FUZZY LOGIC BASED POWER QUALITY IMPROVEMENT USING HYBRID SERIES ACTIVE POWER FILTER

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ABSTRACT

In this paper, we present a Hybrid Power Filter (HPF) which consists of a combined system of Passive Filter (PF) and Series Active Power Filter (SAPF) has been designed by MATLAB/SIMULINK approach for harmonic and reactive power compensation. This filter is a three level PWM voltage source inverter and we use a Fuzzy Logic Controller (FLC) algorithm to control the harmonic voltages. The viability of the proposed algorithm is validated in this work. This combined system of filter is able to compensate the reactive power (showed that source voltage is sinusoidal and in phase with source current), and harmonics (voltage & current) for three phase of the non linear load current proposed with RL load. For the following voltage related problems in the power grid voltage flicker and voltage unbalance in three-phase systems are minimized under norm. The proposed solution has achieved an improvement of power quality in distribution system;

INTRODUCTION

A good power quality is an important factor for the reliable operation of electrical loads.AC power supply feeds different kind of linear and nonlinear loads in traction applications. The non-linear loads produce harmonics and reactive power related problems in the utility systems. The harmonic and reactive power cause poor power factor and distort the supply voltage at the customer service point, increased power losses in customer equipment, power transformers and power lines, flicker, shorter life of organic insulation [1].

Conventionally passive filters are used to compensate the lagging power factor of the reactive load and suppress the harmonic problems, but these passive filters are having some drawbacks; such as resonance, large in size, weight, and are limited too few harmonics. Recently, Active Power Filters (APF) is developed for compensating harmonics and reactive power simultaneously. There are two main categories of APF exist: shunt filters and series filters. The active power filter topology can be connected in series for voltage harmonic compensation and in parallel for current harmonic compensation. Most of the applications need current harmonic compensation, so the shunt active filter is popular than series active filter. The shunt active power filter has the ability to keep the mains current balanced and sinusoidal after compensation regardless of whether the load is non-linear [1].

The feasibility of fuzzy logic controller along with PLL synchronization controller based shunt active power filter for the harmonics and reactive power mitigation due to the non-linear loads. The fundamental component of the reference current is extracted from load current using fuzzy logic controller methods and dc-side capacitor voltage of the inverter is continuously maintained constant. The voltage source inverter switching signals are generated from hysteresis band current control techniques. The proposed concept for shunt APF system is validated through extensive simulation with nonlinear load. [2]

The control strategy is important to enhance the performance of a hybrid series active power filter (HSAPF). In reality, many papers for a hybrid power filter have already proposed advanced techniques to reduce current harmonics created by these nonlinear loads. In [7], a linear feedback-feed-forward controller is designed for a hybrid power filter. But this controller is not easy for getting both steady-state and transient-state performances with the linear control strategy because the dynamic model of the HSAPF system contains multiplication terms of control inputs and state variables. Due to the nonlinear characteristics of the HSAPF, a sliding-mode controller is presented in[8]. The sliding-mode control is known as an appropriate control technique for controlling nonlinear systems with uncertain dynamics and disturbances due to its order reduction property and low sensitivity to disturbances and plant parameter variations, which reduces the burden of the requirement of exact modeling. Furthermore, this sliding-mode control also diminishes the complicacy of the feedback control design by means of decoupling the system into individual subsystems of lower dimension. Because of these given properties, the implementation of the sliding mode control can be found in the areas of power electronic switching devices.

The principle of the sliding-mode control is defined as to enforce the sliding-mode motion in the predefined switching surfaces of the system state space using discontinuous control. The switching surfaces should be selected in such a way that sliding motion would maintain desired dynamics of motion according to a certain performance criterion. The conventional control methods, such as linear–quadratic regulator [9] or linear–quadratic Gaussian servo controller [10] for linear systems, are required to choose proper switching surfaces. Then, the discontinuous control needs to be chosen such that any states outside of the discontinuity surface are enforced to reach the surface at finite time. Accordingly, sliding mode occurs along the surface, and the system follows the desired system dynamics. The main difficulty of hardware implementation of a classical sliding-mode control method is chattering. Chattering is nothing but an undesirable phenomenon of oscillation with finite frequency and amplitude. The chattering is dangerous because the system lags control accuracy, high wear of moving mechanical parts, and high heat losses occur in electrical power circuits. Chattering occurs because of un modeled dynamics. These un modeled dynamics are created from servomechanisms, sensors, and data processors with smaller time constants. In the sliding-mode control, the switching frequency should be considerably high enough to make the controller more robust, stable, and no chattering because chattering reduces if switching frequency of the system increases. In the application of sliding mode controller in power converter system, the chattering problem can be reduced in the natural way by increasing switching frequency.

However, it is not possible in the case of power converters because of certain limitations in switching frequency for losses in power converters, for which it results in chattering. Therefore, this chattering problem cannot blame sliding-mode implementation, since it is mainly caused by switching limitations. In [11], it is shown that the chattering exponentially tends to zero if the relative degree of the system with actuators or sensors is 2. The relative degree of the HSAPF system is 2. Because of this relative degree of the HSAPF system and also for these obstacles in a classical sliding-mode controller, this paper proposes a new controller, i.e., sliding-mode controller-2 (SMC-2). This proposed controller suppresses chattering and enhances the performance of the HSAPF. This controller is completely new for this topology of the HSAPF system. A recent research paper [12] focuses on carrier-based pulse width modulation (CBPWM) for the HSAPF topology. But, in some cases, the CBPWM-based HSAPF may not be completely measurable in most of the real-world situations. In the case of CBPWM, power system perturbations have not been taken into consideration, and also, the presence of a time delay at the reference tracking point gives rise to a slow response of the overall system. Thus, tracking error is not reduced effectively, and the stability of the system is minimally improved. To overcome this, SMC-2 is proposed for a voltage-source converter. The idea behind this controller is to achieve gain stability, perfect tracking, and distortion-free current and load voltage. In view of the abovementioned issues, we give more emphasis on the development of the robust controller with a faster reference tracking approach in the HSAPF, which permits all perturbations such as load voltage distortion, parametric variation of load, source current distortion, and supply voltage unbalance so that compensation capability of the HSAPF system can be enhanced.

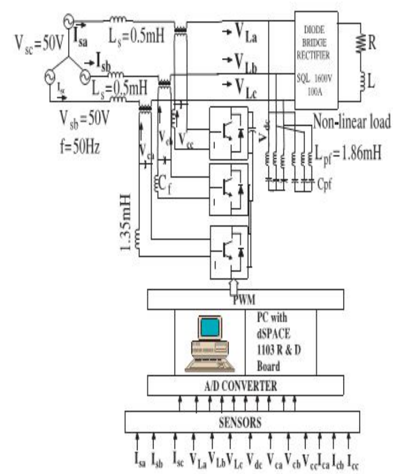

Fig. 1Schematic diagram of the control and power circuit of the HSAPF

Fig. 1 shows the schematic diagram of the control and power circuit of the three-phase HSAPF. The SAPF consists of a VSI connected to the grid through an LC filter and a three-phase linear transformer. The series resistance of the inductors is neglected. ua , ub , and uc are the duty cycles of the inverter legs in a switching period, whereas Vca , Vcb , and Vcc are the output voltages of the series active filter for three phases shown in Fig. 2 and Ica , Icb , and Icc are known as the three-phase currents of the active filter; VaN , VbN , and VcN are the phase voltages for three phases; Isa , Isb , and Isc are known as the three-phase source currents; and VnN is the neutral voltage. By averaging the inverter legs in the circuit diagram,

IV. DEVELOPMENT OF THE CONTROL SYSTEM

A. Reference Voltage Generation Scheme (Hybrid Control Approach-Based Synchronous Reference Frame Method, HSRF) The reference compensation voltage of the HSAPF system adopting hybrid control approach-based synchronous reference frame method is expressed as

$$V_c^* = KI_{sh} - V_{Lh}.$$

This hybrid control approach simultaneously detects both source current Is as well as load voltage VL to obtain their harmonic components. The generation of the reference compensating signal V ∗ c using the combined load voltage and source current detection scheme together with an adopting hybrid control approach-based synchronous reference frame method for the HSAPF system can be obtained

$$U_d = KI_d - V_d$$
$$U_q = KI_q - V_q.$$

The generation of reference compensating signal using the combined load voltage and source current detection scheme

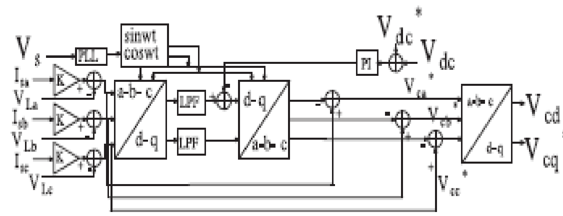

Fig. 2. Reference generation scheme (HSRF).

shown in Fig. 2. shows that the error between the reference and the actual dc-link voltage of the dc-link capacitor of the three-phase PWM inverter fed from the ac system is first passed through a PI controller, and then, it is subtracted from the oscillatory component in the d-axis. Extra fundamental components (i.e. ΔVcaf,ΔVcbf and ΔVccf) are added to the harmonics components in each phase. Thus, the reference compensating voltages can be expressed as

$$\left.\begin{aligned} V_{ca}^* &= KI_{sah} - V_{Lah} + \Delta V_{caf} \\ V_{cb}^* &= KI_{sbh} - V_{Lbh} + \Delta V_{cbf} \\ V_{cc}^* &= KI_{sch} - V_{Lch} + \Delta V_{ccf} \end{aligned}\right\}.$$

Proposed Sliding-Mode Controller Design for the HSAPF This section describes the synthesis of the sliding-mode controller based on the averaged model of the HSAPF system. Based on the system model (6), we differentiate the compensating voltage with respect to time until the control variables ud and uq appear explicitly, which leads to the following equations:

$$\frac{dV_{cd}}{dt} = wV_{cq} - \frac{i_{cd}}{C_f} + \frac{i_{sd}}{C_f}$$

$$\frac{dV_{cq}}{dt} = -wV_{cd} - \frac{i_{cq}}{C_f} + \frac{i_{sq}}{C_f}$$

$$\frac{d^2V_{cd}}{dt^2} = -w^2V_{cd} - w\frac{i_{cq}}{C_f} + w\frac{i_{sq}}{C_f} - \frac{V_{cd}}{L_fC_f} - w\frac{i_{cq}}{C_f} - \frac{u_dV_{dc}}{L_fC_f} + \frac{di_{sd}}{dt}\cdot\frac{1}{C_f}$$

$$\frac{d^2V_{cq}}{dt^2} = -w^2V_{cq} - w\frac{i_{cd}}{C_f} + w\frac{i_{sd}}{C_f} - \frac{V_{cq}}{L_fC_f} - w\frac{i_{cd}}{C_f} - \frac{u_qV_{dc}}{L_fC_f} + \frac{di_{sq}}{dt}\cdot\frac{1}{C_f}.$$

So, the relative degree of the system is "2" because at the second derivative of compensating voltage in the dq-axis, we obtain control variables ud and uq . The Jacobi matrix of j (d) with respect to the control vector "u" can be calculated .

Why Should We Use Fuzzy Controllers?

- It is very robust
- It can be easily modified
- It can use multiple inputs and outputs sources
- Much simpler than its predecessors (linear algebraic equations)
- It is very quick and cheaper to implement.

Architecture of Fuzzy Logic Controller

The architecture of the fuzzy logic controller shown in Fig. 3 includes four components: Fuzzifier, Rule Base, Fuzzy Inference Engine (decision making unit), and Defuzzifier.

Fuzzifier:

Fuzzy logic uses linguistic variables instead of numerical variables. In a control system, error between reference signal and output signal can be assigned as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive small (PS), Positive Medium (PM), Positive Big (PB). The triangular membership function is used for fuzzifications. The process of fuzzification convert numerical variable (real number) to a linguistic variable (fuzzy number) so that it can be matched with the premises of the fuzzy rules defined in the application specific rule base.

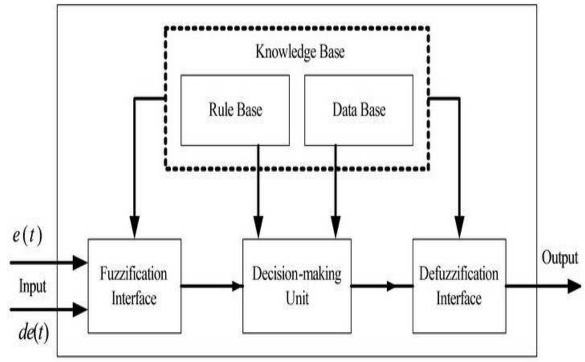

Fig. 3 Architecture of Fuzzy Logic Controller

Rule Base:

The rule base contains a set of fuzzy if-then rules which defines the actions of the controller in terms of linguistic variables and membership functions of linguistic terms. The Rule base stores the linguistic control rules required by rule evaluator (decision making logic).The output of the fuzzy controller is estimating the magnitude of peak reference current. This peak reference current comprises active power demand of the non-linear load and losses in the distribution system. The peak reference current is multiplied with PLL output for determining the desired reference current.

Database:

The Database stores the definition of the triangular membership function required by fuzzifier and defuzzifier.

Fuzzy Inference Engine:

The fuzzy inference engine applies the inference mechanism to the set of rules in the fuzzy rule base to produce a fuzzy output set. This involves matching the input fuzzy set with the premises of the rules, activation of the rules to deduce the conclusion of each rule that is fired, and combination of all activated conclusions using fuzzy set union to generate fuzzy set output.

Defuzzifier:

The rules of fuzzy logic controller generate required output in a linguistic variable (Fuzzy Number), according to real world requirements; linguistic variables have to be transformed to crisp output (Real number). This selection of strategy is a compromise between accuracy and computational intensity.

How Fuzzy Logic Controller works?

Fuzzy logic control is deduced from fuzzy set theory in 1965; where transition is between membership and non- membership function. Therefore, limitation or boundaries of fuzzy sets can be undefined and ambiguous; FLC's are an excellent choice when precise mathematical formula calculations are impossible. Fig. 2 shows block diagram of the fuzzy logic control scheme. In order to implement the control algorithm of a shunt active power filter in a closed loop, the dc capacitor voltage VDC is sensed and then compared with the desired reference value V_{DC},ref. The error signal:

$$e = V_{DC},\ ref - V_{DC}$$

is passed through LPF with a cut off frequency that pass only the fundamental component. The error signal e(n) and integration of error signal is termed as ce(n) are used as inputs for fuzzy processing. The output of the fuzzy logic controller limits the magnitude of peak reference current Imax. This current takes care of the active power demand of the non-linear load and losses in the distribution system. The switching signals for the PWM inverter are generated by comparing the actual source currents isa, isb , isc with the reference current (isa*,isb*,isc *) using the hysteresis current control method.

Fuzzy Control Of Active Power Filter (APF)

The identified Load frequency control and interconnection problems can be effectively reduced by controlling AGC(automatic generation control). Fuzzy logic is wide employed in controlling technique. The word "fuzzy" maintain fact that the logic concerned that can't be expressed as "true" or "false" however rather as "partially true". Though various approaches like genetic algorithms and ANN will perform even as well as formal logic in several cases, formal logic has the advantage that the answer to the matter is forged in terms that human operators will perceive, so their expertise is employed in the controller of prognosticative current control. The linguistic variables area unit outlined as (NB, NM, NS, Z, PS,PM, PB) that means negative big, negative medium, negative small, zero, positive small, positive medium and positive big.

Table. 1 The Membership Functions For FLC

E / CE	NB	NM	NS	Z	PS	PM	PB
PB	Z	PS	PM	PB	PB	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	NM	NS	Z	PS	PM	PB	PB
Z	NB	NM	NS	Z	PS	PM	PB

Active power filter generates compensating currents and induces these generated compensated currents in to the system thus mitigating harmonics in the system. Unwanted neutral currents might flow caused due to non-linear loads with uncompensated and unbalanced systems.

Simulation results

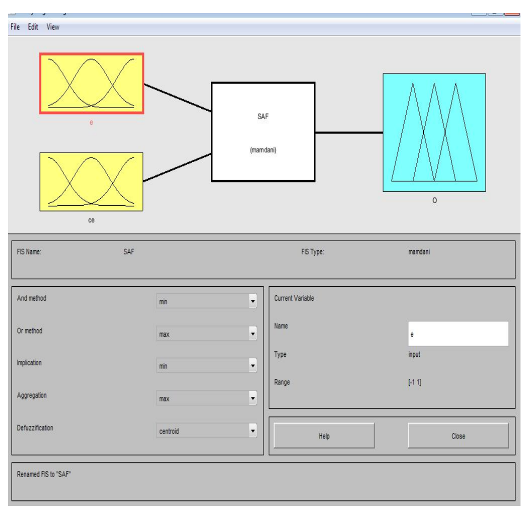

Fig:4 Change in error Input of fuzzy

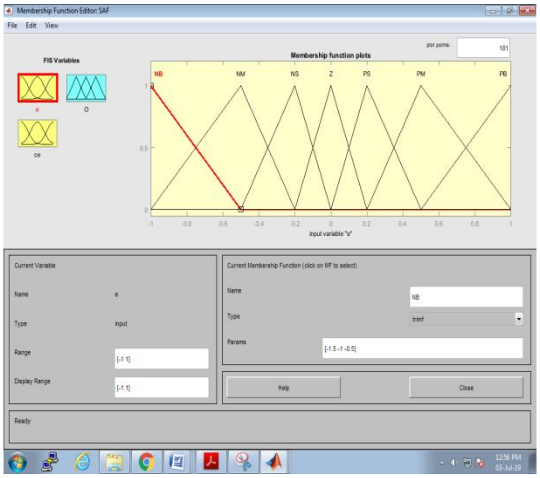

Fig5: Error input of fuzzy

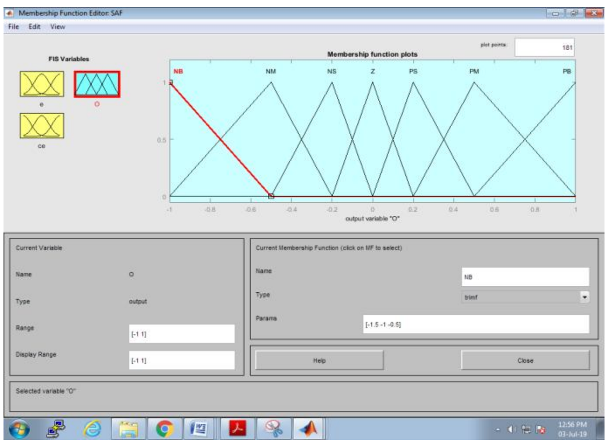

Fig 6: Output of fuzzy

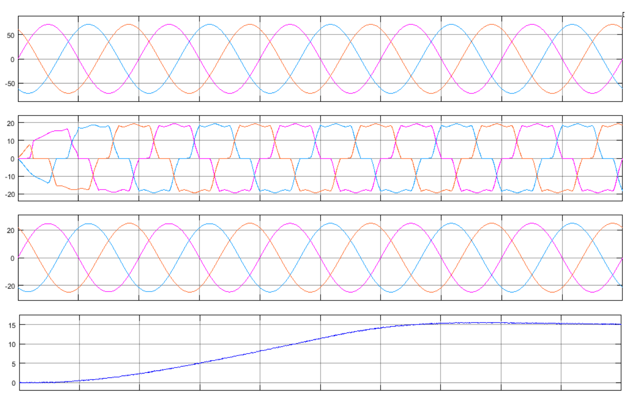

Fig 7 (a) Source voltage(b) Steady-state response of the load current before compensation(c) Steady-state response of the source current after compensation(d) DC-link voltage.

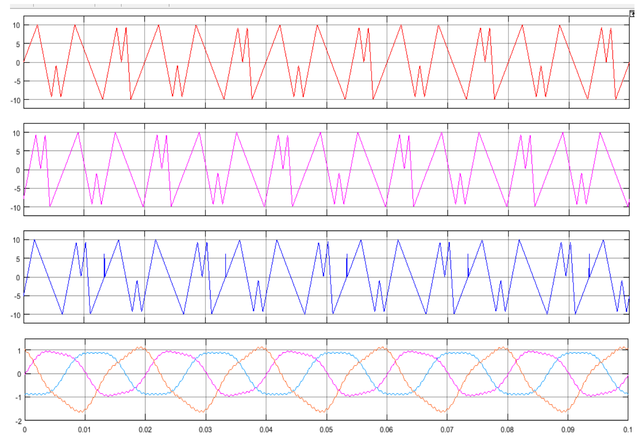

Fig 8 : Three-phase compensating voltages and Load voltage after compensation for fuzzy logic controller-based HSAPF system.

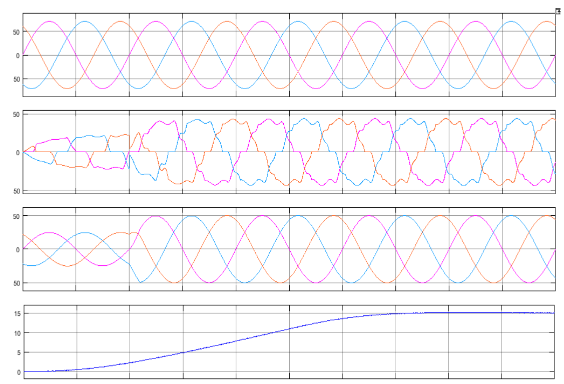

Fig:9 (a) Source voltage. (b) Transient response of the load current before compensation. (c) Transient response of the source current after compensation (d) DC-link voltage.

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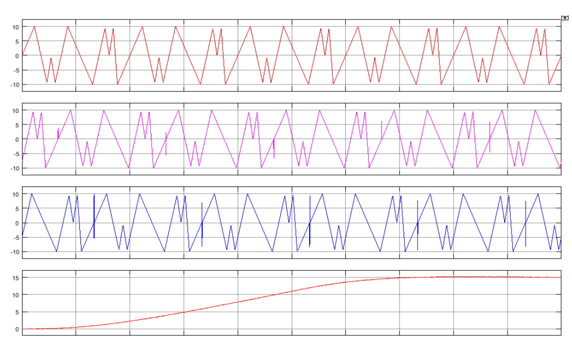

Fig:10 Three-phase compensating voltages and dc link voltage for fuzzy logic controller-based HSAPF system.

CONCLUSION

Fuzzy Logic Controller (FLC) to become one of intelligent controller over conventional controllers because its behaviour is easily understood by a human expert, as knowledge is expressed by means of linguistic rule. Due to the non- linear load connected in the distribution system harmonics will presented, which effects power quality of the at the distribution level. Fuzzy logic controller will perform the function of active power filtering to improve power quality. The series APF system is implemented with voltage source inverter and is connected at PCC for filtering the current harmonics and compensating the reactive power.

The series active power filter can compensate source currents and also adjust itself to compensate for variations in nonlinear load currents, maintain dc-link voltage at steady state, and help in the correction of the power factor of the supply side adjacent to unity. Simulation results under several system-operating conditions of load have verified the design concept of the suggested sliding-mode-based HSAPF to be highly effective and robust

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