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Digital Active Power Filter Controller for Current compensation in a Power System with Fuzzy Controller: A Review

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Abstract* — With *the extensive use of power electronics equipment such as rectifier, inverter etc. in power system generates major difficulty related to power quality. One of such difficulties is creation of current and voltage harmonics producing distortion of load waveform, voltage fluctuation, voltage drop, heating of equipment etc. Harmonic current sources, such as computer power supplies, fluorescent lamps with electronic ballasts, elevator drives, and electronic devices using Switch mode power supplies, are commonly found in commercial, institutional, and medical buildings. Active power filters (APF) are the most practical method for harmonic reduction and can be utilized in a variety of situations. In this study, a digital active power filter is used to eliminate harmonics in the source current in a grid system with a non-linear demand. Nonlinear loads are an important component of any power system. With the advent of power electronics, switching elements now account for a significant portion of the electrical load. These constituents cause discontinuities in lines, which increases line losses while lowering power quality as well as sin wave purity. Passive filters are effective in removing harmonics at specific frequencies that are specified in the design. Active filters, on the other side, operate in accordance with the harmonics that are now in play. Active filter designed in this work consists of a shunt active power filter that compensates current harmonic due to non-linear load. The active filter has a voltage source converter (VSC) which works in back to back configuration with a DC coupling capacitor. Power is injected by the VCS at the point of common coupling (PCC). The reference current is generated using instantaneous power theory.

Keywords— Sag-Swell, Dynamic Voltage Restorer, Distribution Power System, Voltage Source Inverter, Energy Storage Device, Power System Faults

I. INTRODUCTION

Early technology was built to tolerate disturbances like lightning, short circuits, and abrupt over loads without incurring additional costs. If current power electronics (PE) equipment was constructed with the same resilience, prices would be significantly higher. Nonlinear loads such as transformers and saturation coils have polluted power systems, but the rate of disturbance has never reached the current levels. PE is responsible for the majority of pollution problems due to its nonlinear properties and rapid switching. The nonlinear properties and quick switching of PE are responsible for the majority of environmental problems. PE processes around 10% to 20% of today's energy; this percentage is expected tries to 50% to 60% by 2010, owing to the rapid increase of PE capability. On the one side, there is a race between rising PE pollution & Sensitivity, while on the other hand, there is areca among innovative PE-based corrective devices that can mitigate the concerns caused by PE. Increased non-linearity results in a variety of unfavorable characteristics, including low system efficiency and a low power factor. It also creates annoyance to other customer's and communication network interference in the area. Within the next few years, the impact of such non-linearity could be significant. As a result, overcoming these negative characteristics is critical.

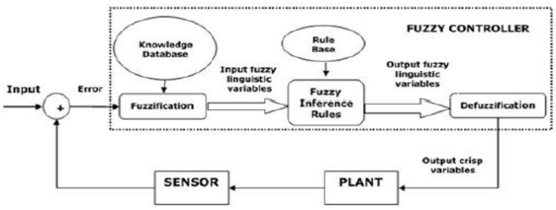

Figure 1: Fuzzy Logic Control System

A. Power Quality "Any incident manifested in voltage, current, or frequency variations that leads in damage, upset, breakdown, or mix-operation of end-use equipment," according to the PQ definition. In practically every part of commercial, home, as well as industrial use, all PQ difficulties are strongly tied to PE. Residential appliances such as televisions and computers, business and office equipment such as copiers and printers, including industrial equipment such as programmable logic controllers, variable speed drives, rectifiers, inverters, CNC machines, and so on all use power electronic devices. Based on the type of concern, one or more of the following symptoms can be used to diagnose a Power Quality (PQ) problem. [4].

Harmonics, inter harmonics, dips, as well as neutral currents are all caused by PEs. Rectifiers, ASDs, soft starters, electrical ballast for discharge lamps, switched-mode power supply, and HVAC employing ASDs all generate harmonics. Transformers, motors, wires, interrupters.

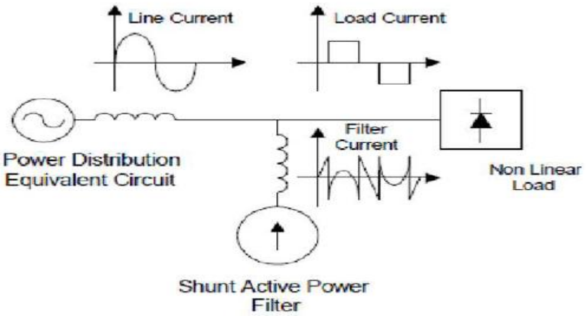

Figure 2: Power Quality Improvement

B. Active Filter An active filter consists of serial/parallel array of arrangement of both active and passive components and it is a type of analog electronic filter. Basic building block of active filter is Amplifiers. As a result, using amplifiers rather than inductors, which are employed in passive filters for the same reason, improves filter performance and responsiveness. Because active filters have a faster response time than passive filters, they can eliminate current distortion, current harmonics, and other issues faster. It could also be used to compensate for reactive power as well as voltage-based aberrations such blinking, voltage dips, and unbalancing. It eliminates load unbalancing as well as neutral shifting issues by employing PW Approaches. There is no possibility of resonating condition as tuning of frequency isn't taking place in active filtering, so the power system network remains more stable during operation. Unlike passive filter, there performance doesn't depend on system parameters and its topology.

Basic Compensation Principle

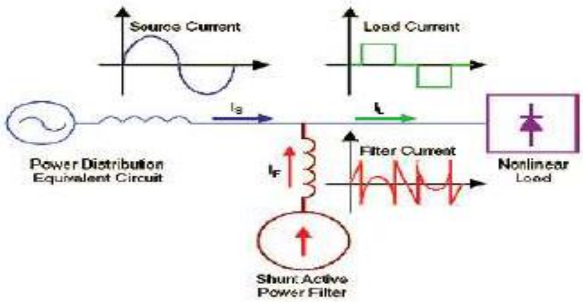

Figure 3: Basic Compensation Principle

C. Types Of Active Power Filter The active filters can be classified into various categories. It can be based on converter type, topology and number of phases. Based on the power circuit configuration, they can be classified into shunt, series and hybrid. Series Active Filter: The Series active filter is a filter which is placed in series with the grid via a matching transformer and is operated to remove voltage issues such voltage harmonics, voltage flicker, voltage balance, and load variations.

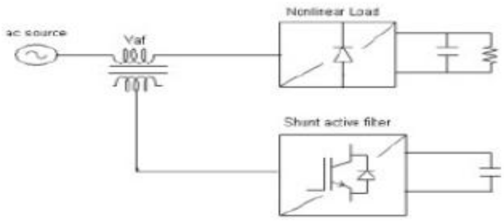

Figure 4: Series Active Power Filter

Shunt Active Filter: The most essential and extensively used sort of filter setup in active filtering is this one. The shunt active filter is a filter that uses a compensated current drawn from a power line to cancel harmonic currents on the source side, which is a grid site where power quality is critical. By infusing (drawing) more current, it is commonly used to reduce current harmonics, mitigate reactive power, and balance imbalanced currents.

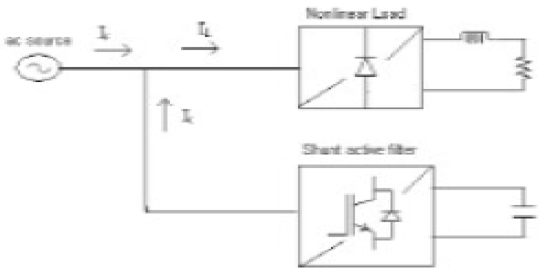

Figure 5: Shunt Active Power Filter

Hybrid active filter: Hybrid Power Filters (HPFs) are a combination of passive and active filters that help to reduce filter rating and cost. Instead of correcting for merely

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harmonic currents, these filters can dampen harmonic resonances.

D. Shunt Active Power Filter Shunt active power filters (SAPF) are connected in parallel to the power system network wherever one source of harmonics is available, as their name suggests. Its main purpose is to neutralize out the harmonic or non-sinusoidal current generated in the power system as a result of the presence of a nonlinear load by producing a current equal to the harmonic current but in the opposite phase, i.e. with a 180o phase shift compared to the harmonic current. SAPF typically employs a current-controlled voltage source inverter (IGBT inverter) that generates compensating current (ic) to offset the harmonic component of the load line current and maintain a sinusoidal source current waveform. Figure shown below depicts the basic setup. [8].

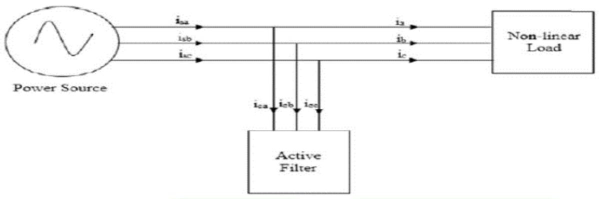

Figure 6: Shunt active Power Filter

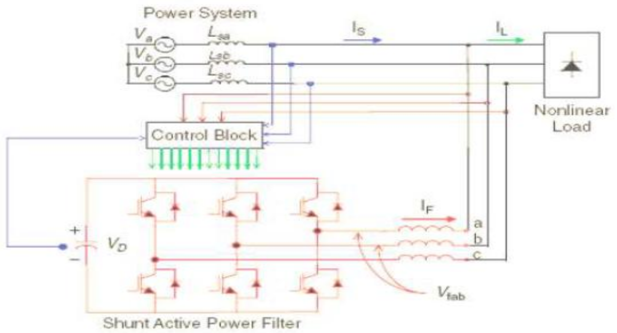

Figure 7: Shunt Active Power Filter Topology

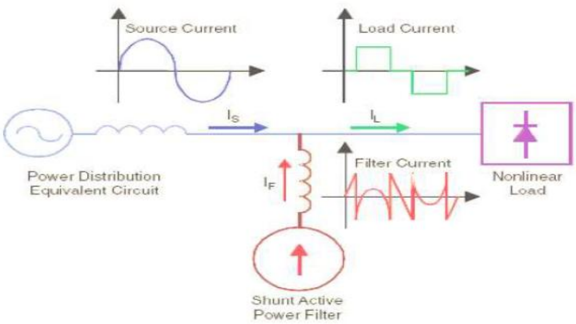

Figure 8: Filter current IF generated to compensate load-current harmonics

In SAPF, compensating harmonic current could be produced by employing various current control strategies to improve system performance by reducing current harmonics in the load current. Control of Active Power Filter The researchers are always at the point of the research to ameliorate the control methods of the SAPF to achieve better results either from the point of view of better perturbation extraction methods, the amelioration of the dynamic regimes, decreasing the value of the THD,…etc, or the development of new control methods to ameliorate the performance of the APF with the different non-linear loads. There are principally two methods for the compensation of the harmonic currents dependent on the measured current

II. LITERATURE REVIEW

Vasuniya & Sahajwani, 2020, Non-linear loads generate harmonic current in power system. These harmonics currents can produce various type of effect that is harmful to the power system. A system required to filter out these harmonics. Design and assessment of shunt active power filter (SAPF) for harmonics elimination using intelligent control controller (fuzzy logic) present in this paper. Generally, conventional phase-locked loop (PLL)technique are used for eliminate harmonics. In PLL technique based system contains more harmonic. This paper compared without filter versus with filter at different loads. Results shows that intelligent control controller based system contain minimum harmonic contain as compared to conventional controller **[1].**

Belgore, 2020, The most critical aspects of a power supply system are reliability and quality. In distribution networks, the widespread usage of nonlinear and electronically switched equipment degrades supply quality. Voltage fluctuations, flickering, harmonics, as well as voltage asymmetries are all examples of power quality issues. Power system experts have shown a great deal of interest in specific analyses of power quality problems and their remedies. Specific harmonics frequencies were bypassed using some of the adjusted passive filters. Since the passive filters were found to operate only over a fixed range, the attention is to be given towards compensating devices like active filtering that can effectively eliminate the harmonic currents. In this paper, the instantaneous p-q technique, synchronous reference frame theory and the hysteresis current control of shunt active filters is studied **[2].**

R. Balasubramanian, 2019, This paper deals with the design, simulation, and implementation of shunt hybrid compensator to maintain the power quality in three-phase distribution networks feeding different types balanced and unbalanced nonlinear loads. The configuration of the compensator consists of a selective harmonic elimination passive filter, a series-connected conventional six-pulse IGBT inverter, and acting as the active filter terminated with a DC link capacitor. The theory and modeling of the compensator based on current harmonic components at the load end and their decomposition in d-q axis frame of reference are utilized in the reference current generation algorithm. Accordingly, the source current waveform is made to follow the reference current waveform using a high-frequency, carrier-based controller. Further, this inner current control loop is supported by a slower outer voltage control loop for sustaining desirable DC link voltage. Performance of the compensator is evaluated through MATLAB simulation covering different types of loads and reduction of harmonic currents and THD at the supply side along with excellent regulation of DC link voltage are confirmed **[3].**

Sahu, 2018, Power electronics converters are commonly used in three-phase transmission lines. When a power electronic converter is used with a non-linear load, harmonics are produced, as well as the voltage waveform in the system is distorted. The adaptive neuron fuzzy inference system (ANFIS) regulated shunt active power filter is described in this study. The proposed controller can significantly reduce overall harmonic distortion. To obtain the appropriate signals for the inverter, the sinusoidal pulse width modulation (SPWM) approach is being used. The fuzzy controller has the advantage of not requiring a mathematical model of a system and can adjust its gain as the load varies. Total harmonic distortion (THD) simulation results are shown using MATLAB/ SIMULINK **[4]**.

George & Basu, 2016, Harmonic removal has traditionally relied on active power filters. The effectiveness of a traditional three-phase shunt Active Power Filter (APF) based on the Synchronous Detection Method (SDM) was evaluated to that of a NARMA-L2 based APF. The implementation of NARMA-L2 control to establish the amplitude of the reference supply current needed by the APF circuit, as well as the successful implementation of the APF system for fault detection is the study's unique features. The MATLAB 6.1 toolbox was used to model the complete system. The NARMA-L2 controller's suitability for APF controls demonstrated through numerical simulations **[5].**

Martinek et. al., 2015, Soft computing methods (a blend of fuzzy system approaches and artificial intelligence, also referred as Adaptive Neuro Fuzzy Interference Systems - ANFIS) are used in this study to provide a new control method for switching a shunt active power filter - SAPF. ANFIS' predictions as well as adaptable features are used to estimate the compensatory current quickly. A complicated adaptive system is based on the ANFIS structure was constructed as a result of the research. The proposed control method's efficiency is demonstrated by experimental findings. This control approach reduces harmonics, has a fast dynamic reaction time, and improves total harmonic distortion (THD) adequately. It's also relevant to various active filters, particularly nonlinear control systems. The modeling and experimental findings reveal that the suggested control approach has the advantages of a quicker response time, great online control, and highly efficient harmonics elimination when compared to previous control methods **[6].**

Saswat, 2014, The use of high-powered electronic devices has skyrocketed. As a result, the power system's power factor is extremely low. These power electrical gadgets also produce harmonics. An active power filter is a technique for lowering harmonics and increasing power factor. The purpose of this study is to present a method for filtering harmonics and improving power factor. The report contains all of the objectives, design techniques, and conclusions. One can minimize any number of harmonics by switching the appropriate PWM modulator pulse. In the power system, 3rd harmonics predominate. The results of simulations are also displayed, demonstrating that this method may be used to eliminate harmonics **[7]**.

Martinek et.al., 2013, This paper examines progressive shunt active performance filter techniques for compensating larger harmonic currents in non-linear loads. The authors of this article discuss how to increase the quality of electric power in a supply network by using a combo of fuzzy system approaches and artificial intelligence, also referred as Adaptive Neuro Fuzzy Interference Systems- ANFIS. A complicated adaptive system is based on the ANFIS structure was constructed as a result of the research. The ANFIS network's many structures have been studied by the authors (structure). The experimental data based on real signals reveal that the described varieties of control through the use of ANFIS provide extremely good harmonic currents of non-linear load compensating features. On the basis of total THD harmonic distortion of current networks after correction, several active shunt filter control schemes are evaluated **[8].**

III. CONTROL TECHNIQUES

A. Instantaneous Real and Reactive Power Theory- The "Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits," also referred as instantaneous power theory or p-q theory, was proposed by researchers in 1983.An algebraic conversion (Clarke transformation) of the three-phase currents and voltages in the a-b-c variables to the —0 coordinates is accompanied by the computation of the p-q theory instantaneous power components. It is based on current and voltage values of the power system at any given time. It is valid for Steady state as well as transient condition. The Clark transformation of voltage is given as: [16].

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Also three phase instantaneous line currents ia, ib and ic can be transformed on αβ0 axis as:

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$$\begin{bmatrix} t_\alpha \\ t_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The compensating current of each phase can be derived by using the inverse orthogonal transformations as shown below in equation

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ \frac{-1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Because the harmonics detecting phase's reaction is delayed, this method gives stronger harmonics compensations. In quick reaction current controlled inverters like active power filters, the current control approach is crucial.

B. Synchronous Reference Frame Theory- The fundamental reference current component of the load current is extracted using the synchronous reference frame theory by transforming iLa, iLb, and iLc into the d-q frame of reference. The translation of coordinates from a three-phase a-b-c stationary coordinate system to the 0-d-q rotational coordinate system is known as reference frame transformation. This transformation is significant because it occurs in the 0-d–q reference frame, which allows the signal to be regulated efficiently to obtain the appropriate reference signal. A synchronization system known as a phase-Locked loop (PLL) is utilized to accomplish the SRF approach. [17].

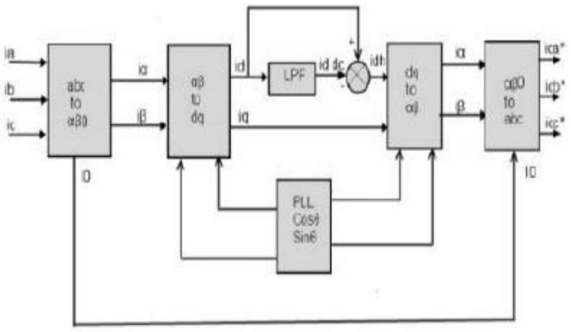

Figure 9: Block Diagram of SRF Algorithm

As a result, the SRF theory is effective in extracting different components in the load currents. By adjusting the VSI using different control schemes like hysteresis current controller as well as sliding mode controller, the source current is adjusted to match these reference fundamental positive sequence currents.

C. Hysteresis Current Control Method-The feedback control strategy's primary principle is to evaluate the reference currents with both the current produced by the inverter, then comparing the gap to a fixed band called the hysteresis band. When the error approaches the bottom band or the upper band, a control command is sent to the VSI to greatly reduce or raise the inverter's output voltage and keep the error inside the reference band.

IV. CONCLUSION AND FUTURE SCOPE

As seen in the above graphs the harmonics mitigation is achieved when the grid system with on-linear load is connected with digital active power filter. Here, the combination of Park transformation and digital PI controller, this varying PWM signal is generated. These PWM signals are control signals to a voltage source inverter (VSI) which injects the harmonics of same magnitude at 180-degree shift to cancel the effect of harmonics or distortion in power line. The DC link voltage with FIS controller is more accurate with 740V generation at DC link as compared PI controller. The THD of the source current is 25.8% when there is no digital active power filter connected and the THD is reduced to 4.64% when connected with the proposed device controlled by PI controller PQ theory. The THD is further reduced to1.45% when the PQ theory is updated with FIS module. Therefore the performance of the digital active power filter is improving when the controller s updated with FIS module.

The study and implementation of different shunt active filter control strategies aids in the mitigation of power quality problems in electrical utilities. Soft computing approaches, such as fuzzy logic control, can also be designed and analyzed significantly. The FIS controller can be further updated with adaptive controller and optimization techniques for faster settling of DC link voltage. The peak current generations can also be reduced when connected with the device while using these controllers.

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