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HARMONIC REDUCTION OF POWER QUALITY WITH A FUZZY LOGIC BASED SHUNT ACTIVE POWER FILTER

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Abstract: In order to support the superiority of one current control strategy over the other, this paper provides a detailed performance analysis of SAPF under two current control strategies: synchronous frame reference theory (d-q) and instantaneous active and reactive power theory (p-q). In both approaches, a reference current is produced for the filter that corrects the power system's reactive power or harmonic current component. This study describes a current controller called a harmonic current controller, which helps to eliminate harmonics by providing the IGBT inverter with a corrected gating sequence. In this study, traditional PI controllers and fuzzy logic controllers are employed to generate pulses properly.

Keywords: Shunt Active Power Filter (SAPF), IGBT, Fuzzy Logic Controller (FLC)

I. INTRODUCTION

Harmonics are generated by non-linear loads, such as power electrical equipment. Reactive and harmonic power contribute to low power factor and supply voltage distortion at the common coupling point or customer service point. Certain harmonic limitations were specified by the international standards recommendation and requirements for harmonic control in electrical power systems [IEEE Standard 92]. The alternate approach must be investigated in order to resolve this issue. First, various passive filter configurations are suggested in order to reduce harmonic current and increase the power factor, which compensates reactive power. However, the drawbacks of these filters include their size, incapacity to adjust to changes in network parameters, resonance issues, and parameter degradation, which renders them useless (Mahalekshmi, 2010). Active power filters (APFs) have been one of the most competitive current ways to suppress harmonic pollution (Sasaki, 2009), improve power quality, and ensure a better power distribution system since the introduction of power electronic equipment in the 1970s. Series active power filters and parallel (shunt) active power filters are the two types of APFs based on how they link to the power system (Peng, 1993). According to studies and practical applications, shunt active power filters are better suited for compensating for harmonic current sources, whereas series active power filters are better for compensating for harmonic voltage sources [Mahalekshmi, 10]. Power quality issues, particularly harmonic distortion, have become more significant with the increasing use of non-linear loads in modern power systems. To address these challenges, Shunt Active Power Filters (SAPFs) have emerged as effective solutions for harmonic mitigation and reactive power compensation. Traditional control techniques for SAPFs, such as the Proportional-Integral (PI) controller, often struggle to deliver optimal performance under varying load conditions and non-linearities.

Recent research has explored the integration of intelligent control strategies, particularly fuzzy logic, into SAPF systems. Fuzzy Logic Controllers (FLCs) offer robust handling of system uncertainties without the need for an accurate mathematical model, making them ideal for non-linear and dynamic environments. Studies by Akagi (1996) and later by Bollen (2000) laid foundational work for active filtering techniques, emphasizing the need for dynamic control methods for harmonics. Further, Bhattacharya and Divan (1995) discussed real-time control of active filters but highlighted limitations in conventional controllers under unpredictable operating conditions.

In subsequent studies, fuzzy logic-based SAPFs have demonstrated superior performance in terms of faster response times, reduced Total Harmonic Distortion (THD), and improved adaptability. Research by Singh et al. (2004) showed that FLCs in SAPFs could maintain THD within IEEE-519 standards even during sudden load changes. Another study by Rahmani et al. (2012) indicated that fuzzy controllers are more effective than classical PI controllers, especially when dealing with non-linear and non-stationary disturbances.

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Moreover, various hybrid approaches combining fuzzy logic with optimization algorithms such as Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) have been proposed to further enhance the performance of SAPFs. These studies reinforce the potential of fuzzy logic-based SAPFs to deliver improved power quality, system reliability, and operational flexibility in modern electrical networks.

Thus, a significant body of literature supports the use of fuzzy logic-based control strategies for the harmonic reduction of power quality issues, positioning them as a promising avenue for future advancements in active filtering technologies. Another method to separate the harmonic components from the fundamental components is by generating reference frame current by using synchronous reference theory. In synchronous reference theory park transformation is carried out to transformed three load current into synchronous reference current to eliminate the harmonics in source current. The main advantage of this method is that it take only load current under consideration for generating reference current and hence independent on source current and voltage distortion. A separate PLL block it used for maintaining synchronism between reference and voltage for better performance of the system. Since instantaneous action is not taking place in this method so the method is little bit slow than p-q method for detection and elimination of harmonics. Figure 1 illustrate the d-q method with simple block diagram.

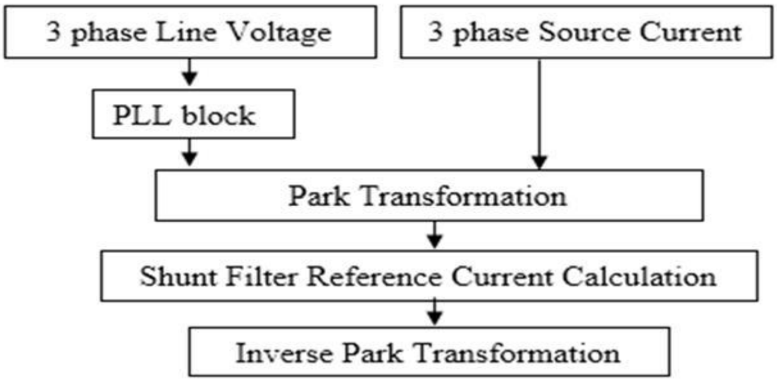

Fig.1. D-Q method control strategy

Usage of Active Filters is the best solution for this problem. In addition to these theories there are many controlling techniques such as extraction of load current RMS component[8-10], indirect current control [14-15], algorithm based on the real component of fundamental load current (I cosF) [16] etc., available in literature. Singh et al. [17] have presented a review on classification of active filters for power quality improvement based on converter type, topology and the number of phases.

II. PV SYSTEM MODELING & SAPF CONTROL SCHEME

2.1 Modeling of PV system

Solar cell arrays contain solar cells in series and parallel connection. A typical model of solar cell is described as Fig.2.

The model contains a sola-based current source, a diode, parallel resistance Rp ad series resistance Rs. Output of current source Ise keeps direct proportion to the light intensity A. Voltage and current of diode Ud ad 1d obeys the normal PN diode characteristic curve[5]. Rs is a equivalent value of body resistance and surface resistance of solar cell, in addition to electrode conductor resistance ad metal electrode resistance. Rp is a equivalent value of leaking resistance of PN-junction caused by pollution on the cell surface and defect of semiconductor. Output characteristics of a single sola cell can be described i (l) below.

$$I = I_{SC} - \left[\exp\left(\frac{q(U + IR_S)}{AkT} \right) - 1 \right] - \frac{U + IR_s}{R_p} \quad (1)$$

2.2 Control Scheme of SAPF

General block diagram showing control structure of a SAPF is shown in Figu 3. and the reference signal is calculated to compensate the distorted load current. Well tuned PI controller unit keeps the total dc bus voltage constant and equal to a given reference value. The reference value of the voltage is equal to the operating voltage of PV generator system.

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Small amount of power required to meet the losses in the inverter circuit are taken into consideration by the dc voltage control unit.

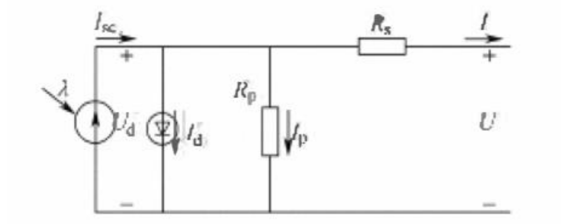

Fig.2. Typical model of Solar cell

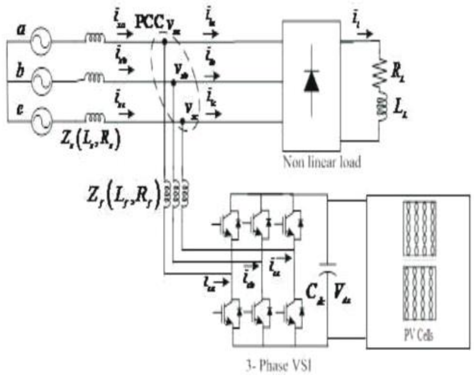

Fig. 3: Basic Compensation Principle of Shunt Active Power Filter (SAPF)

III. OVERVIEW OF FUZZY LOGIC CONTROLLER

The controller needs to be re-tuned if the operating point changes with time. This necessity to re-tune has driven the need for adaptive controllers that can automatically retune themselves to match the current process characteristics.

Analytical techniques may fail to give a precise solution in a controlling process. Where as an expert or a skilled human operator, without the knowledge of their underlying dynamics of a system can control a system more successfully. So it is worth simulating the controlling strategy based upon intuition and experience can be considered a heuristic decision or rule of thumb decision. This can be possible through the Fuzzy controller.

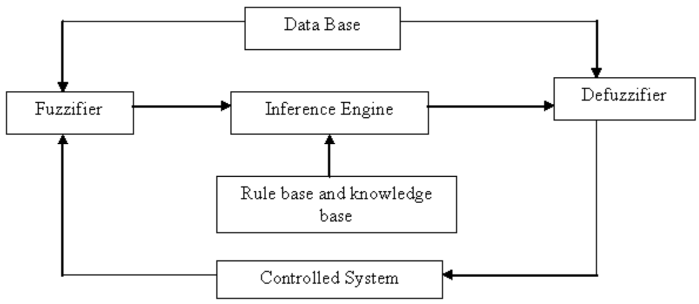

Fig 4. Structure of Fuzzy Logic controller

IV. RESULTS AND DISCUSSION

The test system simulation diagram is shown in fig.5. Figures 6 to 9 shows the response of source, load and PI controller. The Total harmonic distortion of source is 10.09% and load is 32.08%. The voltage and current relation of source is not zero degree, it is deviated from unity power factor and also the effectiveness of contributing load current is better.

Figures 10 to 13 shows the response of source, load with Fuzzy controller. The Total harmonic distortion of source is 4.73% .The voltage and current relation of source is approximately zero degree, therefore it offers unity power factor and also the effectiveness of contributing load current is better than PI controller.

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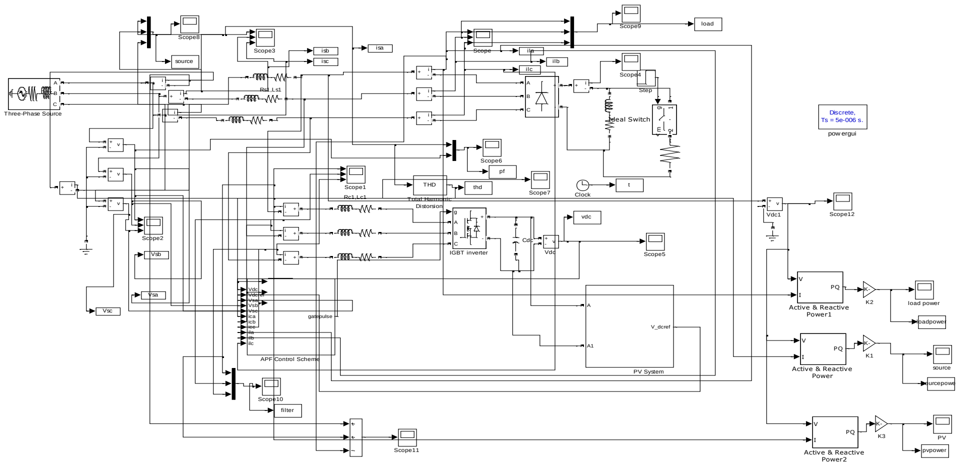

Fig.5. Matlab/Simulink diagram of PI based Active power filter

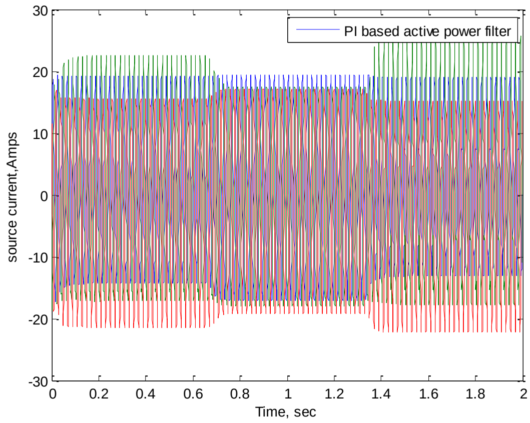

Fig. 6: Source current Vs Time with PI SAPF

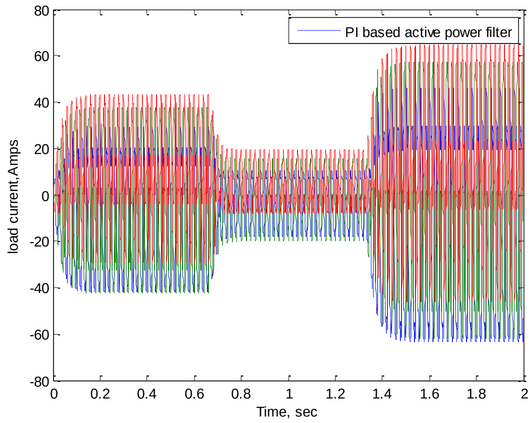

Fig. 7: Load current Vs Time with PI SAPF

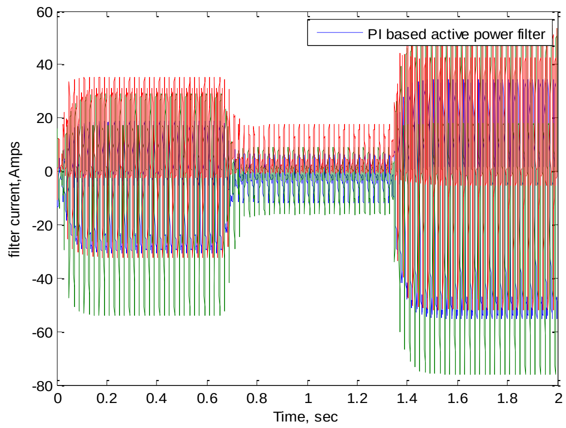

Fig. 8: Filter current Vs Time with PI SAPF

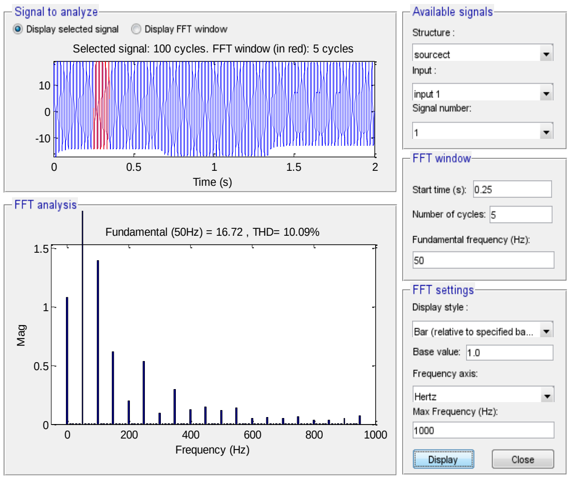

Fig. 9: Source current THD with PI SAPF

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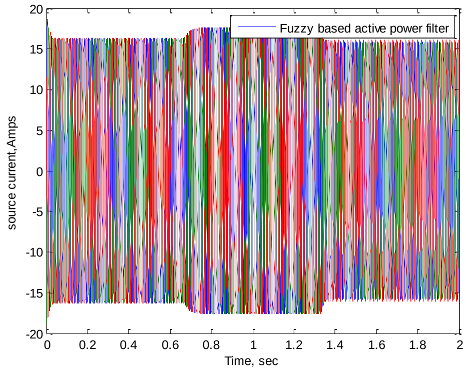

Fig. 9: Source current Vs Time with Fuzzy SAPF

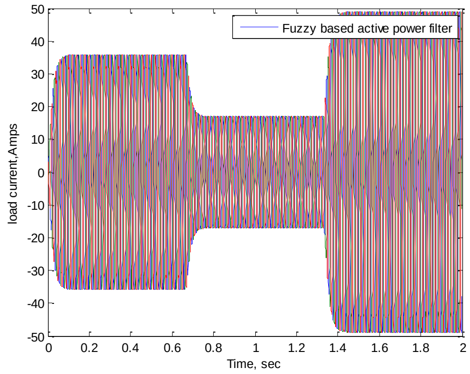

Fig. 10: Load current Vs Time with Fuzzy SAPF

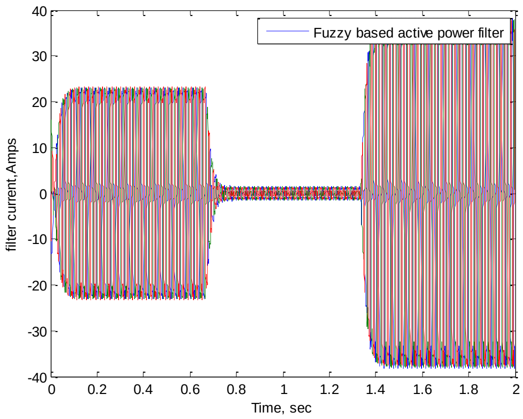

Fig. 11: Filter current Vs Time with Fuzzy SAPF

Fig. 12: Source current THD with Fuzzy SAPF

V. CONCLUSION

This paper proposes SAPF based on Fuzzy logic control to reduce the harmonics in source current due to load.The proposed fuzzy logic controller reduces the THD effectively than PI controller. Proposed controller eliminates the presence of LPF filter, therefore number of controlling components are reduced so this controller is a cost effective one.

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