International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

Modelling of a Hybrid Active Power Filter for Power Quality Improvement using Synchronous Reference Frame Theory

Narendra Babu P [1]*, Bhabani Kumari Choudhury [2], Biswajit Kar [3], Biswajit Halder [4]
Dept. of Electrical Engineering, NIT Meghalaya, Shillong, India, 793003.

***Abstract*— As day to day the power demand increase, the generation also increases, but the generated power output is not a pure one. A lot of harmonics are present in the generated power that can be a voltage harmonics, current harmonics or frequency deviation. Either of these causes instability to the power system. Because of the instability there may be variation of the speed of the motor occurs, may be abrupt surges appears in the output signal in the form of noises which can cause the raise in the temperature, increase in the speed beyond synchronous speed or a large mismatch in the rotor and stator angle which causes the blackout of the system. Due to the presence of harmonics causes many mismatch and problems in the system, this paper presents an innovative way to reduce the harmonics of the signal by which the signal can be directly feed to the grid using Synchronous Reference Frame theory. In this paper describes Proportional Integral and Hysteresis Current Controllers, PI controller are used for feedback mechanism and it is apply to compute switching losses of Active filter inverter, these losses are apply for Active current calculations. A mathematical modelling of a Synchronous Reference Frame (SRF) Compensation theory with proposed controller is explained. Simulation Results is achieved using MATLAB/SIMULINK and the consequences are shown for proposed compensation technique at different load and different filtering conditions.**

Keywords*— Hybrid Active Power Filter; Hysteresis Controller; PI; Power Quality; Power System; Synchronous Reference Frame Theory; Total Harmonic Distortion. Introduction

I. I. INTRODUCTION

The power system agonizes with power quality problems due to manifestation of harmonics due to discontinuous loads. The presence of harmonics reduces life extent and enactment of the equipment connected to the power system. This harmonics causes voltage spikes, weakening, alteration and interference in the wave shape of the power transferring through the transmission lines [1]. The striving of harmonics is more in case of renewable energy generation and HVDC stations, which comprises with the power converters. The power quality is enhanced prominently by using filters [2]. Mainly there are three types filters are existed, they are passive filters (PF), active filters (APF) and hybrid filters (HF) [3]. Fig 1 shows the HAPF position in Transmission system network.

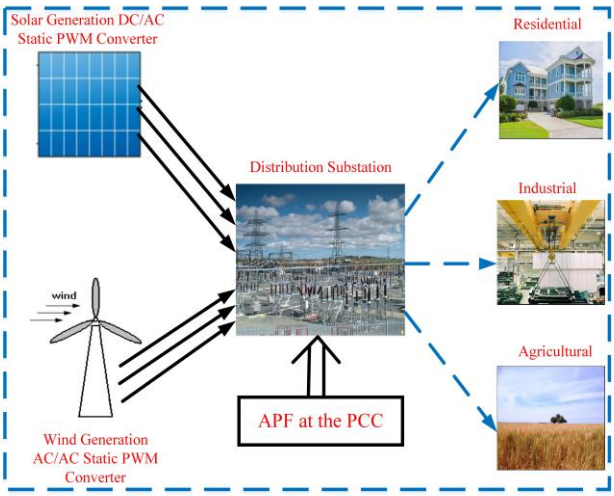

Fig. 1: HAPF Position in Transmission system network

The passive filters entails with the passive elements like resistor, inductor and capacitor to abolish harmonics. Thus, the scheming as well as regulatory of passive filters is simple and cost is also reduced noticeably. The passive filters aches with the difficulty of parallel resonance, bulky and fixed tuning. This difficulties are overwhelmed by the use of active filters. The active filters are more prominent to remove higher order harmonics. Shunt filters and series filters comes under the active power filter classification [4, 5]. The APF is fixed in parallel with the system and is capable of handling the harmonics commendably but it is more costly compared to series active power filters. The Series active power filters fixed in series to eliminate the harmonics by generating the voltages from the power source to filter out the voltages harmonics. To get the welfare's of both passive filters and active filters the hybrid active power filters are designed [6]. The voltage rating of the HAPFs is less comparatively with the active filters, Thus the cost and size of HAPFs are reduced. It also offers superior performance in flattening the harmonic voltages. The controlling and operating of HAPF is thought-provoking task when it's used in case of power converters [7-12].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

There are different linear and non-linear techniques for controlling the power converters with HAPF [8]. Mostly used linear controllers are PI controller, PR controller and dead-beat current controller. Among the non- linear controllers hysteresis controller gives healthier outcomes [6, 7]. The hysteresis current controller supplies gate pulses to power converters corresponding with load current with less THD [6-9]. The MATLAB/SIMULINK results with hysteresis controller are given in this paper.

A. SYSTEM DESCRIPTION

The system mainly consisting an Passive Filter, Active Filter, Three Phase Voltage Source Inverter (VSI), PI, Hysteresis Current Controllers, and linear and discontinuous loads and suggested control algorithm theory. The Compensation theory is working on Park's Transformation matrix. Hysteresis controller gives healthier outcomes. The hysteresis current controller supplies gate pulses to power converters corresponding with load current with less THD. The MATLAB/SIMULINK results with hysteresis controller are given in this paper. And Simulation Results achieved using MATLAB/SIMULINK and the results are shown for suggested compensation technique at different load and different filtering conditions. The Whole structure of HAPF system and its equivalent diagram is display in Figure 2.

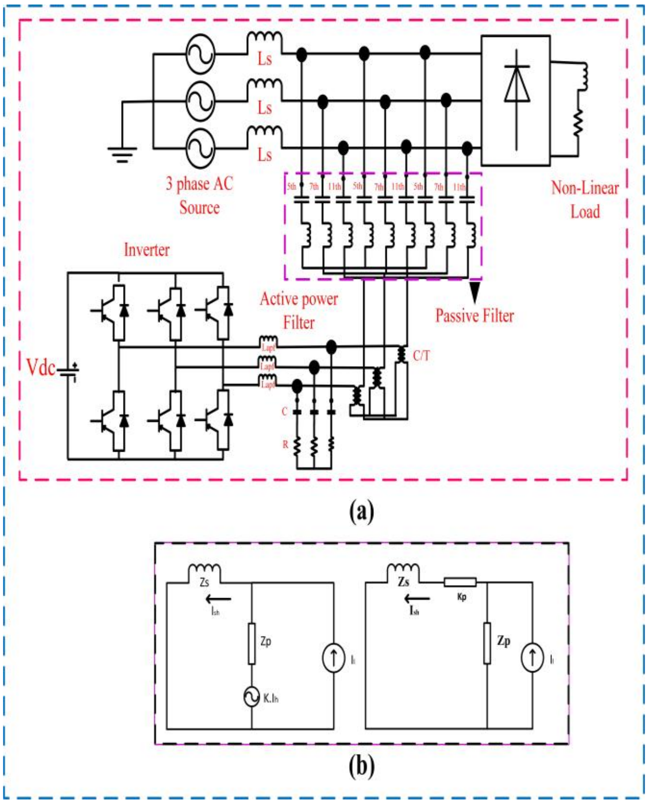

Fig. 2: Block diagram and Single Phase equivalent diagram of HAPF

II. COMPENSATION TECHNIQUE

B. A. SRF Compensation Theory

In Synchronous Reference Frame Compensation theory, discontinuous load currents are converted to dq0 coordinates using Park's transformation. Using Source Voltages calculate the Sine angle and cosine angle using

Phase Locked Loop (PLL), i.e. used for the calculation of SRF Theory, in order to separate the harmonic contents from the fundamentals. Figure 3 displays the dq frame voltage and current space vectors [9].

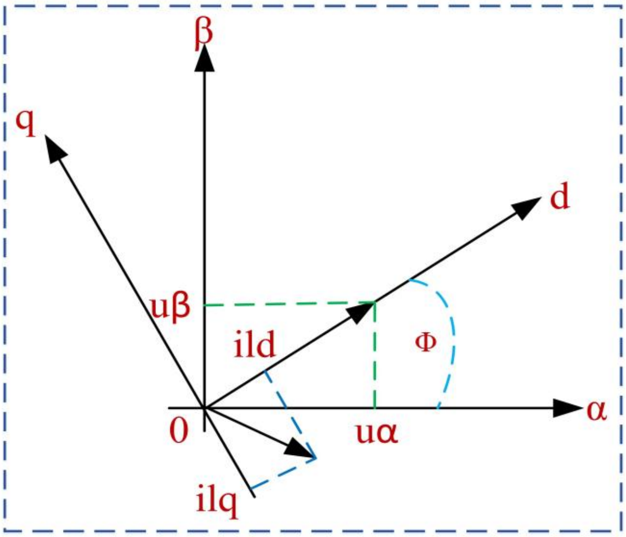

Fig. 3: dq frame Current and Voltage Vector diagram

$$\begin{bmatrix} i_{ld} \\ i_{lq} \\ i_{lo} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} cos\theta & cos(\theta - \frac{2\phi}{3}) & cos(\theta + \frac{2\phi}{3}) \\ -sin\theta & -sin(\theta - \frac{2\phi}{3}) & sin(\theta - \frac{2\phi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (1)$$

In Eq (1), (θ) denotes the angular location of the synchronous reference, this is the fundamental frequency linear function using low pass filter. The reference current harmonics can eliminate from load currents, the synchronous reference currents can be spilt into two equations, and they are shown below

$$i_{ld} = if_{ld} + \bar{i}_{ld}$$

$$i_{lq} = if_{lq} + \bar{i}_{lq}$$

The reference currents having the AC and DC Components, the AC Components having higher order harmonics. The reference currents of APF is Shown as below

$$\begin{bmatrix} i_{fd} \\ i_{fq} \end{bmatrix} = \begin{bmatrix} \widetilde{i_{ld}} \\ \widetilde{i_{lq}} \end{bmatrix} \quad (2)$$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

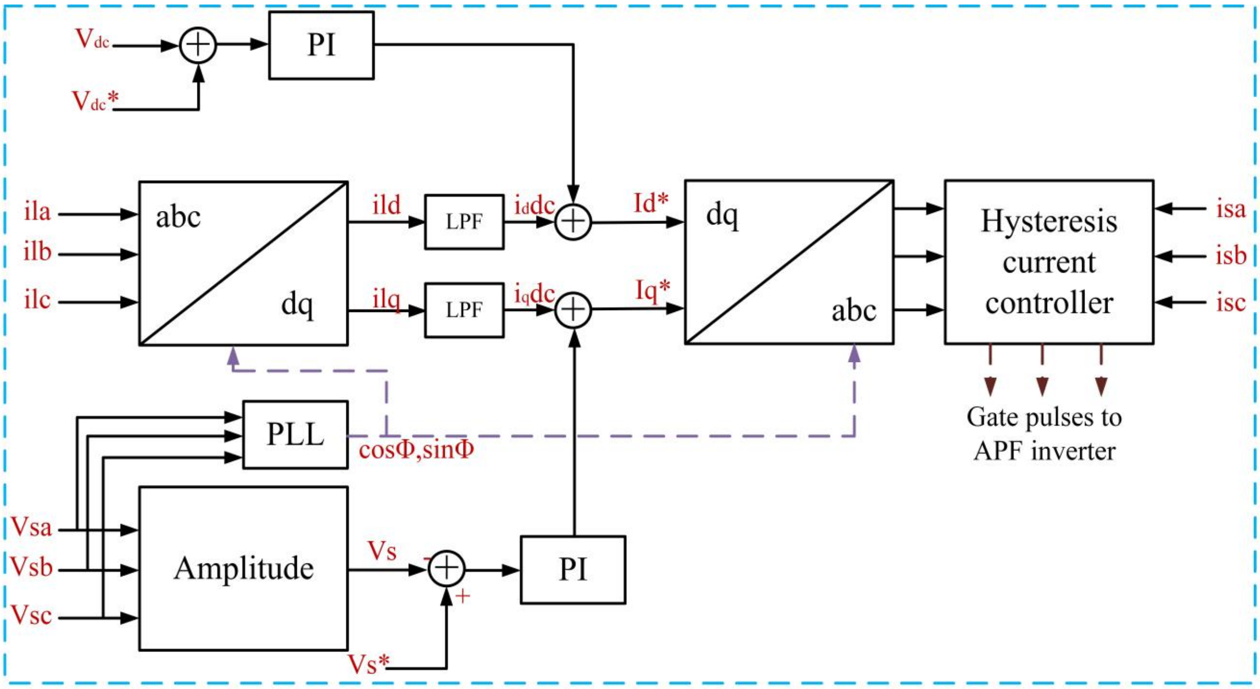

Fig. 4: Control algorithm for SRF theory

Applying inverse Park's transformation matrix calculate the three phase compensation currents, these currents are given to proposed controller input, results controller develop PWM signals. PWM pulses are given to Active Power Filter Inverter, then Inverter develop three phase APF Currents. These Currents are inject to the system. Figure 4 and 5 displays the control circuit for Synchronous Reference frame compensation theory and Flow chart for proposed Compensation theory.

$$\begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} cos\theta & -sin\theta \\ cos(\theta - \frac{2\phi}{3}) & -sin(\theta - \frac{2\phi}{3}) \\ cos(\theta + \frac{2\phi}{3}) & sin(\theta + \frac{2\phi}{3}) \end{bmatrix} \begin{bmatrix} i_{fd} \\ i_{fq} \end{bmatrix} \quad (3)$$

B. Hysteresis Current Control Technique (HCC)

The Current Controllers having direct impact on the system performance operation and it is implemented requires special conditions. The main demand for current controllers are less harmonics, less torque pulsation, less noise and quick response of the system, results high dynamic response of the system [6,7]. In HCC the three phase nonlinear currents (I_{labc}) and three phase compensation currents are within the range of HB (Hysteresis band) by the switching movement of the filter inverter. The upper and lower bands are fixed for the filter currents. In this paper HCC is using to develop the PWM signals to give APF inverter, results inverter develops the Three phase filter currents. Fig 6 and 7 displays the fixed band Hysteresis controller and corresponding hysteresis band [6, 7].

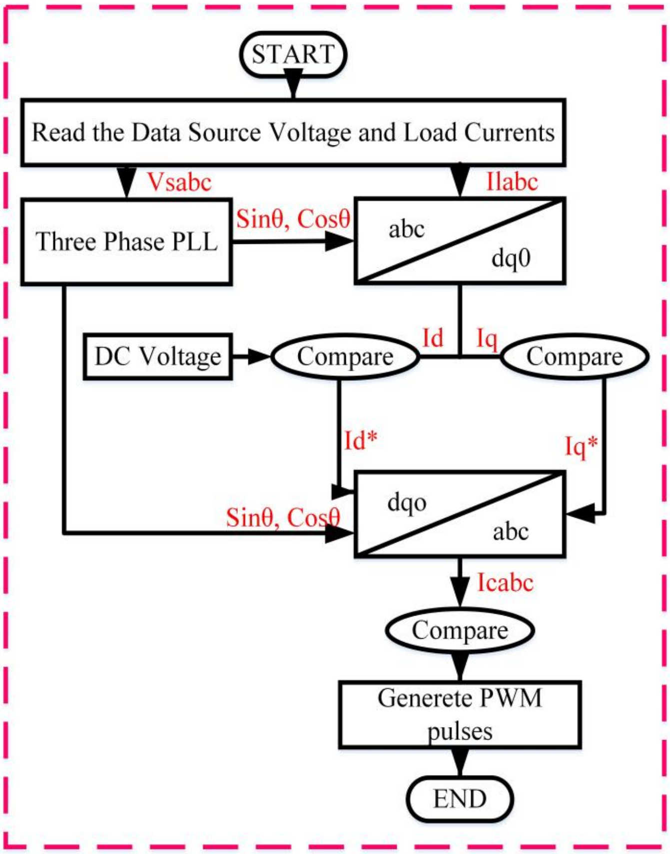

Fig. 5: Flow Chart for SRF Compensation Theory

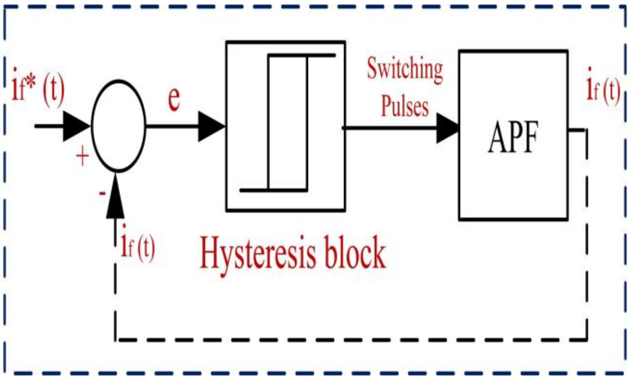

Fig. 6: Fixed band HCC diagram

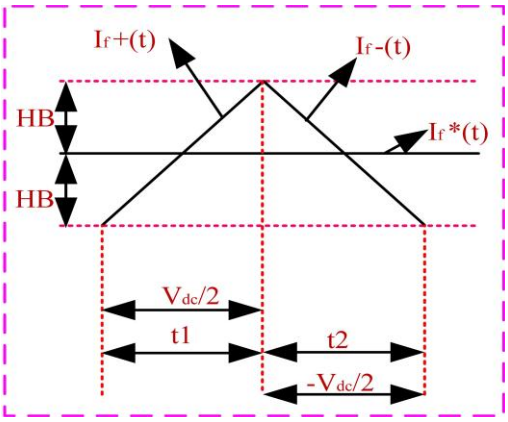

Fig. 7: Corresponding band of HCC diagram

C. PI Control Technique

In Proportional Integral controller (K_p) is utilized to minimize the Instantaneous error and (K_i) is utilize to Minimize the steady state error. As display in Figure (4), Proportional Integral controller is used to develop the Switching losses ($P_{\_loss}$) of the Active Power Filter Inverter [6, 7]. These switching losses are used to calculate the power compensation calculations [6, 7]. The block diagram of PI controller is used in system is displays in Figure (8).

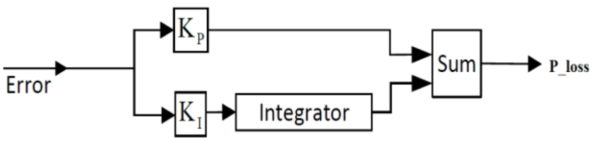

Fig. 8: Internal structure of PI controller

III. RESULTS AND DISCUSSION

The appraise network have been Implemented using MATLAB/SIMULINK with the given variables are display in Table II. Unique filtering schemes with balanced and un-balanced systems systems are examined to decide the potency of the filter. The system is examine with a passive filter, HAPF, and HAPF with increase unbalanced resistive load. The THD analysis under various filtering conditions with balanced and unbalanced systems is accomplished and the output results are listed. From 0 to 0.2s the network is operating a non-linear load without any filtering technique, from 0.2 to 0.5s the network is operating with PF, from 0.5 to 0.75s the network is operated with HAPF and from 0.75 to 1s the network is added with unbalanced resistive load for balanced and unbalanced systems with different filtering conditions. Fig 9 and 10 shows the three phase source and load currents under balanced system with different filtering conditions. Fig 11 shows the three phase APF currents. Fig 12 shows the THD analysis for balanced system's source current for balanced system using synchronous reference frame theory. Fig 13 and 14 displays the three phase source and load currents under unbalanced system with different filtering conditions. Fig 15 displays the three phase APF currents. Fig 16 displays the THD analysis for source current for unbalanced system using synchronous reference frame Compensation theory.

The present network when operated to discontinuous load without filter has a Total Harmonic Distortion pleased of 25.82(%) which can be perceived from Table III, and total harmonic distortion is reduced using Hybrid active power filter for balanced system to 1.19(%). Overall THD content in balanced systems with different filtering conditions is displayed in Table IV. For Three phase Unbalanced system network when operated to non-linear load without filtering has a Total Harmonic Distortion pleased of 34.26(%), 49.91(%), 43.33(%) which can be perceived from Table V, and total harmonic distortion is reduced using Hybrid active power filter for balanced system to 1.72(%), 2.02(%), 1.48(%). Overall THD content in unbalanced systems with different filtering conditions is displayed in Table VI.

TABLE I: IEEE 519 standards

Parameter	Systems (general)	Systems (dedicated)
Depth of Notch	20.00 %	50.00 %
Voltage THD	5.00 %	10.00 %
Size of Notch	22800	36500

TABLE II: Specifications of the System

Specifications	Rating
Supply	3 φ AC Supply
Voltage V_{ph}	230 V
Frequency	50 Hz
Source Impedance (Z_s)	3.3 ohm
Filter Inductor (L_{APF})	10.4 mH
Unbalanced Resistive load (R_l)	2, 4, 6 ohms
Capacitance (C_{dc})	1000 μF
DC Voltage (V_{dc})	600 V

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

TABLE III: THD result under different scenario using SRF theory for Balanced System

Harmonic Order	Without Filter (%)	Passive Filter (%)	HAPF (%)	HAPF + Linear Load (%)
5	8.90	4.96	3.66	1.03
7	4.39	1.87	1.56	0.38
9	3.00	0.01	0.03	0.06
11	3.16	0.96	0.66	0.02

TABLE IV: Total THD content in current for Balanced System

Filter	Total THD (%)
Without Filter	25.82
With Passive Filter	5.46
With HAPF	4.10
With HAPF + Linear Load	1.19

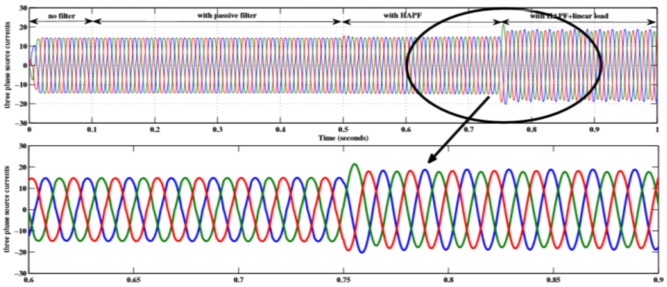

Fig 9: Three phase source current for balanced system

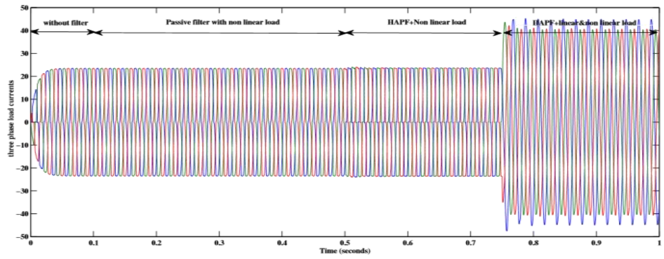

Fig 10: Three phase load current for balanced system

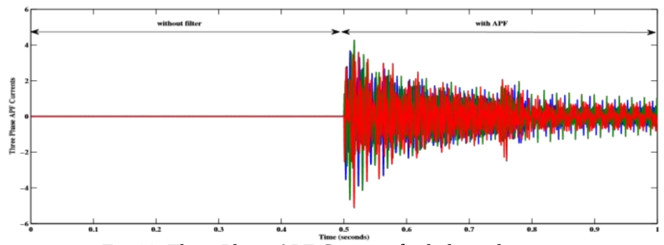

Fig 11: Three Phase APF Currents for balanced system

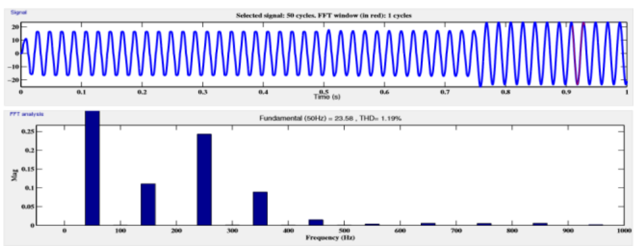

Fig 12: THD Analysis for balanced system

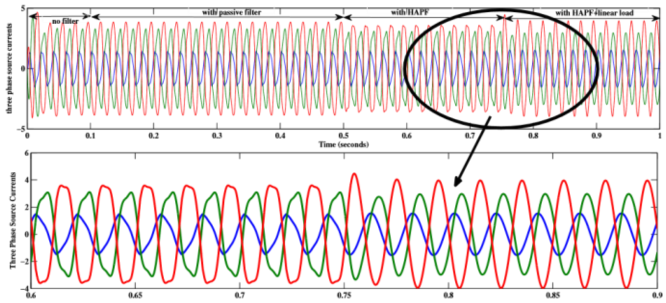

Fig. 13: Three phase source current for unbalanced system

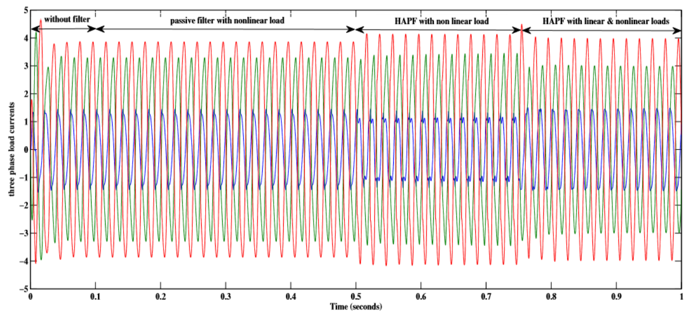

Fig. 14: Three phase Load currents for unbalanced system

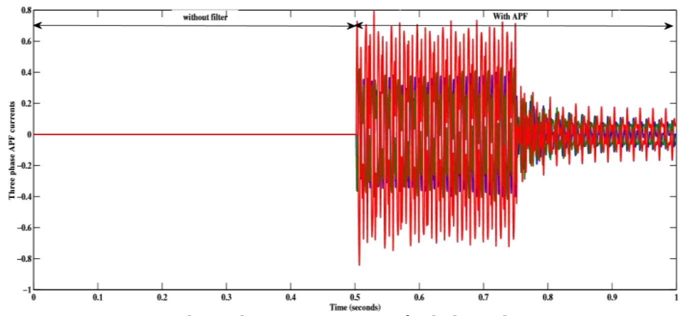

Fig. 15: Three phase APF currents for balanced system

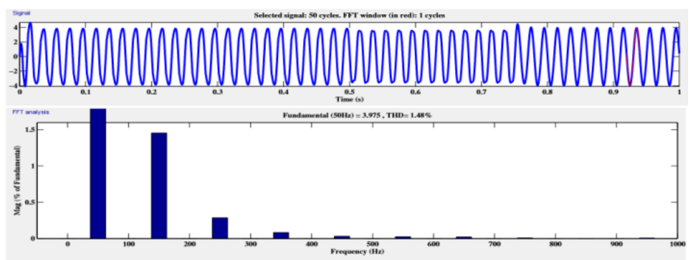

Fig. 16: THD analysis with HAPF and with linear and non-linear load

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

TABLE V: THD result under different scenario using SRF theory for Unbalanced system

Harmonic order	Phases	Without filter (%)	With PF	With HAPF (%)	HAPF + increase load (%)
5	A	5.24	2.32	2.75	0.43
	B	1.96	1.67	1.9	0.26
	C	0.76	0.59	0.66	0.28
7	A	7.12	1.52	3.62	0.12
	B	2.62	0.86	1.12	0.13
	C	0.67	0.4	0.52	0.08
9	A	1.79	0.96	1.57	0.02
	B	2.06	0.48	0.68	0.05
	C	0.52	0.27	0.38	0.03
11	A	1.88	0.63	0.63	0.04
	B	1.07	0.3	0.44	0.02
	C	0.26	0.11	0.17	0.03

TABLE VI: Total THD results using SRF theory for Unbalanced System

Filters	A (%)	B (%)	C (%)
Without Filter	34.26	49.91	43.88
With PF	9.37	13.81	12.58
With HAPF	8.03	11.19	10.18
With HAPF+ Load	1.72	2.02	1.48

IV. CONCLUSION

Upon considering the unpropitious consequences of harmonics in transmission system network, elimination skills are utilizing HAPF has been underlined in this paper. HAPF is a merge of PF and active power filters is one of the premier technique to reduced higher order harmonics, resulting a clean and non-harmonic power at customer side. Synchronous Reference Frame Compensation theory which generates three phase compensating currents for active power filters is examined in detail. And various controllers skills namely HCC (Hysteresis current control) and Proportional integral controllers are examined and harmonic elimination method is introduced using Synchronous Reference Frame Compensation theory .The network is trail for different linear and non-linear load conditions with different filtering techniques with different balanced and unbalanced systems and the Total Harmonic Distortion analysis is carried out in each scenario. Tabulated Total Harmonic Distortion values designate the potency of a HAPF to reduce the system harmonics and compared to isolated passive and active power filtering techniques.

REFERENCES

[1] F.P.Zeng, G.H.Tan, J.Z.Wang and Y.C.Ji, "Novel single-phase fivelevel voltage-source inverter for the shunt active power filter", IET Power Electronics, vol. 3, iss. 4 pp. 480 - 489, 2010.

[2] Pablo Acuna, Luis Moran, Marco Rivera, Juan Dixon and Jose Rodriguez "Improved Active Power Filter Performance for Renewable Power Generation Systems" IEEE Transactions on Power Electronics, vol. 29, iss. 2 pp. 687 - 694,2014.

[3] Wu Jian, He Na and Xu Dianguo "A 10KV shunt hybrid active filter for a power distribution system" Applied Power Electronics Conference and Exposition, 2008 (APEC 2008) Twenty-Third Annual IEEE pp. 927 - 932, 2008.

[4] Chi Seng Lam, Wai Hei Choi, Man Chung Wong and Ying Duo Han "Adaptive DC-Link Voltage-Controlled Hybrid Active Power Filters for Reactive Power Compensation" IEEE Transactions on Power Electronics, vol. 27, iss. 4 pp. 1758 - 1772, 2012.

[5] Siddharth singh K. Chauhan, Mihir C. Shah, Ram Ratan Tiwari and P. N. Tekwani "Analysis, design and digital implementation of a shunt active power filter with different schemes of reference current generation" IET Power Electronics, vol. 7, iss. 3 pp. 627 639, 2014.

[6] Alamelu Nachiappan, K. Sundararajan and V. Malarselvam "Current controlled voltage source inverter using Hysteresis controller and PI controller" Power, Signals, Controls and Computation (EPSCICON), 2012 International Conference ,pp.1-6, 2012.

[7] Donghua Chen and Shaojun Xie "Review of the control strategies applied to active power filters" Electric Utility Deregulation, Restructuring and Power Technologies, 2004. (DRPT 2004). Proceedings of the 2004 IEEE International Conference, vol.2, pp. 666 - 670 , 2004.

[8] Kanchan Chaturvedi1, Dr. Amita Mahor and Anurag Dhar Dwivedi "Active Power Filter Techniques for Harmonics Suppression in Non Linear Loads" International Journal of Scientific Engineering and Technology, ISSN: 2277-1581 , vol.1, iss. 2 pp. 123127, 2012.

[9] N. Mariun, A. Alam, S. Mahmod and H. Hizam "Review of control strategies for power quality conditioner" Power and Energy Conference, PECON 2004 Proceedings pp: 109-115, 2004.

[10] Sangamesh Bukka, Mohammad Yunus M Hakim, Sanjeev T.M and S. G. Ankalik "Performance Analysis of three phase shunt hybrid active power filter" IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308.

[11] B. Singh, K. Al-Haddad and A. Chandra "A review of active filters for power quality improvement" IEEE Transactions on Industrial Electronics, vol. 46, iss. 5 pp. 960 - 971, 1999 .

[12] Joao Afonso, Mauricio Aredes, Edson Watanabe and Julio Martins "Shunt Active Filter for Power Quality Improvement" International Conference UIE 2000 Electricity for a Sustainable Urban Development, Lisboa, Portugal, pp. 683-691, 2000.