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Performance Analysis of Hysteresis Controller based D-STATCOM as Shunt Active Power Filter for Mitigation of Current Harmonics of Non Linear Load

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Abstract—*In the current era, application of power electronics converters has been increasing rapidly. The power electronics converters have non linear characteristics and considered as non linear loads. It increases the A.C current harmonics and generates non sinusoidal voltage at the point of common coupling (PCC) where other loads are connected to the distribution systems. The existence of current harmonics results in more power loss, interference with communication systems, and failures of protecting devices and equipments in the distribution systems. Hence to overcome these issues, in this paper a simplistic shunt active power filtercontrol strategy (SAPFCS) is designed to mitigate the harmonic current injected by non linear load, in which D-STATCOM is acting as shunt active filter. Again a hysteresis band scheme has been used to generate gate pulses for shunt active power filter (SAPF) because of its faster response. The performance of SAPFC is investigated using MATLAB / Simulink platform.*

Keyword: Non linear load, SAPFCS, D-STATCOM, Hysteresis controller, THD

1. Introduction

The advancement in the advent of power electronics converters has increased the number of power semiconductor switches in the power system on a large scale. These switches have non-linear characteristics and more involvement of these non-linear loads lead to current harmonics in the power distribution network and generation of non-sinusoidal voltage at the PCC. The non-sinusoidal PCC voltage, in the power distribution network, generates numerous issues such as increased power loss, interference with communication lines, failures of protecting devices and equipments. These drawbacks significantly affect the industrial process and commercial activities as to a decrease in the output and also affect the product quality [1, 2]. The exhaustive use of nonlinear loads has increased the demand for harmonics mitigation and reactive power compensation. Again it has been proved by many researchers that the non- linear loads are the root of poor power factor and high total harmonic distortion [3]. The way to mitigate harmonics is the use of power electronic based devices such as Distribution Static Compensators (D-STATCOMs). The DSTATCOMs have numerous control algorithms. Among the various algorithms, the instantaneous power (P-Q) theory based algorithms have been most widely used due to its simplicity [4]. The active power filters are being applied as an efficient method to solve the problem of harmonics distortion [5]. These types of filters are being taken as a suitable technique to smooth voltage and current distortion [6,7]. The active power filter injects compensated current (for shunt active filter) or compensated voltage (for series active filter) into the power supply to mitigate load harmonics. A number of harmonic current detection and mitigation techniques have been used such as synchronous reference frame (SRF) control theory, instantaneous real-reactive power (P-Q) theory, modified instantaneous real-reactive power (P-Q) theory, flux-based algorithm, notch filter, and neural network [8–11]. The instantaneous real-reactive power (P-Q) theory has excellent transient response and steady-state response [7], but it is in appropriate for estimating reference current under the condition of non ideal voltage source [7, 12]. Hence, in this paper a D-STATCOM has been designed with non-linear load which is acting as a shunt active power filter. The reference current for the shunt active power filter is obtained by sensing source voltage, source current and non-linear load current by using a novel P-Q theory. Hysteresis based scheme is used to generate gate pulses for the shunt active power filter.

2. Principle of D-STATCOM as A Shunt Active Filter for Non Linear Load

The STATCOM (Static synchronous compensator) is a 3-phase shunt connected power electronics device that works as moderator to regulate the demand and supply of reactive power in the system [13].When it is used in low voltage distribution system, the STATCOM is categorized as D-STATCOM. It is a bi-directional device and is connected near the load end of the distribution system. The major components of a DSTATCOM include a DC capacitor, a 3-phase inverter, an AC filter and a control strategy. The operating principle of shunt active power filter is that it injects the harmonic current to the supply in a direction that oppose the flow of non-linear load harmonic current as such to nullify its impact and produce resultant current that is free from harmonics. It is implemented by connecting a capacitor to the converter of DSTATCOM such that it will act as a supply source and switched at high frequency to generate harmonic current. Structure of D-STATCOM as a shunt active power filter is depicted in Fig. 1.

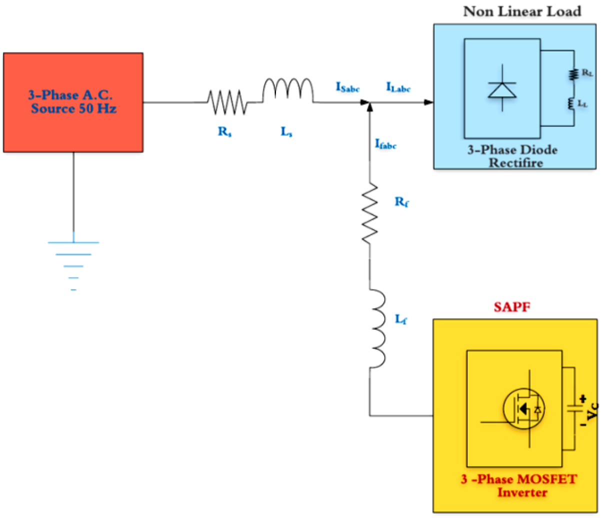

Fig. 1 Structure of D-STATCOM as Shunt active power filter (SAPF)

As depicted in Fig. 1, D-STATCOM is connected to the source and non-linear load at the point of common coupling (PCC). Here the D-STATCOM is a Pulse width modulated voltage source MOSFET inverter supplied by a D.C capacitor voltage V_c. Let, I_{sabc} = phase current of the 3-phase source, IL_{abc} = phase current of the 3-phase non-linear load and I_{fabc} = 3-phase shunt active filter current then the source current can be expressed as

$$I_{sabc} = IL_{abc} - I_{fabc} \qquad (1)$$

The performance of shunt active power filter depends primarily on the process used to recognize and extract the reference current and also on the inverter control approach [10, 14]. The current harmonics from shunt active power filter which will repress load current harmonics is obtained by the voltage source inverter in the current controlled mode with an interfacing inductor filter [15].

3. Shunt Active Power Filter Control Strategy (SAPFCS)

The block diagram for the shunt active power filter control strategy (SAPFCS) is depicted in Fig. 2. The block diagram has the following components

1. A 3-phase A.C voltage source
2. Calculation of instantaneous power (P_{sint})
3. Calculation of I^*_{fabc}.
4. Hysteresis current controller
5. D-STATCOM as shunt active power filter.
6. Non-linear load (3-phase diode rectifier with R-L load)

A.C voltage source:

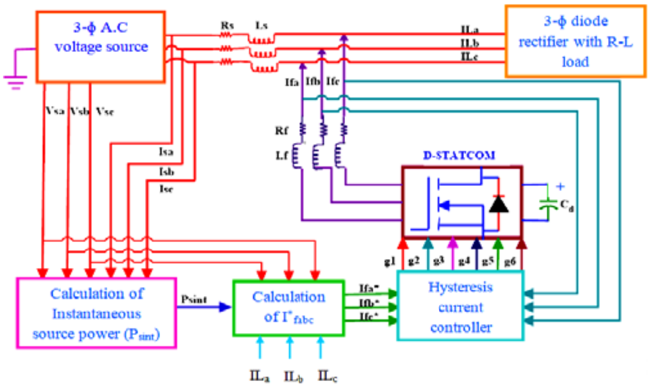

Fig. 2: Block diagram for control strategy 1

The first block of SAPFCS is 3-phase A.C voltage source. It is not ideal, it has internal impedance. If source resistance is Rs and source inductance is Ls then internal impedance

$$Zs = Rs + j\omega Ls \qquad (1)$$

Where ω=angular frequency of supply in radian/second
The instantaneous voltages of 3-phase A.C source is expressed by the following relationships

$$V_{sa} = V_m \sin \omega t \qquad (2)$$

$$V_{sc} = V_m \sin(\omega t - 120^0) \qquad (3)$$

$$V_{sc} = V_m \sin(\omega t - 240^0) \qquad (4)$$

Calculation of instantaneous power:

The instantaneous power supplied by the source (P_{sint}) can be expressed as

$$P_{sint} = V_{sa}I_{sa} + V_{sb}I_{sb} + V_{sc}I_{sc} \qquad (5)$$

Where I_{sa}, I_{sb}, I_{sc} represents the instantaneous source currents respectively.

Calculation of I^*_{fabc}:

The instantaneous reference currents or harmonic current of SAPF i.e. I^*_{fabc} is obtained by using the following steps:

1. Calculation of reference source currents I_{sabc*} using equation (5) i.e.

$$\begin{bmatrix} I_{sa}^* \\ I_{sb}^* \\ I_{sc}^* \end{bmatrix} = \frac{P_{sint}}{V_{sa}^2+V_{sb}^2+V_{sc}^2} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \qquad (6)$$

2. Measurement of instantaneous load currents $IL_{abc.}$

3. Calculation of instantaneous reference currents or harmonic currents of SAPF using the relationship

$$I_{fabc}^* = I_{sabc}^* - IL_{abc} \qquad (7)$$

Hysteresis Current Controller:

The hysteresis controller has been used to control the shunt active power filter (SAPF), which is depicted in Fig. 3.

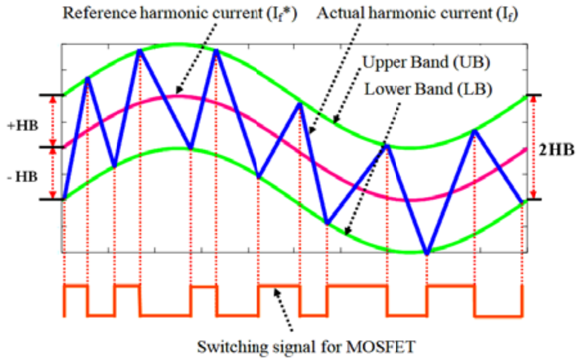

Fig. 3: Diagram of Hysteresis current controller

It has two bands i.e. upper band (UB) & lower band (LB) having a band width of 2HB (-HB to +HB through 0) and it provides switching signals to the switches of MOSFET of SAPF in order to keep the actual injected harmonic current (I_{fabc}) within the hysteresis band width. It generates the reference harmonic currents with the inverter within a range which is fixed by the width of the band gap. In this controller the reference harmonic current (I_{f*}) of a given phase is summed with the negative of the measured current (I_f). The error (e_r) is fed to the comparator having the hysteresis band. When the error (e_r) crosses the lower band (LB), the upper switches of the MOSFET inverter is turned on. But when the current attempts to become less than the upper band (UB), the bottom switches of MOSFET inverter is turned on. The controlling action is represented mathematically as given below:

$$\left.\begin{array}{l} \text{If } e_r \geq +HB \text{ or } (I_f^* - I_f) \geq +HB \text{then} \\ \text{SW}_1 \text{ or SW}_3 \text{ or SW}_5 \text{ off and SW}_4 \text{ or SW}_6 \\ \text{or SW}_2 \text{ on} \\ \\ \text{If } e_r \leq -HB \text{ or } (I_f^* - I_f) \leq -HB \text{then} \\ \text{SW}_1 \text{ or SW}_3 \text{ or SW}_5 \text{ on and SW}_4 \text{ or SW}_6 \\ \text{or SW}_2 \text{ off} \end{array}\right\} \qquad (8)$$

Where (SW_1, SW_3, SW_5) represents the upper switches and (SW_4, SW_6, SW_2) the lower switches of the 3-phase MOSFET inverter as depicted in Fig. 4.

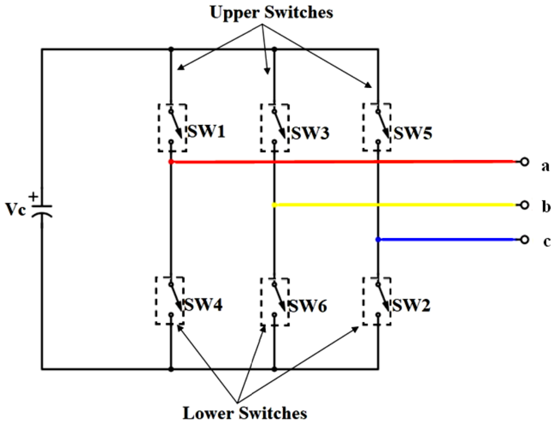

Fig. 4 Configuration of 3-phase MOSFET inverter

Generation of switching signals (g_1, g_2, g_3, g_4, g_5 & g_6) for all the six switches to get 3-phase AC outputs is shown in Fig. 5.

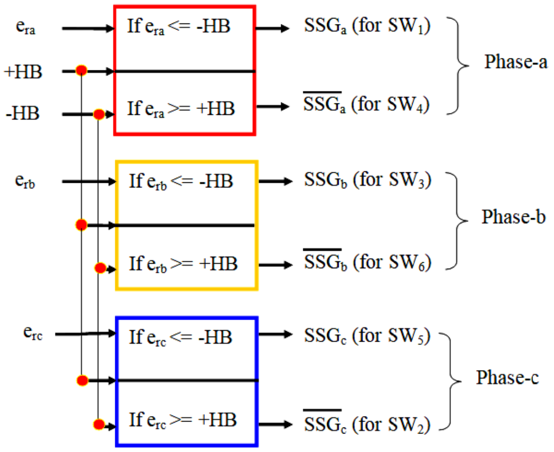

Fig. 5: Generation of switching signals for MOSFET

For phase a, actual harmonic current (I_{fa}) is compared with the reference harmonic current (I_{fa*}) and error signal (e_{ra}) is passed through the hysteresis controller. When e_{ra} <= -HB then SW_1 is turned on and SW_4 is turned off but when e_{ra} >= +HB then SW_4 is turned on and SW_1 is turned off i.e. the controller generates complementary signals for SW_1 & SW_4 represented by SSGa (g_1) and $\overline{\text{SSGa}}$ (g_4) respectively. Procedure is same for other two phases b and c as depicted in Fig. 5.

D-STATCOM as shunt active power filter:

D-STATCOM has a combination of voltage source converter (VSC), coupling inductors and D.C link capacitor. These combination acts as source or sink of reactive power. The

VSC produces a set of three controllable output voltage of frequency magnitude same as A.C power system frequency. This controllable output voltage control the reactive power exchanged between converter and A.C power system. There are three different conditions arrived depending upon the magnitude of source voltage and controllable output voltage.

1. If the amplitude of output voltage increased above the A.C system voltage then current flow through coupling inductor from converter to A.C power system and converter generates reactive power for A.C system. So the converter works as an inverter.

2. If the amplitude of output voltage decreased below the A.C system voltage then current flow through the coupling inductor from A.C power system to converter and converter absorbs reactive power form A.C system. So the converter works as a rectifier.

3. If the amplitude of output voltage is equal to AC system voltage then there is no reactive power exchanged between converter and A.C power system.

The function of shunt active power filter (SAPF) is to inject current harmonics to the P.C.C to mitigate the harmonic distortion of the load current. Hence the D-STATCOM can be used as shunt active powers filter (SAPF) if converter only supplies power to the P.C.C or if converter acts as an inverter. It is possible if the D.C link capacitor acts as a supply source as depicted in Fig. 2. where the D.C link capacitor (C_d) supplying power through MOSFET inverter, coupling inductor (L_f) and coupling resistor (R_f) to the P.C.C.

Non-linear load:

A non-linear load provides non sinusoidal current due to the variation of impedance. This non-sinusoidal current causes harmonic distortion that affects both distribution system equipments and its connected load. In this paper a 3-phase diode bridge rectifier with inductive load has been taken as non-linear load. The parameters of this load are resistance (R_L) and inductance (L_L).

Implementation of SAPFCS:

The implementation of SAPFCS has the following steps:

Step-1: Calculation of instantaneous power of source (Psint) by using expression (5).

Step-2: Calculation of SAPF reference 3-phase currents (I^*_{fabc}) using equation (7) i.e.

$$I^*_{fa} = I^*_{sa} - IL_a$$

$$I^*_{fb} = I^*_{sb} - IL_b$$

$$I^*_{fc} = I^*_{sc} - IL_c$$

Step-3: Generation of switching signals for MOSFET (g_1 - g_6) using the condition given in equation (8)

4. Simulation Results and Discussions

The following simulation results were obtained using the simulation parameters as given in Table-II.

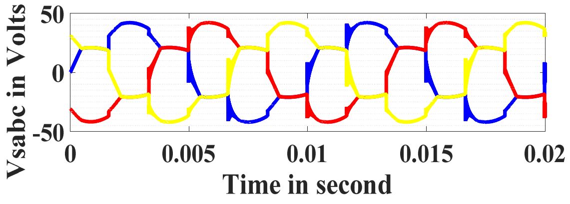

Fig .6 Variation of phase voltages (V_{sabc}) of 3-phase source with Rs, Ls and non linear load w.r.t time

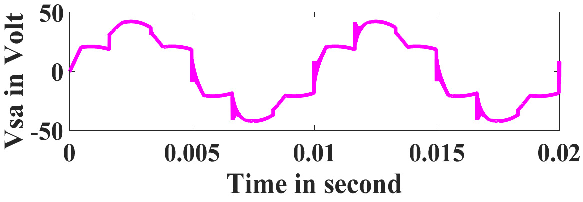

Fig. 7 Variation of phase-a voltage of 3-phase source with Rs, Ls and non linear load w.r.t time

The source voltage waveform is non-sinusoidal and its magnitude is less than actual value, this is due to the presence of non-linear load and source impedance as shown in Fig. 6. Phase-a voltage is shown in Fig. 7.

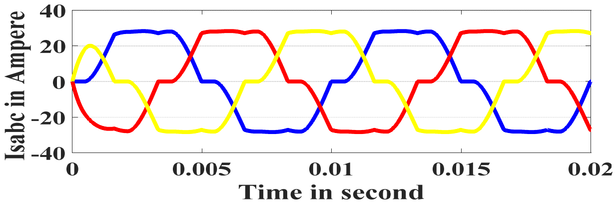

Fig. 8 Variation of source currents (I_{sabc}) of 3-phase source with Rs, Ls and non linear load w.r.t time

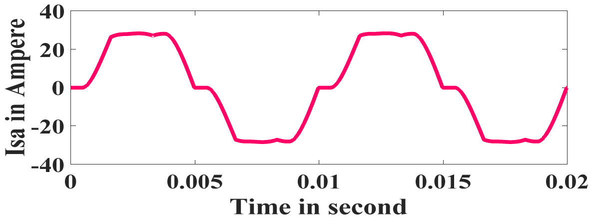

Fig. 9 Variation of phase-a current of 3-phase source with Rs, Ls and non linear load w.r.t time

Fig. 8 and Fig. 9 shows the 3-phase source current and phase-a source current waveforms respectively. The current waveforms are distorted due to the presence of non linearity in the load.

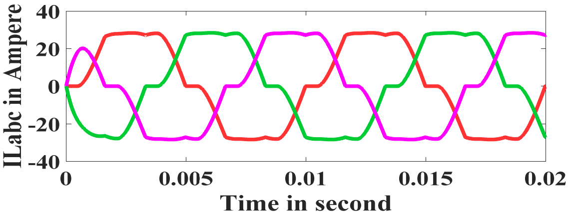

Fig. 10 Variation of load currents (IL_{abc}) of non-linear load w.r.t time without using SAPF (taking into account source Rs & Ls)

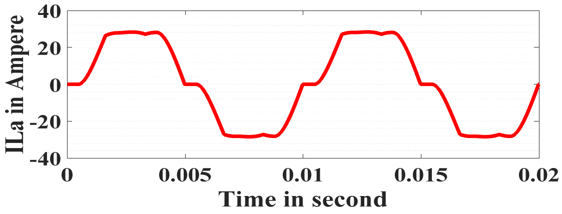

Fig. 11 Variation of phase–a load current (IL_a) of non-linear load w.r.t time without using SAPF (taking into account source Rs & Ls)

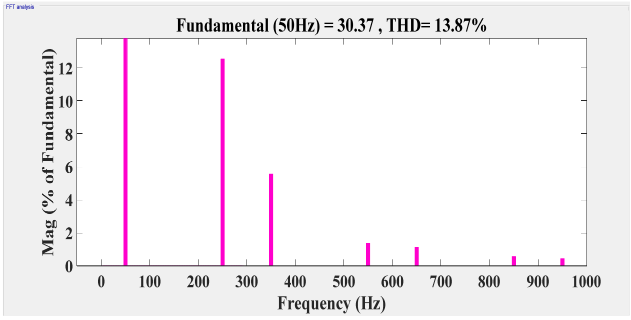

Fig. 12 Harmonic analysis of IL_a without using SAPF

Without SAPF, the nature of input current of load is non sinusoidal because the 3-phase diode rectifier itself injects harmonic in its input as shown in Fig. 10 and Fig. 11 respectively and percentage of THD injected to the input current ILa by the load is 13.87 as shown in Fig. 12.

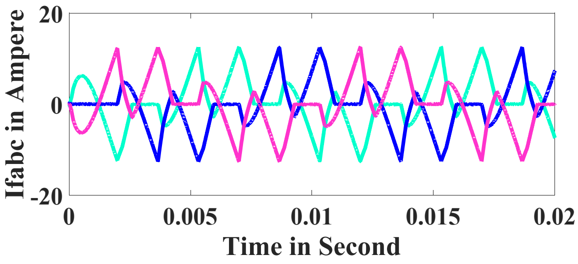

Fig. 13 Variation of SAPF 3-phase actual current (I_{fabc}) w.r.t time

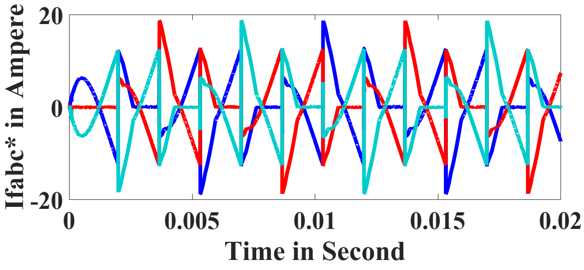

Fig. 14 Variation of SAPF 3-phase reference current (I^*_{fabc}) w.r.t time

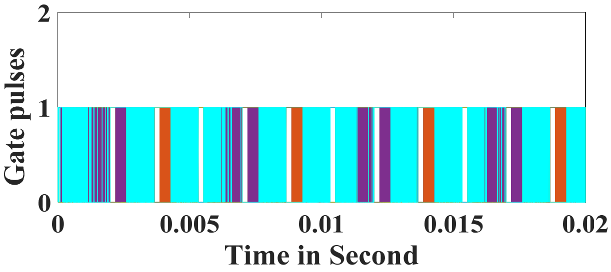

Fig. 15 switching signals for the switches of MOSFET for harmonic mitigation

The 3-phase waveforms of generated reference SAPF current (I^*_{fabc}) and actual SAPF current (I_{fabc}) are shown in Fig. 13 & Fig. 14 respectively. I^*_{fabc} and I_{fabc} are compared and error signal is passed through hysteresis controller to generate switching signals for MOSFET. The required sequence of gate signal of switches to mitigate the current harmonics is shown in Fig. 15.

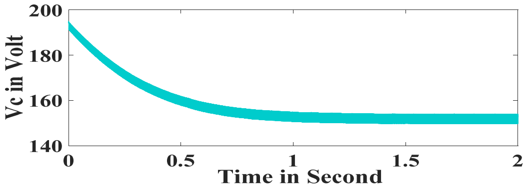

Fig. 16 Variation of capacitor voltage V_c of SAPF w.r.t time

To inject desired current for current harmonic mitigation, a charged capacitor has been connected in the system with an initial voltage of 195V as shown in Fig. 16. From the figure it can be observed that the capacitor supplying power or discharging initially and becoming stable at 150V after 1 second when the magnitude of injected harmonic current cancelling the supply harmonic contents.

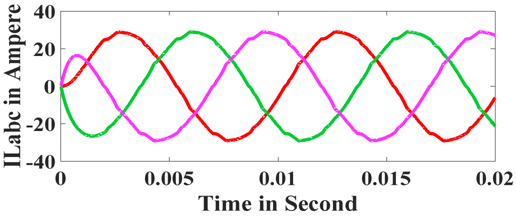

Fig. 17 Variation of load currents (IL_{abc}) of non-linear load w.r.t time with SAPF (taking into account source Rs & Ls)

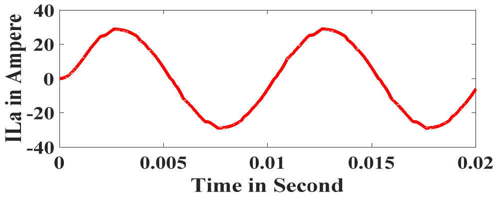

Fig. 18 Variation of phase–a load current (IL_a) of nonlinear load w.r.t time with SAPF (taking into account source Rs & Ls)

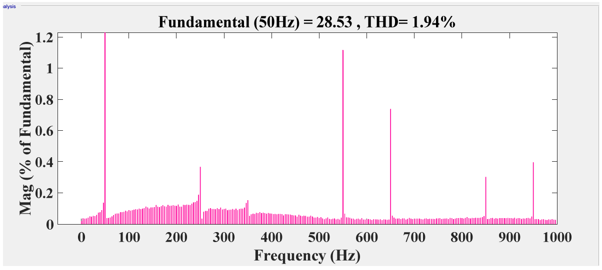

Fig. 19 Harmonic analysis of IL_a with SAPF

With SAPF, the variation of load currents (ILabc) and phase-a current (ILa) is shown in the Fig. 17 and Fig. 18 respectively. It is observed from the figures that the harmonics has been reducing to a great extent by using SAPF because the waveforms are approaching towards a sinusoidal waveform. The harmonic analysis of phase-a current with SAPF is shown in Fig. 19. From the figure it can be observed that the THD percentage has been reduced to 1.94%. A comparison of phase-a load current waveform with and without SAPF is shown in Fig. 20. The comparison results is tabulated in Table-I.

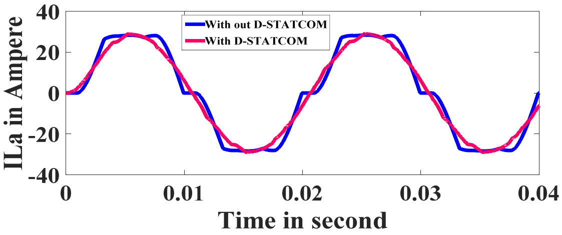

Fig. 20 Comparison of waveform of IL_a with and without SAPF

TABLE-I: Comparison of %THD of IL_a with and without SAPF

% THD of ILa without SAPF	% THD of ILa with SAPF	% THD reduction using SAPFC
13.87	1.94	11.93

TABLE-II: Parameter table

S. No.	Parameters	Value
1.	Source Voltage	L to L - 86.6V L to N - 50V
2.	Frequency	50Hz
3.	Source resistance (R_s)	1Ω
4.	Source inductance (L_s)	0.98mH
5.	Filter resistance (R_f)	2Ω
6.	Filter inductance (L_f)	6.64mH
7.	D.C link capacitor (C_d)	2030µF
8.	Hysteresis band Limit	U_{upper}=0.01 U_{lower}=-0.01
9.	Load resistance(R_L)	2.2Ω
10.	Load inductance(L_L)	2mH

5. Conclusion:

This paper presented a shunt active power filter control strategy (SAPFC) to control the harmonic current of non-linear load using hysteresis band current control technique. The performance of the above control strategy was investigated using the MATLAB/Simulink environment. From the obtained results, it was estimated that SAPFC controlled the THD of non linear load by 11.93% i.e. it reduced the THD from 13.87% to 1.94% which is well below 5% as per IEEE 519 standard. Hence it is concluded that SAPFC control strategy is a good option to reduce harmonics current of non-linear load in distribution system.

References:

[1] Alexander E Emanuel," Summary of IEEE standard 1459: Definitions for the Measurements of electric power qualities under sinusoidal, non sinusoidal, balanced, or unbalanced conditions," *IEEE Trans. Ind. App.*, vol.40, issue.3, pp.869-876, May / June 2004

[2] E. Ozdemi, K. Mura, and S. Ozdemir, "Active power filter for power compensation under non-ideal mains voltages," in *Proceedings of the 11th Mediterranean Conference on Control and Automation (MED'03)*, 2003.

[3] J. L. Afonso, C. Couto, and J. S. Martins, "Active filters with control based on the p-q theory," *IEEE Industrial Electronics Society News letter*, vol.47, no.3, pp.5–10, 2000

[4] H. Akagi, E.H. Watanabe, and M. Aredes, Instantaneous Power Theory and Applications to Power Conditioning, *Hoboken, NJ: Wiley*, 2007

[5] M. I. M. Montero, E. R. Cadaval, and F. B. Gonz ´ alez, “Comparison of control strategies for shunt active power filters in three-phase four-wire systems,” *IEEE Transactions on Power Electronics*, vol.22, no.1, pp. 229–236, 2007

[6] R.A.Hooshmand and M.Torabian Esfahani, “A new combined method in active filter design for power quality improvement in power systems,”*ISA Transactions*, vol.50, no.2, pp.150–158, 2011

[7] M. Ucar and E. Ozdemir, “Control of a 3-phase 4-leg active power filter under non-ideal mains voltage condition, “*Electric Power Systems Research*, vol.78, no.1, pp.58–73, 2008

[8] K. M. Mahajan, S. George, and S. Thale, “Simulation of shunt active filter using D-Q theory, “*in Proceedings of the 3rd Biennial National Conference (NCNTE'12)*, pp. 21–25, 2012

[9] H.Akagi, E.H.Watanabe, and M.Aredes, Instantaneous Power Theory and Applications to Power Conditioning, *IEEE Press*, vol. 4, 2007

[10] V. F. Corasaniti, M. B. Barbieri, P. L. Arnera, and M. I. Valla, “Hybrid power filter to enhance power quality in a medium voltage distribution network,” *IEEE Transactions on Industrial Electronics*, vol.56, no.8, pp. 2885–2893, 2009

[11] L.Merabet, S.Saad, D.O.Abdeslam, and A.Omeiri, “A comparative study of harmonic currents extraction by simulation and implementation,” *International Journal of Electrical Power and Energy Systems*, vol.53, no.1, pp. 507–514, 2013

[12] R. Belaidia, B. A. Haddouchea, and H. Guendouza, “Fuzzy logic controller based three-phase shunt active power filter for compensating harmonics and reactive power under unbalanced mains voltages, ”*Energy Procedia*, vol.18, pp. 560–570, 2012

[13] G D Kamalapur, V R Sheelavant, Chandrika Kulkarni, Padmaja Kallimani, Shivakumar B, Sagar,” Simulation and Analysis of DSTATCOM in Power System”*Asian Journal of Convergence in Technology*,vol.3, issue-2, 2016

[14] G. Sincy and A. Vivek, “A novel, DSP based algorithm for optimizing the harmonics and reactive power under non sinusoidal supply voltage conditions,” *IEEE Transactions on Power Delivery*, vol.20, no.4, pp.2526–2534, 2005

[15] A. Singh and S. kumar, “Performance investigation of active power line conditioner using Simulink,” *International Journal of Emerging Technology and Advanced Engineering*, vol. 2, no. 10, 2012