Performance of Fuzzy Logic based Shunt Active Filter (SAF) for Harmonics Mitigation in a Non-Linear Distributed System

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Abstract

Performance investigation of Shunt Active Power Filter for harmonic elimination is an interdisciplinary area of interest for many researches. The performance improvement of 3¬¬-phase Shunt Active Filter Power Filter (SAPF) with Hysteresis Current control technique for elimination of harmonic in a 3-phase distribution system. The disturb quality of voltage and current of the distribution system voltage sag, swell, harmonics in current and voltage, reduce power factor etc. Due to this load draw excessive current for the same output with increased copper losses, reduce efficiency of the system, produce excessive heat due to in nonlinear load condition produce pulsation in torque in dynamic load condition and create disturbance in power quality of neighbouring loads. For solution of these entire problems a reactive power compensation device is required. A proportional integrated (PI) and Fuzzy logic controller (FLC) are designed to adjust the parameters of the SAPF system. The proposed system has achieved a low Total Harmonic Distortion (THD) which demonstrates the effectiveness of the presented method. To overcome the problem SHUNT ACTIVE POWER FILTER is used to improve the power quality problem. The SHUNT ACTIVE POWER FILTER is used to improve power factor and THD of source currents in inductive and non-linear load respectively. The simulation of global system control and power circuits is performed using Matlab-Simulink and Sim Power System toolbox. The simulation results presented demonstrate improved performance of the SAPF system with the proposed fuzzy logic control approach.
Keywords: Power quality, Shunt active power filter, Hysteresis control, Harmonic, Fuzzy logic controller, Total harmonics distortion, Non-linear loads

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I. INTRODUCTION

Power quality is a set of electrical limitation that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy. Early equipment was designed to withstand disturbances such as lightning, short circuit and sudden overloads without extra expenditure. In the last decade several solutions have been developed in order to mitigation the mains current harmonic content. The harmonics presence in the power lines results in varied problems, likes – greater power losses in distribution, problems of electromagnetic interference in communication systems and operation failures of protection devices, electronics equipment and industrial processes. This research area has a reached a major importance because the number of non-linear loads, which are responsible for the grid current shape deformation, has drastically increased in the latest years. To overcome all this problem the most effective solution , designed to work out this problematic are designated by shunt active filter (SAPF) in short. The active filter has been recognized as a valid solution to harmonic and reactive power compensation due to the presence of non-linear loads. The principle of operation of active filters is based on the injection of the harmonics required by the loads.

Various topologies of active power filter have been developed so far, but the most common are the ones based on the multi-phase or single phase half bridge inverter with inductive decoupling. Classical topologies, such as those oblige the use of switching devices rated to operate at voltage equal or above the line voltage. But this represents a severe limitation when intending to built SAPFs for medium voltage grids that’s why this classical topologies are now replaced by new topologies aiming to be more reliable and less expensive. A new scheme has been proposed in which the required compensating currents is determined by sensing load current which is further modified by sensing line currents only. The new solution allow the reduction of the voltages of both the storage capacitors and the switching devices, to voltages lower than the mains peak voltage. An instantaneous reactive volt-ampere compensator and harmonic suppressor system is proposed without the use of voltage sensors but require complex hardware for current reference generator. Recently, fuzzy logic controllres (FLCs) have generated a good deal of interest in certain applications.

The advantages of fuzzy controller over conventional controllers, robustness, no need to accurate mathematical model, can work with imprecise inputs, and can handle non-linearity. In this work fuzzy logic controlled shunt active power filter for the harmonics and reactive power compensation if a nonlinear load are implemented. The control scheme is based on sensing line currents, which are based on sensing harmonics and reactive volt-ampere requirements of the nonlinear load. The three-phase currents\voltages are detected using only two current\voltage sensors.

II. Shunt active power filter operation

The shunt APL is designed to be connected in parallel with the nonlinear load. It detects the harmonic current of nonlinear load and injects into the system a compensating currents, identical with the nonlinear load harmonic current but in opposite phase. Therfore, the net current drawn from the distribution network at the point of coupling of filter and the load will be a sinusoidal current of only fundamental frequency. The current compensation characteristic of the shunt active power filter is shown in Fig.1.

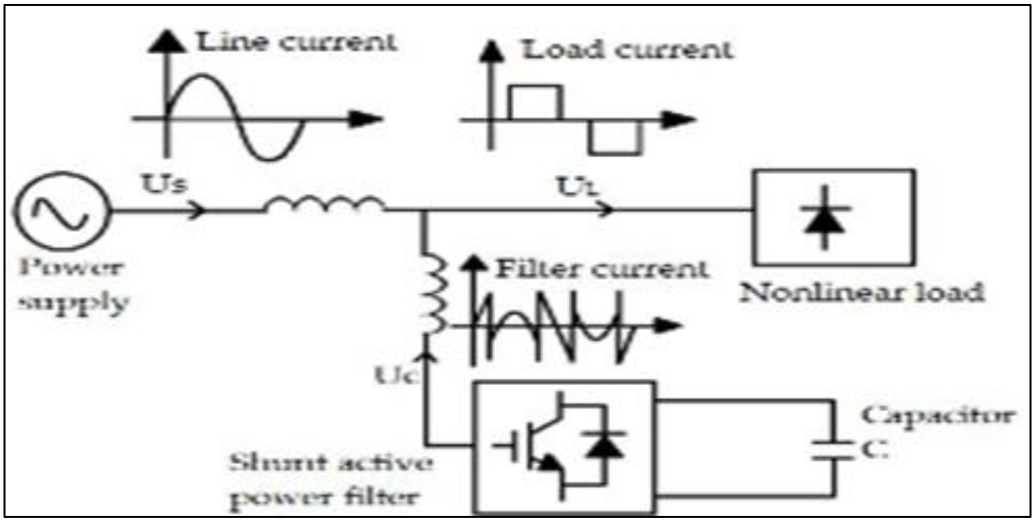

Fig. 1: Shunt active power filter

The injected currents are meant to “cancel” the harmonic and reactive currents drawn by the non-linear loads. However, the reference or desired current to be injected must be determined by extensive calculations with inherent delays, errors and slow transient response Conventionally, the shunt type APF acts to eliminate the reactive power and harmonic currents produced by linear loads from the grid current by injecting compensating currents intended to result in sinusoidal grid current with unity power factor. This filter has been proven to be effective in compensating harmonic current sources, but it cannot properly compensate for harmonic voltage sources. Many electronic appliances, such as switch mode power supplies and electronic ballasts, are harmonic voltage sources.

In the present paper, the three shunt active filter based on fuzzy logics current controller is proposed to compensate current harmonics. The new controller is designed to improve compensation capability of SAPF by adjusting the DC voltage error is using a fuzzy rule. The performances of the proposed SAPF are evaluated through computer simulations for transient and steady state conditions with nonlinear loads using Matlab-Simulink program and Sim Power System toolbox.

III. Control scheme of shunt active power filter

The basic compensation principle of shunt active filter is controlled to supply compensating current from/to the utility. So that it cancels a current harmonic on the AC side and makes the source current in phase with the source voltage. A shunt active filter is connected to the supply through filter inductances and operates as a closed loop controlled current source. The output voltage of the inverter is controlled with respect to the voltage at the point of common coupling.

Modeling of control scheme of SAPF system for feeding three phase load is given as follows. Three phase load currents of SAPF feeding load considered as a sinusoidal and hence their amplitude is computed as:

$$V_t = [2/3(Vsa^2 + Vsb^2 + Vsc^2)]^{1/2} \quad (1)$$

The in phase unit voltage vectors are computed by divide individual load current by their amplitude.

$$Usad = vsa/vt; \quad Usbd = vsb/ vt; \quad Uscd = vsc/ vt \quad (2)$$

The error in DC bus voltage of SAF V_{dcer} (n) at n^{th} sampling Instant is:

$$V_{dce}r(n) = V_{dc}(n)^* - V_{dc}(n) \quad (3)$$

Where $V_{dc}(n)^*$ is the reference DC voltage and $V_{dc}(n)$ is the sensed DC link voltage of the SAF. The output of fuzzy logic controller for maintaining DC bus voltage of the SAF at the n^{th} sampling instant is expressed as I^*_{cmd} .Vcd(n-1)* is the amplitude of In-phase component of the reference load voltage at $(n-1)^{th}$ instant. The In-phase components of the reference source current are computed as;

$$I^*_{sad}=I_{smd}^*.U_{sad};\quad I_{sbd}^*=I_{smd}^*U_{sbd};\quad I_{scd}^*=I_{smd}^*U_{scd} \qquad (4)$$

These reference source current signal and sensed signals are passing through a hysteresis controller to generate gating pulses switch the IGBT's of the Voltage Source Convertor.

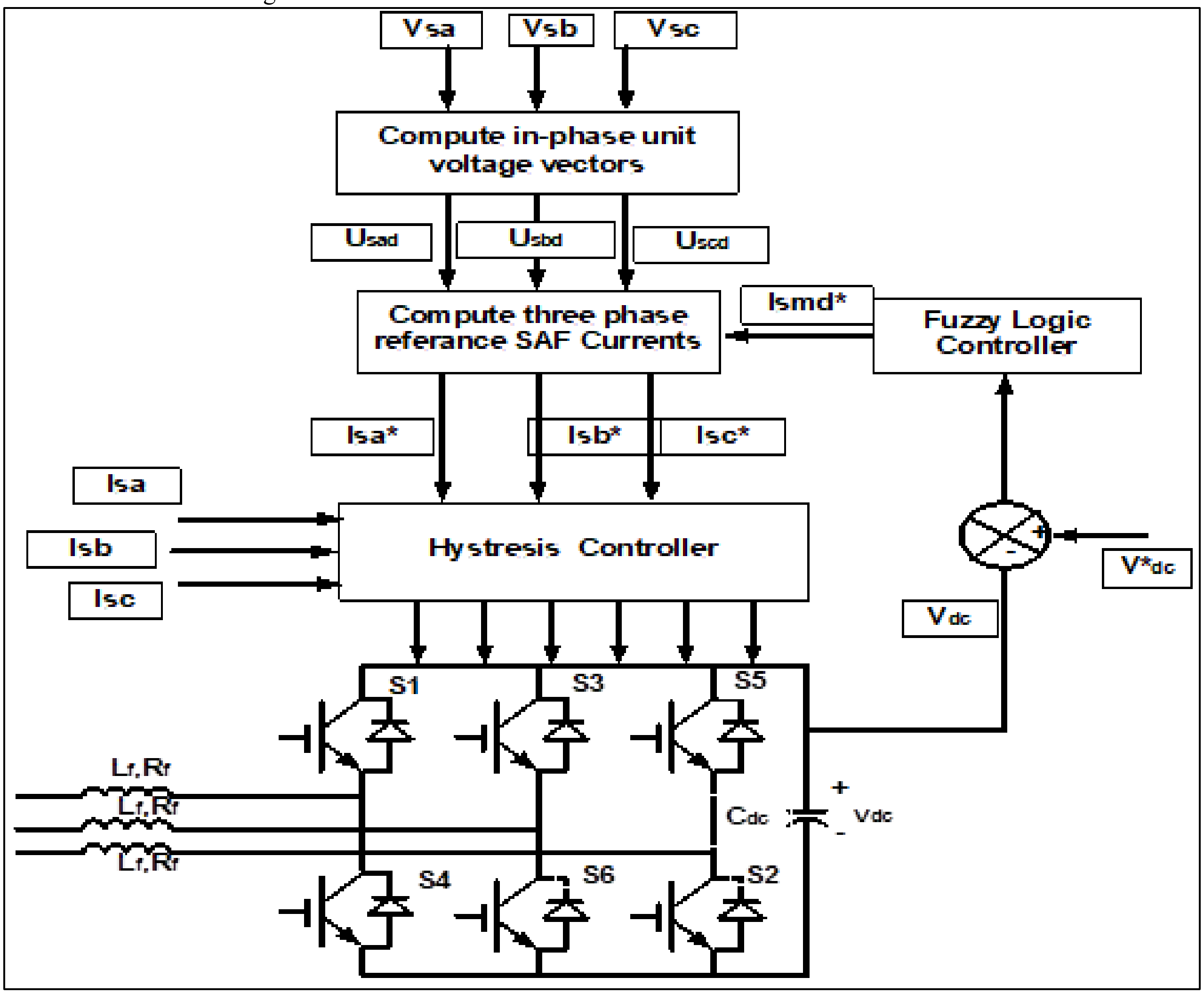

Fig. 2: Control Scheme of SAPF

IV. THE PROPOSED FUZZY CONTROLLER

Fuzzy logic becomes more popular due to dealing with problems that have uncertainty, vagueness, parameter variation and especially where system model is complex or not accurately defined in mathematical terms for the designed control action. The conception of the fuzzy logic introduced by Zadeh. It is a combination of fuzzy set theory and fuzzy inference system (FIS). A fuzzy inference system basically consists of a formulation of the mapping from a given input set to an output set using fuzzy logic. This mapping process provides the basis from which the inference or conclusion can be made. A fuzzy inference process consist of the following steps;

1) Step 1: Fuzzification of input variables
2) Step 2: Application of fuzzy operator (AND, OR, NOT) in the part of the rule
3) Step 3: Implication from the antecedent to the consequent part of the rules
4) Step 4: Aggregation of the consequents across the rules
5) Step 5: Defuzzification

Elements of a fuzzy set belongs to it with a certain degree, called degree of membership function (MF). The progression which maps the specified input data to the output using logic is known as fuzzy inference.

In this paper main control input variable is the DC link voltage error and output of FLC is the peak value of the reference source current. The range of operating current, normalization and de-normalization is one of the important design factors of fuzzy controller. The input and output variables are converted into linguistic variables. The crisp inputs are converted to linguistic variables in fuzzification based on membership function (MF). An MF is a curve that defines how the values of a fuzzy variables in a certain domain are mapped to a membership value between 0 and 1. A membership function can have different shapes. The simplest and most commonly used MF is the triangular type, which can be symmetrical or asymmetrical in shape. A trapezoidal MF has the shape of a truncated triangle.

V. Simulation results

To simulate the proposed FLC based control scheme with reduced sensors, a model in MATLAB\ SIMULINK and SimPower System Block set is developed. The complete 3-phase active filter system is composed using a supply source, a voltage source inverter, coupling and smoothing inductors with highly non-linear characteristic based load. Various simulations are carried out to verify the performance of the active power filter using proposed FLC and conventional PI controller with during steady-state and transient conditions. The system parameters selected for simulation studies are given in Table 2. The system connected with unbalance load of 8 KW at 0.8s .the voltage of system maintain constant of rated 415VL_L (532 peak voltage) and terminal voltage maintain constant with maintain constant D.C link voltage of the SAPF.Nonlinear loads can be semiconductor devices here we are using a universal bridge with resistance and parallel connected capacitor. The current is increasing up to full load current at 0.8s. For this system waveform of voltage and current are given

Table - 2
System Parameters

System parameters	Values
Supply voltage and frequency	230 V, 50Hz
Source impedance (R_s , L_s)	0.05 Ω, 0.5 mH
Filter impedance (R_c , L_c)	0.25 Ω, 4 mH
Smoothing inductor (R_{sm} , L_{sm})	0.5 Ω, 1.5 mH
Load impedance (R_{L1}, R_{L2}, L_{L1}, L_{L2})	25 Ω, 75 Ω, 10 mH, 15 mH
Reference DC link voltage ($V_{dc,ref}$)	680 volts
DC link capacitance (C_{dc})	1650 µF
Switching frequency (f_{sw})	10-12 KHz

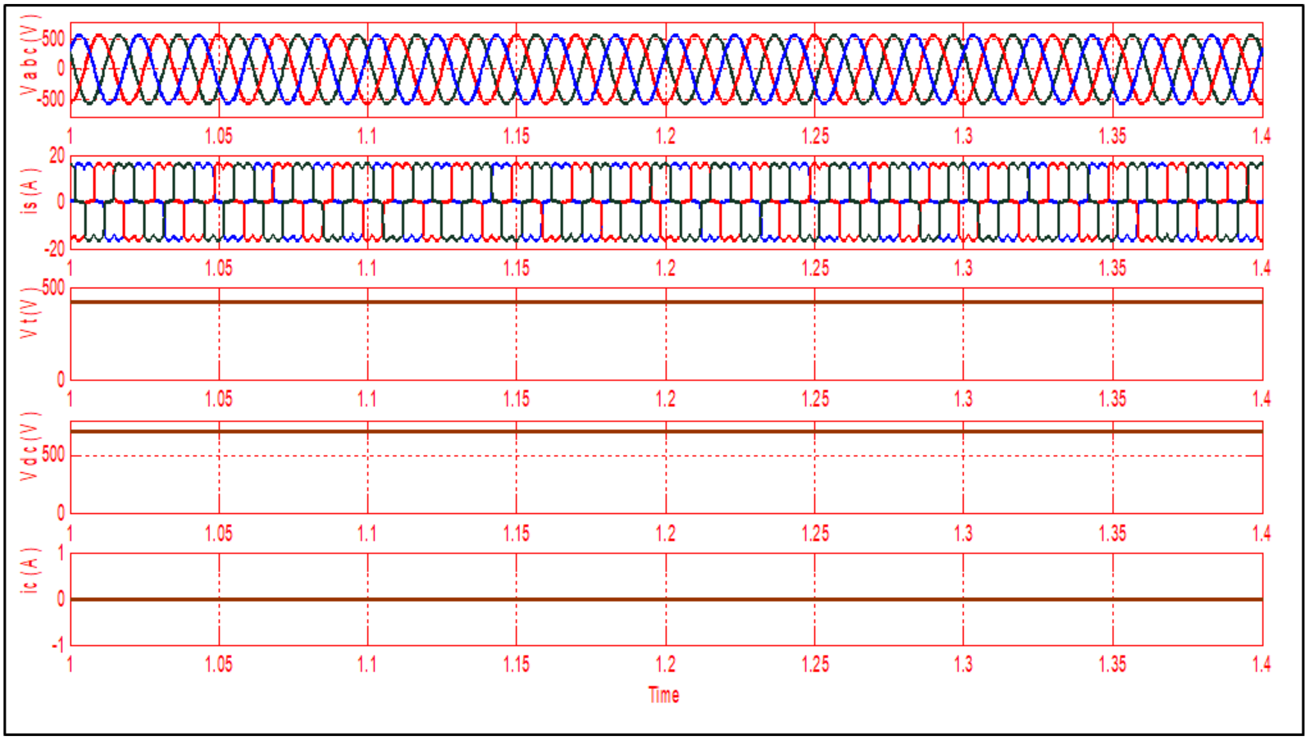

Fig. 3: Performance of system with 8Kw, nonlinear load without controller

A. FFT Analysis for Nonlinear Load without Controller

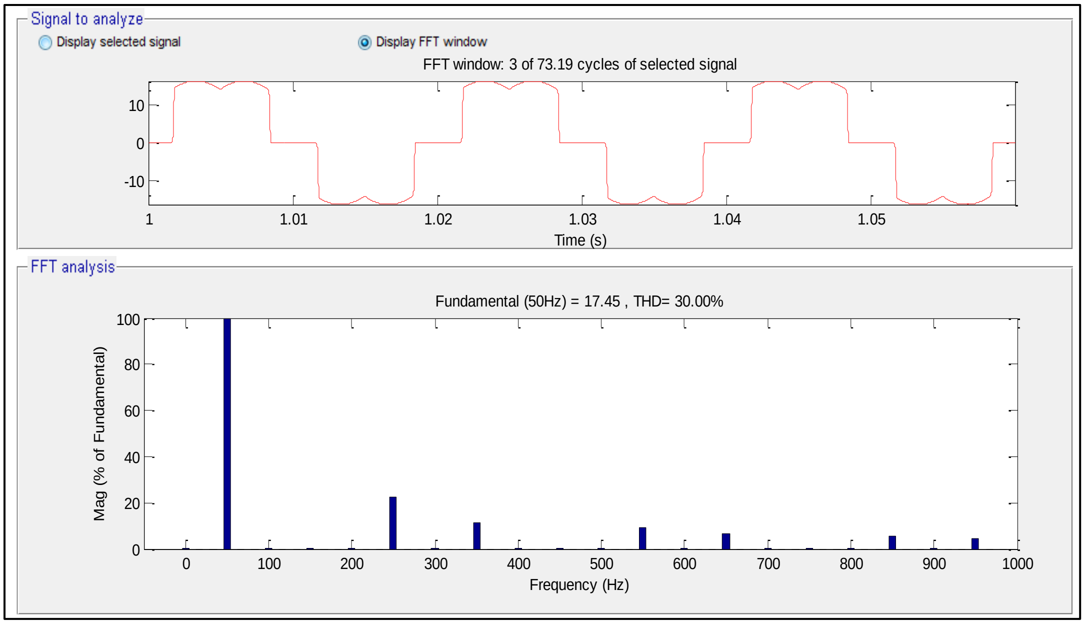

Fig. 4: THD of source current for nonlinear load without SAPF

FFT analysis for nonlinear load are discussed in which THD (Total Harmonic Distortion) are discussed and we found that THD is very high and system is not successful for connected load. Figure shows that THD is very high without controller and it is 30% which is not desirable for system.

Nonlinear load with controller-This system is also connected with non linear load of 8 KW at 0.8s .the voltage of system maintain constant of rated 415VL_L (532.7 peak voltage). The current is increasing up to full load current at 0.8s. For this system waveform of voltage and current are given.

B. FFT Analysis for Nonlinear Load with Controller

FFT analysis for nonlinear load are discussed in which THD (Total Harmonic Distortion) are discussed and we found that THD is very less and system is successful for connected load. Figure shows that THD is very less with controller and it is 3.43% which is desirable for system. In this work system which is used for compensation of reactive power is found to be good and desirable for improvement in power quality. Results shown in the above satisfied that system is good.

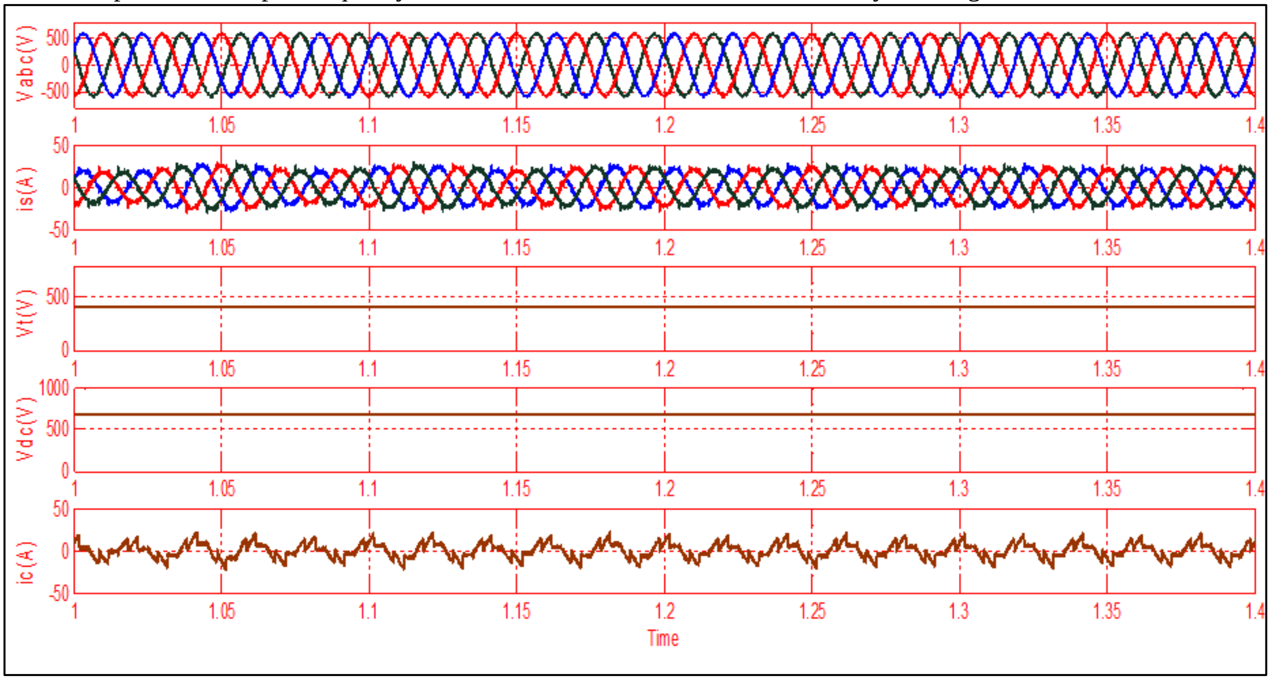

Fig. 5: Performance of system with 8Kw, nonlinear load with controller

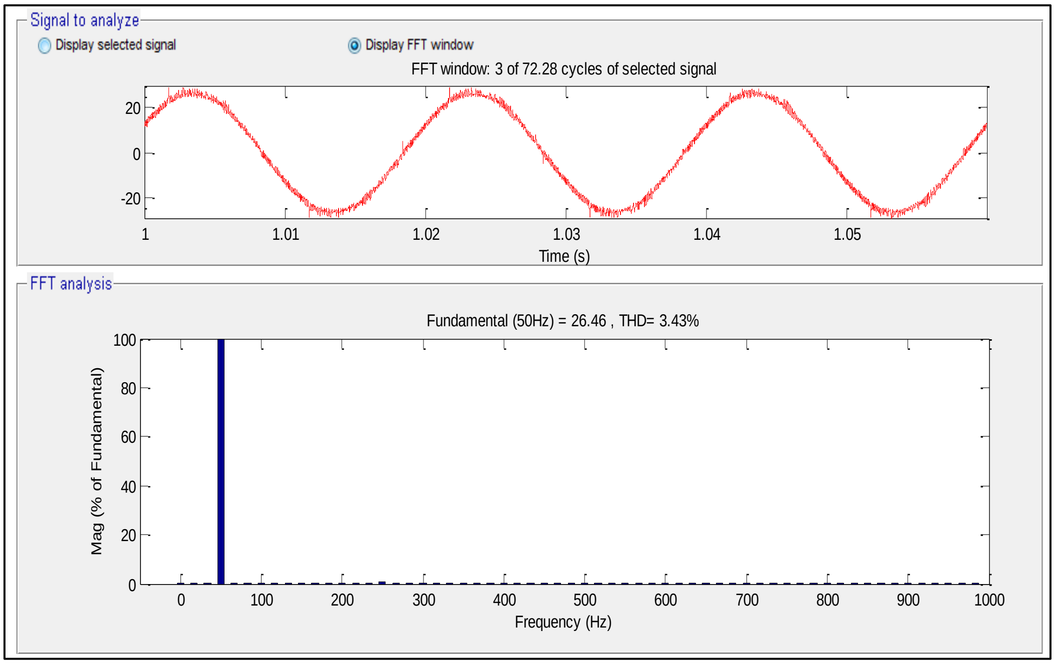

Fig. 6: THD of source current for nonlinear load with SAPF

VI. Conclusion

In the present paper theoretical study with simulation of, a three phase three-level shunt active filter with neutral with neutral-point diode clamped inverter based on fuzzy logic current controller is presented. Use of the filter is aimed at achieving the elimination of harmonics introduced by nonlinear loads. The results have proved that DC capacitor voltage and the harmonic currents control using FLC and SAPF are very important. This type of controller and filter are adapted easily to severe conditions such as distorted voltage conditions. Several simulations with various nonlinear loads (AC/DC converter with R, L) under different conditions are performed using the fuzzy current controllers.

The three phase shunt active power filter is simulated and the THD measured verifies the reduction of harmonics to a low level when the fuzzy logic control is employed. The results show the superiority and effectiveness of the proposed fuzzy controller in terms of eliminating harmonics and response time, the THD is significantly reduced from 30% to 3.43% for fuzzy controller with APF in conformity with the IEEE standard norms. The current source for the controllers after compensation is sinusoidal. Hence, the proposed fuzzy logic current controller is an excellent candidate to control shunt active filter based on inverter topology to eliminate the harmonic currents without scarifying performance.

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