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Fuzzy Controlled Harmonic Analysis for Current Compensation in Power System Using Digital Active Power Filter Controller

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Abstract-- The widespread usage of power electronics equipment in power systems, such as rectifiers and inverters, creates significant challenges in terms of power quality. One of these challenges is the generation of current and voltage harmonics, which cause load waveform distortion, voltage fluctuation, voltage drop, equipment heating, and so on. Harmonic current sources are ubiquitous in commercial, institutional, and medical facilities, including computer power supplies, fluorescent lights with electronic ballasts, elevator motors, and electrical equipment that use Switch mode power supplies. Active power filters (APF) are the most practical way of harmonic reduction and may be used in a wide range of applications. In this work, a digital active power filter is utilized to remove harmonics from source current in a grid system with non-linear demand. Nonlinear loads are a crucial part of any power system. With the introduction of power electronics, switching components now account for a significant amount of the electrical demand. These elements induce discontinuities in lines, increasing line losses while reducing power quality and sin wave purity. Passive filters are good in removing harmonics at predetermined frequencies in the design. Active filters, on the other hand, function in line with the harmonics that are now in play. The active filter created in this study is a shunt active power filter that adjusts for current harmonics caused by non-linear loads. The active filter incorporates a voltage source converter (VSC) that operates in tandem with a DC coupling capacitor. VCS injects power at the point of common coupling (PCC). The reference current is derived using the instantaneous power theory. The instantaneous power theory, or PQ theory, has been modified with the FIS control system to improve DC voltage production over the DC link capacitor. The fuzzy system that replaces the PI controller has a (7x7) 49-rule base structure for generating error signals. A comparative examination of DC voltage and THDs is performed using MATLAB software and the FFT analysis tool.

Keywords-- *Active Power Filter, Instantaneous Power Theory, Harmonics, Non-Linear Load, MATLAB Simulink and FFT analysis tool, PI Controller, Fuzzy logic Controller.*

I. INTRODUCTION

Early technology was designed to withstand disturbances such as lightning, short circuits, and unexpected overloads without incurring extra expenditures. If existing power electronics (PE) equipment was built with the same resilience, costs would skyrocket. Nonlinear loads like transformers and saturation coils have fouled power networks, but the rate of disruption has never been as high as it is now. [1] Because of its nonlinear features and quick switching, PE causes the vast majority of pollution concerns. The bulk of environmental concerns may be attributed to PE's nonlinear features and fast switching. PE processes around 10% to 20% of today's energy; this figure is predicted to climb to 50% to 60% by 2010, due to the fast expansion in PE capabilities. On the one hand, there is a race between escalating PE pollution and sensitivity, while on the other, there is a race for novel PE-based remedial devices that may alleviate PE worries. Increased non-linearity produces a number of adverse features, including poor system efficiency and power factor. It also annoys other customers and interferes with the communication network in the neighborhood. Such nonlinearity has the potential to have a big influence in the coming years. As a consequence, conquering these undesirable traits is crucial.

Shunt passive filters, which are composed of tuned LC filters and/or high passive filters, are often used to reduce harmonics, while power capacitors are used to improve power factor. However, they have fixed compensation, are quite large in size, and may produce resonance issues. [2]

Active power filters are increasingly being considered as a viable alternative to standard passive filters for compensating for harmonics and reactive power needs of non-linear loads. The purpose of an active filter is to address these concerns by incorporating it with substantially lower ratings than the requisite passive filters. However, the traditional PI controller was employed to create a reference current template. The PI controller needs exact linear mathematical models, which are difficult to construct and do not work adequately in the presence of parameter fluctuations, nonlinearity, load disturbance, and so on. [3]

Fuzzy logic controllers (FLCs) have lately gained popularity in a variety of applications. FLCs offer various benefits over traditional controllers, including the fact that they don't need a flawless mathematical formula, can function with imperfect inputs, can handle lion-linearity, and are significantly more resilient than ordinary nonlinear controllers. The passage of harmonic and reactive currents harms the power system by reducing the power factor and degrading voltage quality. These negative consequences are becoming more significant for the following reasons: [4]

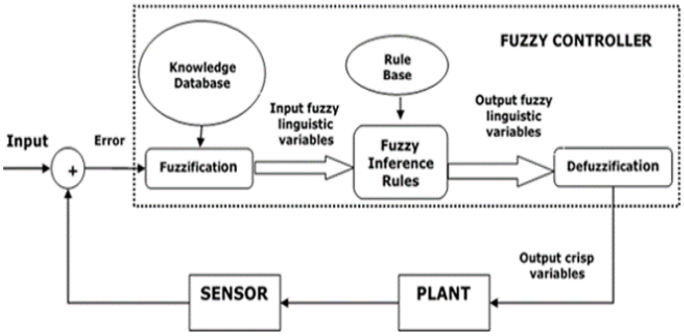

Figure 1.1 Fuzzy Logic Control System

- While the power demand is growing, public concerns over environmental impacts of transmission lines and right of way costs are making it more difficult for utility companies to build new transmission lines. The need to build new lines is reduced if the current carrying capacity of the existing transmission facilities is fully utilized by improving the power factor.
- Deregulation of the power industry is putting additional pressure on the utility companies to remain competitive by improving the voltage quality and by reducing the costly system losses.
- Addition of harmonic generating loads such as power electronic equipment by consumers is increasing the level of harmonic current flow in power systems

  This paper implements a PI and fuzzy logic-controlled shunt active power filter for harmonics as well as reactive power correction of a nonlinear load. The control scheme is based on sensing line currents only; an approach different from convention ones, which are based on sensing harmonics and reactive volt-ampere requirements of the nonlinear load. [5]

II. POWER QUALITY

"Any incident manifested in voltage, current, or frequency variations that leads in damage, upset, breakdown, or mis-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. [6]

- Lamp flicker
- Frequent blackouts
- Sensitive-equipment frequent dropouts
- Voltage to ground in unexpected
- Locations
- Communications interference
- Overheated elements and equipment

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, as well as capacitors are all impacted by harmonic (resonance). Converters are the primary source of notches, which have a significant impact on electrical control systems. Equipment that uses switched-mode power sources, including as PCs, printers, photocopiers, as well as any triplets generator, generate neutral currents. Neutral currents have a significant impact on the temperature of the neutral conductor as well as the transformer's capabilities. Static frequency converters, cyclo-converters, induction motors, and electric current devices all generate inter harmonics. [7]

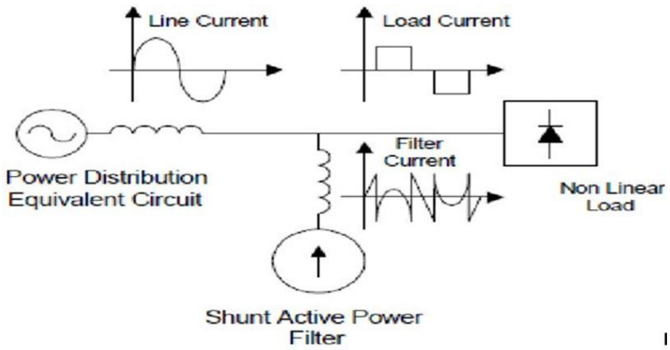

Figure 2.1 Power Quality Improvement

There are two ways to handle power quality concerns. The first way, known as load conditioning, ensures that the equipment is less susceptible to power disruptions, allowing it to function even when the voltage is severely distorted. Installing line-conditioning technology to reduce or eliminate power system disruptions is another possibility. [8] Passive filters have been the most widely used means of restricting the passage of harmonic currents via distribution networks. They are often manufactured to order for a particular application. Furthermore, their performance is limited to a few harmonics, and they may create power system resonance. Active power filters have shown to be an important and flexible alternative for adjusting for voltage and current changes in power distribution systems, among other innovative technological solutions for improving power quality. The notion of active filters is not new, but it has only recently become a reality because to advances in power electronics and microcomputer control strategies, as well as decreasing electronic component prices. Active power filters are rapidly increasing market share as their prices fall below those of passive power filters. The active filter generates current or voltage components using power electronics, eliminating the harmonic components of nonlinear loads or supply lines. A variety of active power filter topologies have been designed, and some are now commercially available. [9]

III. SHUNT ACTIVE POWER FILTER

Shunt active power filters (SAPF) are linked in parallel to the power system network whenever a single source of harmonics is accessible, as the name implies. Its primary function is to cancel out the harmonic or non-sinusoidal current created in the power system as a consequence of the presence of a nonlinear load by creating a current equal to the harmonic current but in the opposite phase, i.e. with a 180o phase shift. SAPF commonly uses a current-controlled voltage source inverter (IGBT inverter) to create compensating current (ic) and balance the harmonic component of the load line current while maintaining a sinusoidal source current waveform. The figure below displays the basic configuration. [10]

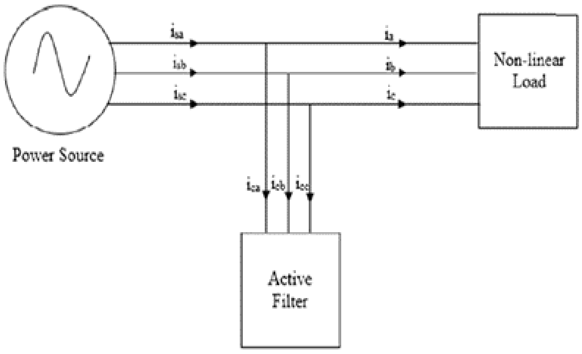

Figure 3.1 Shunt active Power Filter

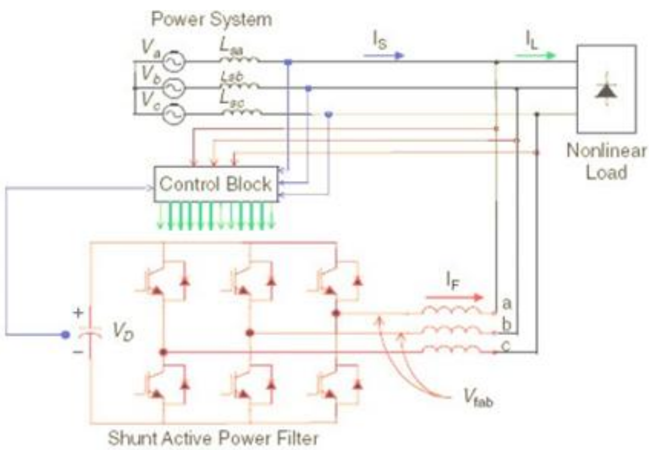

Figure 3.2 Shunt Active Power Filter Topology

IV. HARMONICS IN POWER SYSTEM

Harmonic related problems are not new in the electric power system. From the early 1920's harmonics are observed in power equipment because of telephone line interference. The proliferation of power converter equipment connected to the distribution power system which limits harmonic current injection maintains good power quality. The various standards and guidelines have been established that specify limits on the magnitudes of harmonic currents and voltages. [10] The Committee European de Normalization Electro technique (CENELEC), International Electro technical Commission (IEC), and Institute of Electrical and Electronics Engineers (IEEE) specify the limits on the voltages at various harmonic frequencies of the utility frequency. In 1983, IEEE Working Group made a reference about harmonic sources and effects on the electric power system. There is significant activity in the IEEE-Power Engineering Society and IEEE-Industry Applications Society to detect harmonic effects. These societies and institutes define standards for harmonics. Researcher surveyed and reported the harmonic levels (three classes of distribution circuits; residential, commercial and industrial) in the American Electric Power Distribution System.[11]

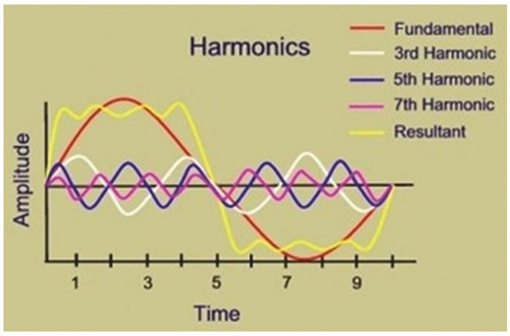

Figure 4.1 Harmonics in Power System

A. Mitigation of harmonics

The harmonic related problem is mitigated by using active power quality conditioner. The active power quality conditioner can also be coupled in series, parallel, or hybrid topologies, and also combos of both (unified power quality conditioners). In between nonlinear load and also the distribution system, the series APLC acts as a voltage regulator as well as harmonic isolator. The series active filter infuses a voltage component in series with the supply voltage, making it a controlled voltage source that compensates for voltage sags as well as surges on the load side. [12] The injected harmonic voltages are added or subtracted, to / from the source voltage to maintain pure sinusoidal voltage across the load. Hybrid APLC is a combination of passive and active power line conditioner. By injecting a controlled harmonic voltage source into the hybrid series APLC, it can operate as a harmonic isolator between the source as well as the non-linear load. The series and shunt APLCs are combined in a unified power quality conditioner. At the utility-consumer point of common connection, the series active power filter may regulate voltage and compensate for harmonics.

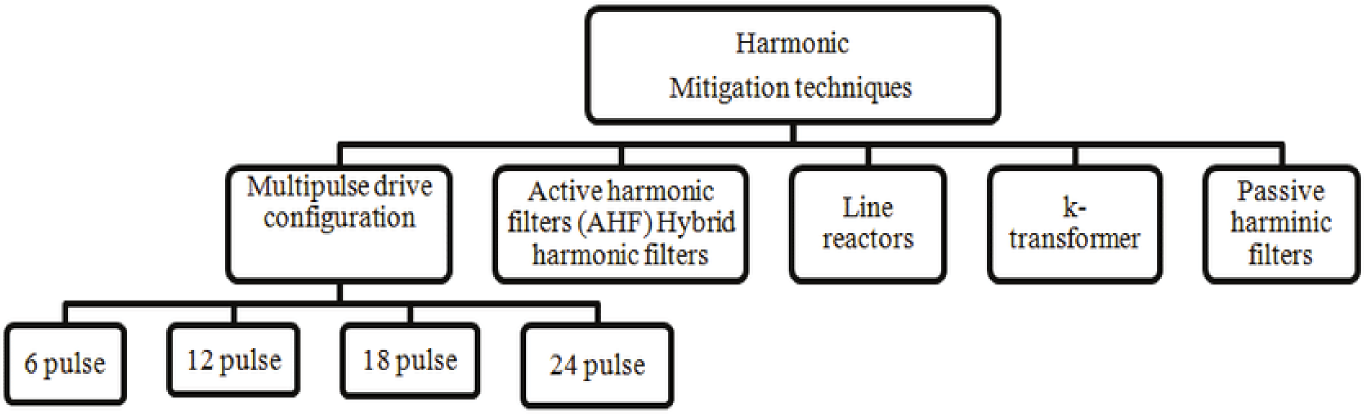

Figure 4.2 Harmonic Mitigation Technique

The shunt active power filter captures current harmonics, compensates for reactive power as well as negative-sequence current, and controls the dc link voltage between the two active power line conditioners. Because of the growing utilisation non-linear loads, power system current harmonics are a serious challenge in the distribution network. According to the literature, the shunt active power line conditioner is a viable option for resolving present harmonic and reactive-power issues. Aside from power factor correction, the shunt APLC compensates for harmonic currents generated by non-linear loads.

V. FIS CONTROL SYSTEM

Fuzzy logic is a multidimensional logic system in which each parameter in the fuzzy logic set has a membership degree. A fuzzy set is made up of three main elements: 1) the set membership function; 2) the possible domain variables for the set along the horizontal axis (X); and 3) the degree of membership determined along the vertical axis (Y) (a continuous curve that connects the domain values to the degree of membership in the set). A large class of fuzzy sets provides approximations of one or more types of members. [13] Some of these fuzzy sets are deliberately fuzzified numbers, while others just reflect the fuzzy numeric interval across a variable's domain. As a result, fuzzy numbers can take a variety of shapes, including triangular, trapezoid, sigmoid, and bell shapes, among others. The fuzzy set assigns two fuzzy values to each item: a centre value and a degree of spread. The degree of dispersion is also known as the fuzzy number's expectation (E); when the fuzzy number is a single point, it is referred to as single tone.

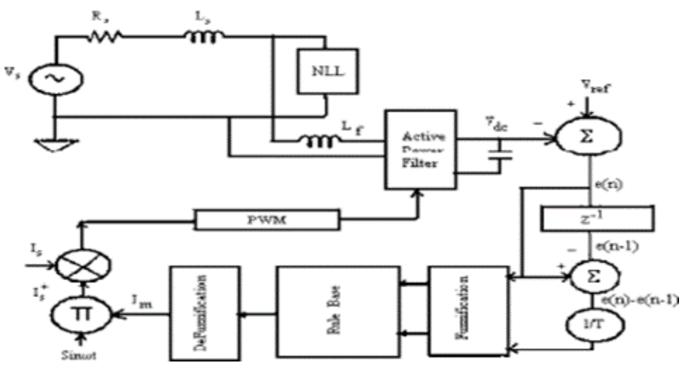

Figure 5.1 Structure of the fuzzy controller for APF

A. Fuzzy Logic Controller

LotfiZadeh, a computer scientist at the University of California, Berkeley, created fuzzy logic or fuzzy set theory in 1965 as a way of representing and processing data that is not precise, but instead fuzzy or unclear. He was initially chastised by the professional community, but Fuzzy logic (FL) gradually gained traction in the professional community's minds, eventually emerging as an entirely new field of Artificial Intelligence. Because it performs a decent job of balancing significance and precision – something people have been doing for a long time – the FL has become an intriguing subject of investigation.

The FL promotes the application of approximate human reasoning abilities to knowledge- based systems by providing an inference. The FL theory provides an analytical foundation for capturing the uncertainties associated with information, including such reasoning and thinking. The classical set theory is based on Boolean logic, where a particular object or variable is either absolutely belongs to a set □□ □*x*□ □1□, or absolutely does not belong to the set □□ □*x*□ □0□. In fuzzy set theory centered on FL, on the other side, a given object has a degree of membership in a given set that might vary from 0 (absolutely does not belong to set) to 1 (absolutely does belong to set) (absolutely belong to set). As a result, FL is frequently referred to as multi-valued logic (0 to 1) rather than bi-valued Boolean logic. As a result, FL-based techniques provide an adequate conceptual foundation for dealing with common sense representation of knowledge. [14]

Fuzzy logic has been employed in a wide range of problem domains throughout the last few decades. While fuzzy logic is a comparatively recent theory, it has a wide range of applications. L.A. Zadeh established fuzzy set theory as a strategy for dealing with the inaccuracy of practical systems in 1965.

"Almost the entire decision making in the actual world takes place in a context where the objectives, restrictions, and consequences of different actions are not understood accurately,"

Bellman and Zadeh write. This "ambiguity" or "inaccuracy" is at the heart of fuzzy sets and fuzzy logic implementations.

As an expansion of traditional set theory, fuzzy sets were developed. For long years, fuzzy logic was confined to highly specialised and mathematical technical journals, partly due to this feature. With the extremely public success of some applications requiring in the late 1980s, this dramatically changed. Power engineers rely heavily on heuristics, perception, specialized knowledge, experience, and language descriptions. Almost every practical engineering challenge necessitates some "imprecision" in approach and evaluation.

Fuzzy control is a way for formally representing, manipulating, and implementing human heuristic knowledge about how to manage a system. The block diagram of a fuzzy logic controller with a closed-loop control system is shown in Figure 3. The process outputs are designated by y (t), the process inputs are represented by u (t), as well as the fuzzy controller's reference input is represented by r. (t).

The fuzzy controller is made up of four primary parts: The knowledge in the form of a collection of rules outlining the optimal way to manage a system is stored in the rule-base. To measure knowledge, membership functions are being used. The inference system determines which control rules are applicable at this time and then determines which plant input must be activated. [15] The inputs are modified by the fuzzification interface so that they may be understood and matched to the rules in the rule-base. The defuzzification interface converts the plant's inputs into the conclusions derived by the inference engine. A circuit illustration of a fuzzy logic controller is shown in fig.

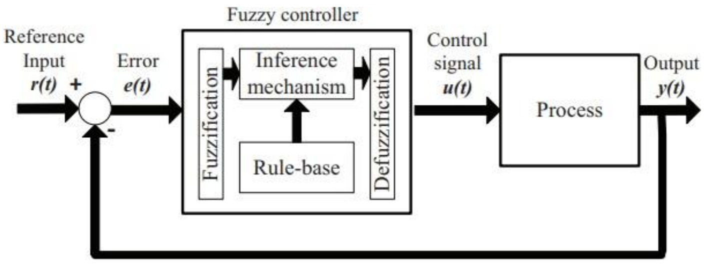

Figure 5.2 Scheme of a fuzzy logic controller

VI. RESULTS AND DISCUSSION

A simulation study is done using MATLAB/SIMULINK to study the performance of shunt active filter based on d-q transformation and SRF theory.

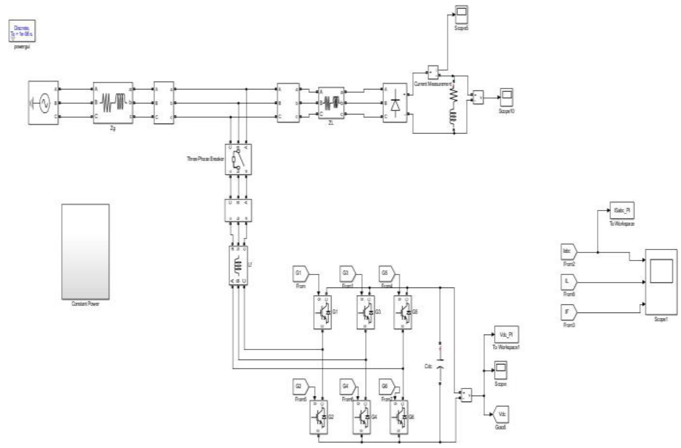

Figure 6.1 Grid system with non-linear load connected to digital active power filter at PCC

As seen in the above fig. 6.1 modelling the grid is connected to non-linear load as diode bridge rectifier connected RL load. This load generates harmonics in the system and the source currents get disrupted. A digital active power filter with six switches and DC link capacitor is connected at PCC to mitigate harmonics in the system which is controlled by PQ theory. The modelling of the PQ theory can be seen below in fig 6.2

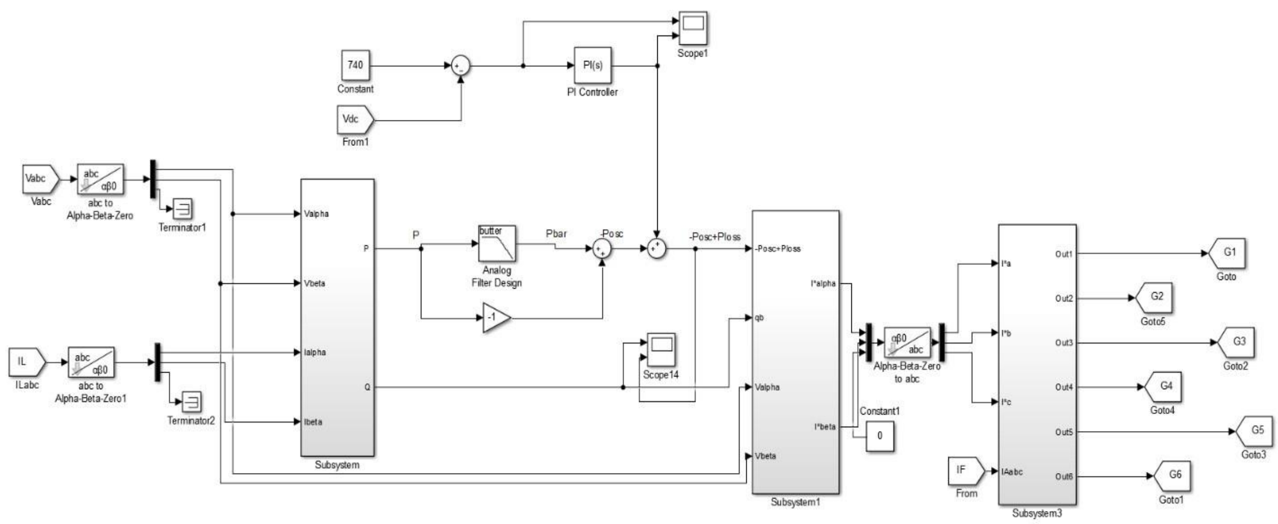

Figure 6.2 PQ theory control structure with PI controller of digital active power filter

The Ploss signal is generated by comparison of reference DC value with measured DC link voltage fed to PI controller. The below fig. 6.3 is the hysteresis current loop controller for generation of pulses to digital active power filter IGBT switches.

There are many techniques of generation of gating pulses but the most widely used technique is hysteresis controller because of this simplicity and quick response. This technique also does not require the knowledge of load constraints. Variation of switching frequency with variation in fundamental period of load parameters is one of the drawbacks of this.

In hysteresis controller the reference current which was obtained by SRF technique or instantaneous power technique are compared with the filter current. For generation of gate pulses of switching elements according to the need of injecting power into the line, this controller is used. It compares the reference current (generated by instantaneous power theory inside the controller) and the filter current to generate the gate pulses.

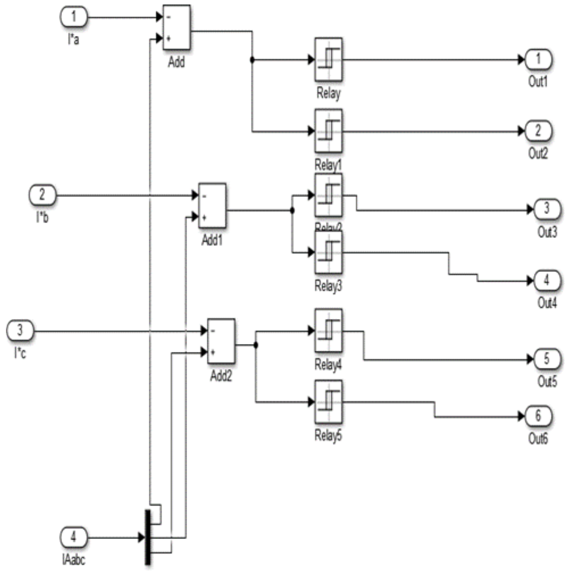

Figure 6.3 Hysteresis current loop controller for generation of pulses

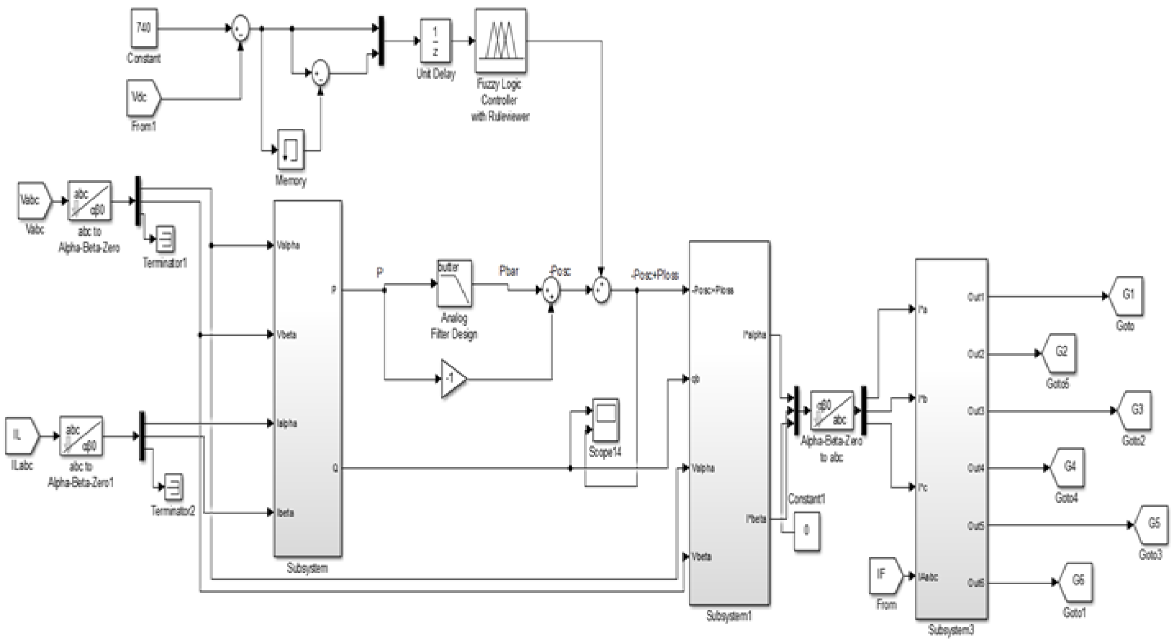

Figure 6.4 PQ theory control structure with FIS controller of digital active power filter

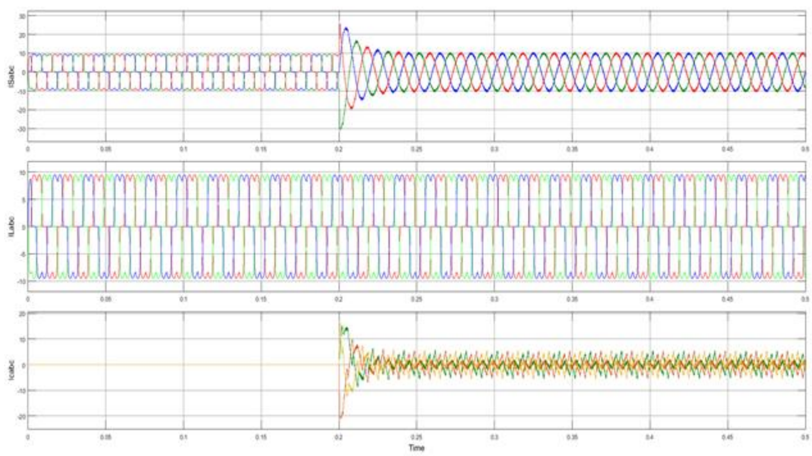

Figure 6.5 Source currents, Load currents and compensating current before and after digital active power

filter

The above fig 6.5. Shows the source currents, load currents and compensation currents from the digital active power filter comparison before and after the device connected at 0.2sec

The PQ theory is further updated with FIS controller at the DC link comparison and the simulations are carried out with 0.5sec simulation time. From 0-0.2sec there is no digital active power filter connected, and at 0.2sec the device is connected and from 0.2-0.5sec the system is with digital active power filter. The results of system currents and DC link voltages with THD analysis of the source current are given below in fig 6.5.

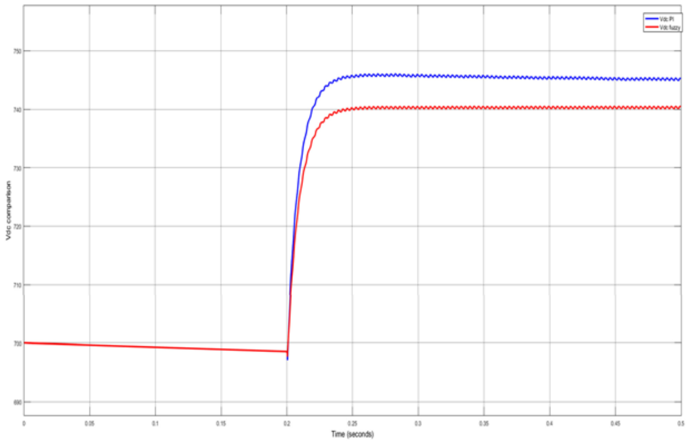

Figure 6.6 DC link voltage comparison at DC capacitor with PI and FIS controllers

The above fig 6.6 is the DC link voltage comparison of PI and FIS controller of the PQ theory.

Fast Fourier Transformation (FFT) :

FFT is algorithm for calculating Discrete Fourier analysis of complex calculation signals. Then it is used for calculating total harmonic distortion (THD) in signal. THD is measure of harmonic distortion in signal. It is ratio of sum of power of all harmonic components to the power of fundamental frequency.

The THDs of the source current without and with digital active power filter by PI and FIS are shown below in fig 6.7, 6.8, and 6.9.

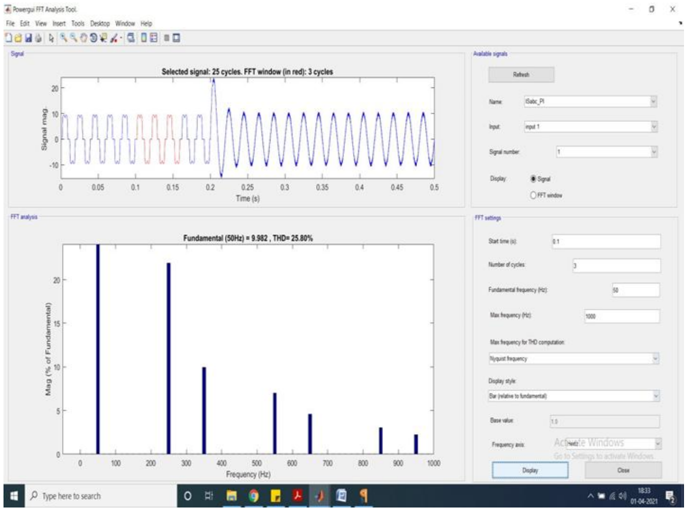

Figure 6.7 THD of source current without digital active power filter

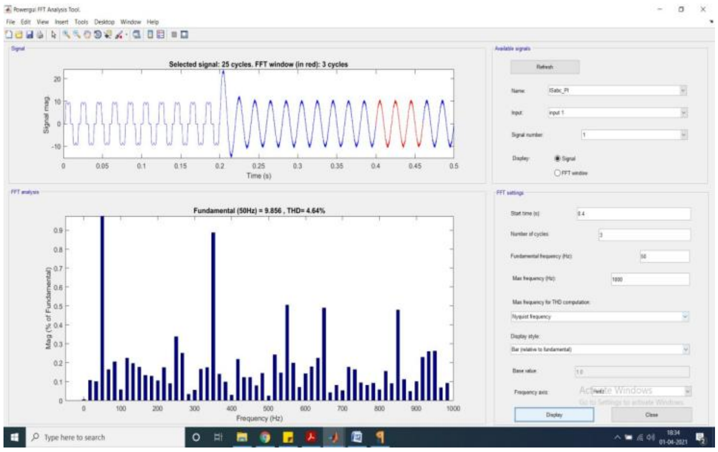

Figure 6.8 THD of source current with PI controller digital active power filter

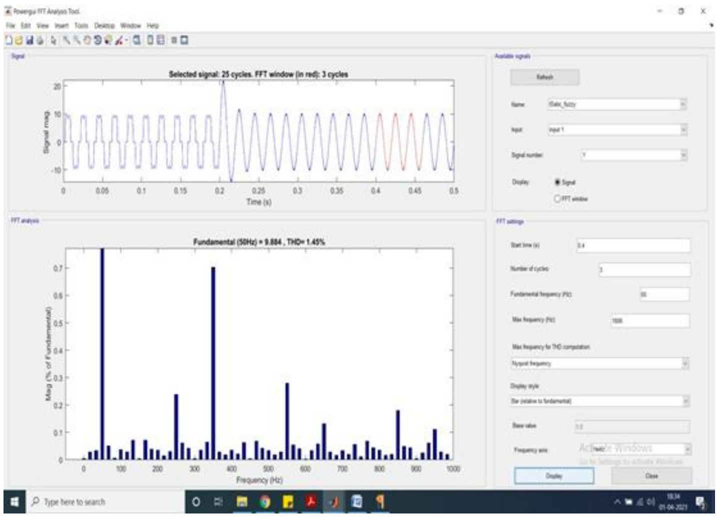

Figure 6.9 THD of source current with FIS controller digital active power filter

CONCLUSION

As seen in the figures above, harmonics are mitigated when the grid system with non-linear load is linked to a digital active power filter. This changing PWM signal is formed by combining Park's transformation with a digital PI controller. These PWM signals are control signals for a voltage source inverter (VSI), which injects harmonics of the same magnitude at a 180-degree shift to balance out the effects of harmonics or distortion in the power line. In comparison to the PI controller, the FIS controller generates a more precise DC link voltage of 740V. The THD of the source current is 25.8% when no digital active power filter is attached, and it is decreased to 4.64% when linked to a device controlled by PI controller PQ theory. The THD is lowered to 1.45% when the PQ theory is upgraded with the FIS module. As a result, the performance of the digital active power filter improves when the controller is upgraded with the FIS module.

FUTURE SCOPE

The research and application of various shunt active filter control systems assists in the reduction of power quality issues in electrical utilities. Soft computing techniques, such as fuzzy logic control, may also be devised and tested extensively. The FIS controller may be modified using adaptive controller and optimization methods to improve DC link voltage settling time. When these controllers are used in conjunction with a device, peak current production may be lowered.

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