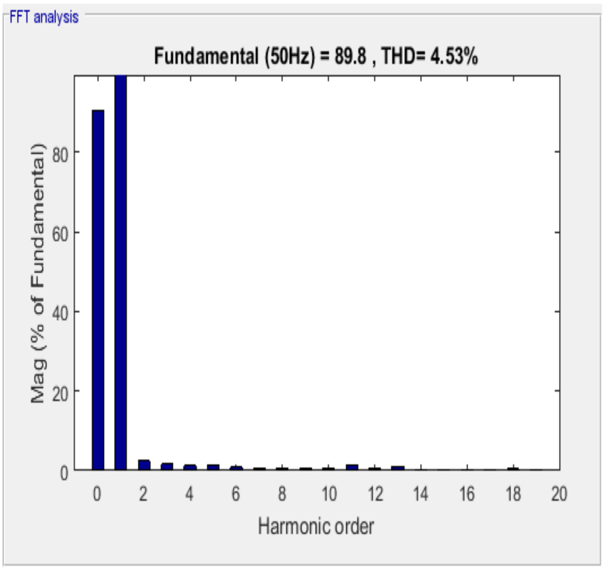

Fig.12 THD Analysis of SDM Based Shunt Active Power Filter

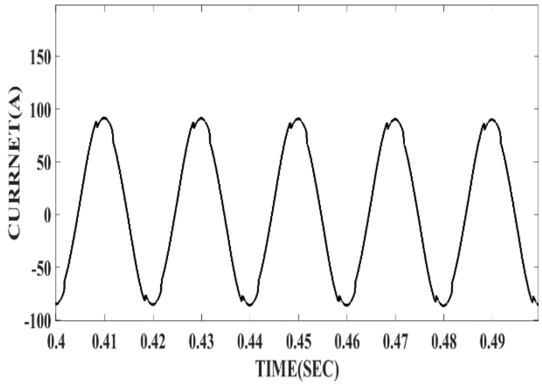

Fig.13 Simulation Result of PHC Based Shunt Active Power Filter

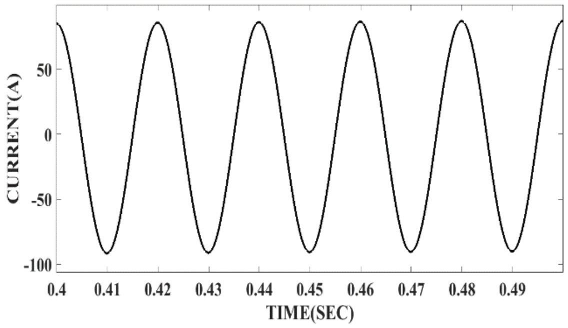

Fig.14 Injected currents in PHC method

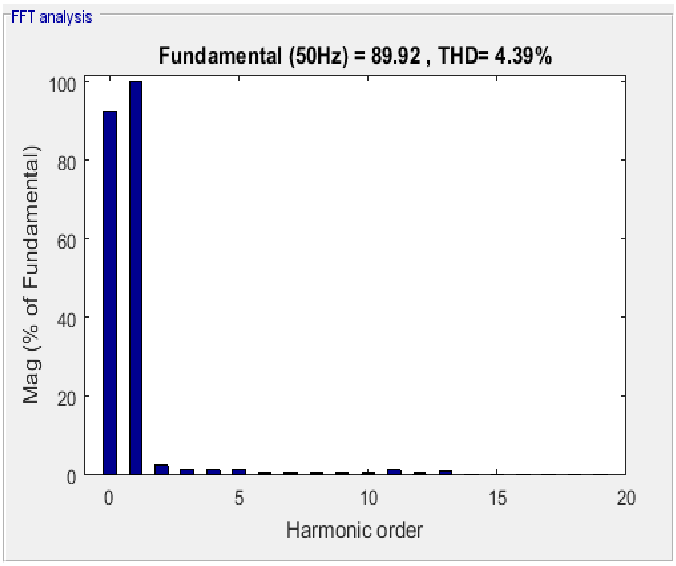

Fig.15 THD Analysis of PHC Based Shunt Active Power Filter

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

IV. SIMULINK PARAMETERS

Control strategies for shunt active filters are performed with Simulink parameters shown in table below [6] and simulation is done by using MATLAB 2016a software.

Table 1: Simulation Parameters

S.No.	PARAMETER	VALUE
1.	Supply	415V,50Hz
2.	Source resistance(Rs)	0.1 Ω
3.	Source inductance(Ls)	0.15mH
4.	Filter inductance(Lf)	12mH
5.	Load(R-L)	20 Ω, 60mH
6.	Capacitor	300V,35uF
7.	PI controller Kp Ki	 0.01 1.5

V. COMPARISON OF CONTROL STRATEGIES RESULTS

By comparison of four control strategies we can observe that instantaneous P-Q theory was best for systems with less variations in supply voltages since they are very sensitive to voltage variations. D-Q theory somewhat better in this phenomenon but not completely effective, and D-Q theory have got poor results when harmonics presents at Point of Common Coupling (PCC) [4] voltages. Synchronous detection method was an old method and this technique is not suitable for latest fast acting systems.

Perfect harmonic cancellation is the only method which gives best results compared to other control methods. This method is also useful in distributed generation systems since it is considering voltages at PCC. The comparison of control methods shown in following table.

Table 2: Comparison of Control Strategies for Shunt Active power Filter

S.No.	Control Strategy Name	Reduction THD (Original Is 29.47%)
1.	Instantaneous P-Q theory	4.40%
2.	Synchronous reference Frame (D-Q) theory	4.40%
3.	Synchronous Detection Method	4.53%
4.	Perfect harmonic cancellation method	4.39%

VI. CONCLUSION

In this paper four control strategies for shunt active filters are applied and verified. Although each control strategy has its advantages, except perfect harmonic cancellation method rest of all are failed in different cases. So as per IEEE -519 standard and for requirements of load in distribution systems Perfect Harmonic Cancellation (PHC) is the only best solution. It also meet power quality problems like fundamental reactive power compensation, imbalances in distribution systems.

REFERENCES

1. V. Soares, Pedro Verdelho, "An Instantaneous Active and Reactive Current Component Method for Active Filters," Vol.15, No.4,July 2000,IEEE Transactions on Power Electronics.
2. H. Akagi, Y. Kanazawa, A. Nabae, "Instantaneous reactive power compensators comprising switching devices without energy storage components", vol. IA-20, no. 3, pp. 625-630, May/Jun. 1984, .IEEE Trans. Ind. Appl.
3. T. Chandra Sekar, B. Justus Rabi, “A Review and Study of Harmonic Mitigation Techniques”, IEEE Conference on Emerging Trends in Electrical Engineering and Energy Management 2012.
4. María Isabel Milanés Montero, Member, IEEE, Enrique Romero Cadaval, Member, IEEE, and FermínBarrero González, Member, IEEE, “Comparison of Control Strategies for Shunt Active Power Filters in Three-Phase Four-Wire Systems”, VOL. 22, NO. 1, JANUARY 2007, IEEE Transactions on Power Electronics,
5. AnandPanchbhai, Shreya Parmar, NikunjPrajapati “Shunt Active Filter for Harmonic And Reactive Power Compensation Using p-q Theory”, IEEE Conference, 2017 International Conference on Power and Embedded Drive Control (ICPEDC)
6. AnandPanchbhaiNikunjPrajapati Shreya ParmarEnggenius Classes GEC, Bharuch SVIT, Vasad Elect. Dept. Elect. Dept. anand.panchbhai1@gmail.com prajapati.nikunj18@gmail.com shreya150496@yahoo.in “Comparative Study of Reference Current Generation for Shunt Active Power Filter,” International Conference on Power and Embedded Drive Control (ICPEDC) 2017.
7. A. Cavallani and G. C. Montarani, “Compensation strategies for shunt active-filter control,” vol. 9, no. 6, pp. 587–593, Nov. 1994.IEEE Trans. Power Electron.
8. JaykumarPrakashchandraTopiwala, 2Prof. Bijal K. Mehta Department of electrical engineering, Sarvajanik College of Engineering and Technology, Surat, Gujarat, India-395001 “Control Strategies for Shunt Active Power Filter for Three-Phase Four-Wire System” International Journal of Innovative and Emerging Research in Engineering
9. M.E. student, Electrical Power System Engineering, G.H.R.C.E.M. Amravati, Maharashtra, India, Assistant Professor, Electrical Engineering Department, G.H.R.C.E.M. Amravati, Maharashtra, India “Harmonic Mitigation using Modified Synchronous Reference Frame Theory”,e-ISSN: 2395-0056 Volume: 04 Issue: 08 | Aug -2017 International Research Journal of Engineering and Technology (IRJET).
10. Md. AshfanoorKabir and UpalMahbub “Synchronous Detection and Digital control of Shunt Active Power Filter in Power Quality Improvement” Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. E-mail: ashfanoorkabir@yahoo.com
11. Daphne Schwanz, Math Bollen “A Review of Solutions for Harmonic Mitigation” Anders Larsson Luleå University of Technology Electric Power Engineering Group Skellefteå, Sweden,IEEE Conference.
12. IEEE standard -519-2014.

AUTHORS PROFILE

M.V.S.Sivakrishna,
M.TECH (Power Systems and Automation) Student, S.R.K.R.Engineering College.
Received B.Tech degree from JNTU Kakinada University.Email:siva444krishna@gmail.com

K.S.S.Prasad Raju, Assistant Professor, S.R.K.R. Engineering College.Received B.Tech and M.Tech degrees from JNTU Hyderabad University. Currently pursuing PhD degree in Andhra University, Area of interests are power converters, power electronics andrenewable energy systems.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication