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POWER QUALITY IMPROVEMENT BY MITIGATION OF HARMONICS USING COMBINATION OF PASSIVE AND ACTIVE FILTER

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ABSTRACT

Order to improve the power quality in MATLAB Simulink, this paper presents a modeling and simulation-based study of a system made up of a hybrid energy source based on solar photovoltaic and wind turbine energy sources, a traction load, specifically an induction motor, and a shunt active power filter connected between sources and load. The over-reliance on coal-based thermal energy, which produces significant environmental damage despite being abundant and inexpensive, accounts for about 40% of global power output. To address this, the adoption of non conventional resources power should be encouraged. There are two renewable energy resources: solar and wind. that are most frequently used. each has drawbacks of its own, such as reliance on irradiance levels, issues with solar PV array overheating, and dependency.

Keyword :- THD, SAPF, PWM, VFD, Harmonics, Frequency

INTRODUCTION

Subservience and their business and industrial customers are increasingly worried about the quality of power. In recent years, system loads have increased. controls that are sensitive to power quality, and an increase The number of system loads causing poor power quality (for example, harmonics produced by variable-speed motor drives). Computers, industrial control systems, and communications devices are extremely sensitive to power quality. fluctuations caused by system disturbances than in the past. There was also. Power electronics' usefulness has grown over time. Components to increase the overall efficiency of the power system. To make controls simpler to implement. These gadgets impair the power quality. End customers looking for high power quality for theirs appliance are becoming more aware of voltage problems such as voltage sags, swells, surges, harmonic distortions, interruptions, outages, under voltages, over voltages, electrical noise, frequency deviations, impulses, transients, and notches. To mitigate the effects of disturbances on sensitive loads, appropriate specifications or power conditioning systems should be designed and implemented. [1]. The high number of restrictions complicates managing power system harmonics and often leads to costly mitigation measures that do not help customers or the power system overall. Improving the situation can yield significant communal benefits[2]. Harmonic limitations have become widely accepted throughout time, despite a lack of defined process for their selection. This paper proposed a a novel methodology based on only four different limits: There are recognized physical impacts. These restrictions depend on limiting Additionally, harmonic thermal losses occur in motors and capacitors. Reducing voltage waveform distortion affects the operation of full-bridge rectifiers. These boundaries are derived. Quantifying the damaging harmonic effects on customers and network infrastructure[2].

HARMONICS

A harmonic is a periodic wave (or signal) with a frequency that is an integral multiple of the fundamental frequency. Non-linear loads, including furnaces, inverters, rectifiers, and variable speed drives, all generate harmonics. These currents have a 50 Hz fundamental frequency component, with additional multiples of the fundamental frequency shared by several overlapping currents. The end result is current (and thus voltage) distortion, which has a range of downstream consequences. effects. The graph below depicts harmonic waveforms of higher frequency, which can affect the overall effect of a sine wave.

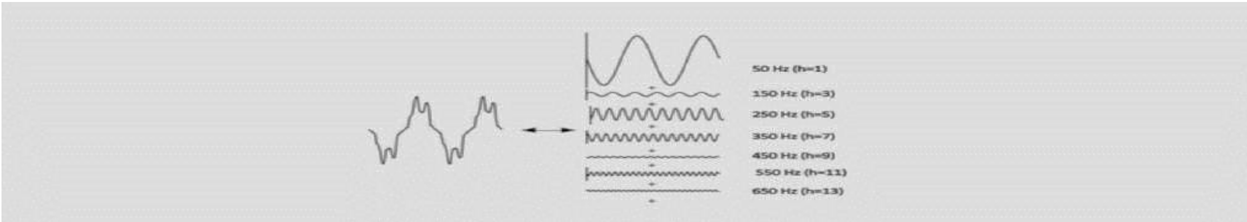


Figure No. 1

IEC/TS 61000-3-12 applies to equipment that draws current >16A and 75A per phase. IEC 61000-4-7 specifies the harmonics measurement and evaluation procedures for both standards. Harmonic distortion from nonlinear loads in the electricity grid is a major concern for both customers and utilities[3]. Harmonics in a system can originate from a variety of sources. Harmonic voltages in medium-voltage networks can be caused by equipment connected to low-, medium-, or high-voltage networks[4]. As a result, each particular piece of equipment can only produce a portion of any compatible harmonic voltage level, limiting efficiency and introducing other problems as well[4]. As a result, harmonics play a significant role in the decline of power quality rating. THD is a common method for measuring the harmonics in a system. A system's THD is defined as"a measure of the distortion or impurity present in an electrical. system's voltage or current waveform due to the presence of harmonics." The following expression is used to compute a system's THD.

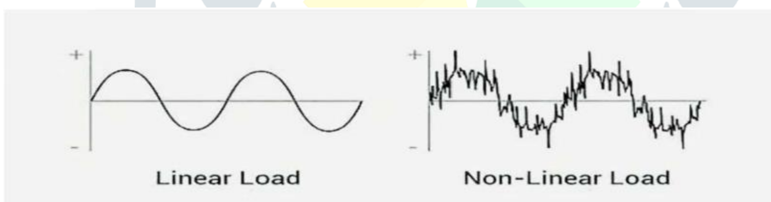


Figure No. 2 Linear and Non-Linear

$$\frac{\sqrt[2]{\sum_{N=2}^{\infty} V_N^2}}{V_{1(rms)}}$$

Harmonics can be measured using a variety of methods, including the fast Fourier transform. Y. Baghzouz's two-part study on time changing harmonics reveals the issues connected with computing non-steady state harmonics, summation of time-varying harmonics, harmonic power flow calculations, and applications. The first section of this paper examines potential issues with time- varying harmonic measurement and concludes that the Fast Fourier Transform (FFT) has numerous flaws, including multiple peaks in probability densities. The study also indicates that by dissecting the signal via calculations, might reduce this difficulty to some level[5]. The second section of the essay discusses the summation and propagation of harmonics with random components. The study included numerous statistical techniques for gathering data on harmonics in the system[6]. Because the intricacy of such data is difficult to analyze using traditional methods, ML models have emerged as an appropriate way for doing so.

VOLTAGE HARMONICS: In particular, we investigated the harmonics in two samples of major customers at 150 kV and one sample of large consumers at 70 kV in high voltage networks[21]. The results demonstrate that two significant customers' Total Demand Distortion (TDD) situations exceeded 4% of the IEEE standard limits 5191992[21]. In particular, the cause was the client who had an arc furnace load of the network's most recent harmonic pollution.

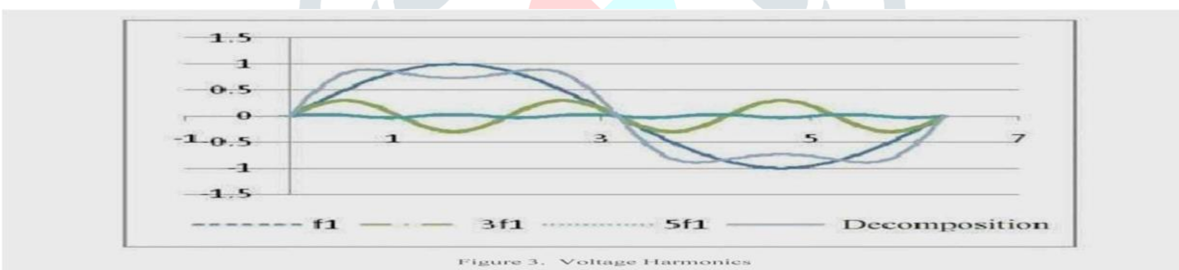


Figure No. 3 Voltage Harmonics

Limits to harmonic voltage distortion Voltage distortions are divided into three types: single fast voltage shifts, voltage dips and swells, and ripples. Overvoltages, phase imbalance, flicker, and harmonics are all instances of transient overvoltages[7].

CURRENT HARMONICS: Current harmonics are aberrations from an electrical system's ideal sinusoidal current waveform. Extra currents at integer multiples (harmonics) of the fundamental frequency of the power source are indicative of these aberrations. Depending on the area, the fundamental frequency is typically either 50 Hz or 60 Hz. International harmonic standards define by IEEE 519 and IEC 61000.3.6 power systems voltage harmonics [2].

The guidelines outlined supply constraints for VTHD and individual harmonics. Limits between h=2 and h=40 are routinely studied, implying that achieving standards often requires meeting 40 distinct criteria. IEC and IEEE standards have very different harmonic constraints for similar harmonics, which emphasizes how arbitrary the current limitations are[2].

LOW FREQUENCY HARMONICS: High frequency harmonics are resisted by inductive loads, which causes I2R losses and low harmonic currents.[2] Low frequency harmonics (h≤13) interpret inductive loads as having low impedance, which raises harmonic currents and I2R losses[2]. .Electrical systems to avoid excessive heating losses in low frequency harmonic voltages and currents, limit motors that are synchronous and induction [2]. High frequency harmonics (h>13) typically have a detrimental effect currents in capacitors. Client loads, such as tiny switch node power supplies, contain capacitors. or as a part of the power system network, power factor correction equipment [2].

HIGH FREQUENCY HARMONICS: High frequency harmonics (h>13) can cause capacitor currents to drop[2]. Small switch node power supply and other client loads contain capacitors, or they can be found as a Equipment for adjusting power factor is a crucial part of the power network system [2].

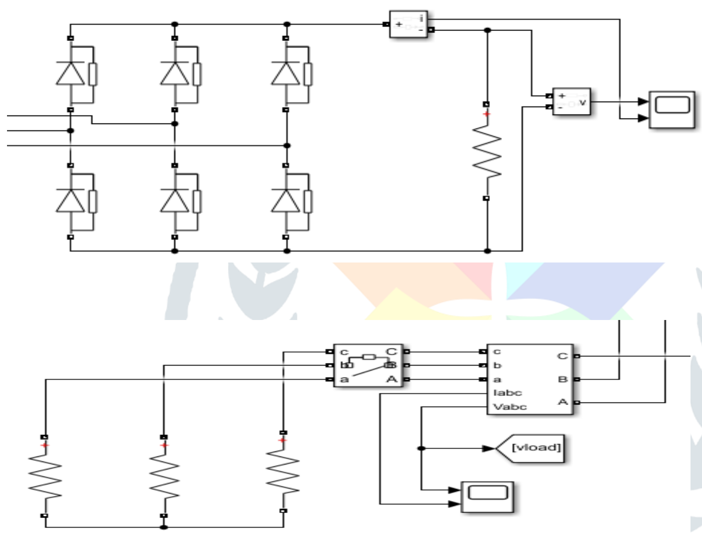
MITIGATION OF HARMONICS

Harmonic mitigation systems are classified into three types passive harmonic filters, active harmonic filters, and hybrid harmonic filters. Passive filters include tuned harmonic filters, converter circuits with larger pulse numbers, and series reactors. This approach consists of two basic parts: a capacitor and an inductor. Chang-Song's research explores the effectiveness of harmonic distortion power, as described in IEEE standard 1459-2010, for detecting harmonic sources[8]. There are three types of harmonic filters: hybrid, active, and passive. Series reactors, converter circuits with more pulses per cycle, and tuned harmonic filters are examples of passive filters. There are two main components to this approach: a capacitor as well as an inductor. Chang-Song investigates the usefulness of harmonic distortion power in his studies, such outlined in IEEE Standard 1459-2010, to identify sources of harmonic distortion. It proves that the It is possible to effectively use the link between apparent and instantaneous power to ascertain the harmonics source It demonstrates that the relationship between instantaneous and apparent power can be efficiently exploited to determine the source of harmonics[8]. M. Erhan Balci verifies many approaches (APD, SLQ, HG, LC, SP, and NP) for detecting harmonic sources in a typical distribution system. Validation was performed on three important loads: an RL load corrected using passive capacitors, a collection of impedances with varying power factors, and an active compensator[9] . An electronic circuit known as a passive filter uses passive parts to selectively allow or block particular electrical signal frequencies while allowing other frequencies to pass through. These parts include resistors, capacitors, and inductors These filters are commonly used in applications such as audio processing, signal conditioning, and RF (radio frequency) communications to change a circuit's frequency response or reduce unwanted noise. They don't need an external power supply. Some of the different types of passive filters are band-pass, low-pass, high-pass, and band-stop (notch) filters; each has a unique filtering function[2]. An advanced electrical device that reduces harmonic distortion in power systems is called an active power filler. Unlike passive power filters, active power filters make use of active electrical components and control algorithms to actively mitigate and lower the system's harmonic currents.. As a result, they are particularly effective at addressing harmonic issues in complex and dynamic power systems. Active power filters constantly check the current waveform at the connecting point. They can detect harmonic frequencies and magnitudes in real time[11]. Shunt active power filters, or SAPFs, are a type of specialized electrical apparatus.[18]Power quality is raised in electrical power networks while harmonic distortion is reduced. It is linked concurrently with the actively safeguarded lead. adjusts for voltage variations and harmonic currents. An controls the reference current PI. Generalized Instantaneous Power Theory is used as an SMC controller. The PI controller's FFT analysis of THD is 0.46%, and the PI plus SMC controller's FFT analysis of THD is 0.37%. are tested concurrently and implemented in Simulink[20]. The active part of a hybrid active power filter is part that eliminates higher order harmonics and passive filters calibrated for fifth and seventh order Lower order harmonics are attenuated by harmonic frequencies.[22]which improves power quality and eliminates harmonic distortions. It actively compensates for harmonic currents and reactive power in real time and is connected in parallel with the load it protects.[18] Shunt active power filters can change power factor and are particularly effective at reducing harmonic distortion caused by nonlinear loads.[18] The shunt APF continually monitors the current waveform at the connection site. It recognizes harmonic frequencies and magnitudes. Based on the detected harmonic content, the shunt APF generates compensatory electrical currents that are 180 degrees out of phase with the measured harmonic currents. These regulating currents eliminate the harmonic components[16].

PROBLEM IDENTIFICATION

Traditionally, nonlinear load applications were mostly found in large industrial applications such as arc furnaces, large variable frequency drives (VFD), heavy rectifiers for electrolytic refining, and so on. Often, skilled individuals were responsible for localizing and controlling their harmonics.These days, standard home voltages and nonlinear loads are used more often in the commercial and industrial sectors. Electrical systems and appliances that draw current that is not proportionate to the applied voltage are known as nonlinear loads. In contrast to linear loads, which have linear current and voltage fluctuations, nonlinear loads have nonlinear voltage-current characteristics. Nonlinear loads include things like air

conditioners, rectifiers, refrigerators, arc furnaces, and induction heating equipment. The voltage-current relationship between resistive heaters and incandescent lights is simple and linear. Through voltage and current distortions brought on by non-linear loads, equipment failure, flickering lights, and increased heat in transformers and conductors can all be signs of poor power quality. Electronic gadgets like LED lighting systems, laptops, and televisions frequently have non-linear demands. Non-linear loads are frequently used in industrial applications. Examples of these include switch-mode power supplies (SMPS) for converting AC to DC power and variable frequency drives (VFDs) for motor control. The pulse waveform with a high crest factor is the most prevalent kind of distorted current. One such load is the SMPS, which has a large filter and a 2-pulse rectifier bridge to convert AC to DC.Its DC bus has a capacitor. Short, high-amplitude pulses of power are periodically drawn by the SMPS. which converts AC to DC using a 2-pulse rectifier bridge and a big filter.It has a capacitor on its DC bus. An intermittent supply of brief, high-amplitude power pulses is drawn by the SMPS. the voltage's positive and negative peaks. Large current spikes typically result in 120VAC is the required supply voltage for the clip or flat-top. The current waveform of the "double-hump"Distribution system clipping at 480V or 600V can also be caused by a 6-pulse rectifier in a UPS or VFD. The system's harmonics are substantially greater than required. We can therefore conclude that a significant source of harmonics in the power system is nonlinear loads. Both nonlinear loads and harmonics are known to be significant contributors to power quality degradation.



Non Linear Load connected in the MATLAB simulation

1. Rectifier Load
2. Unbalanced three phase load

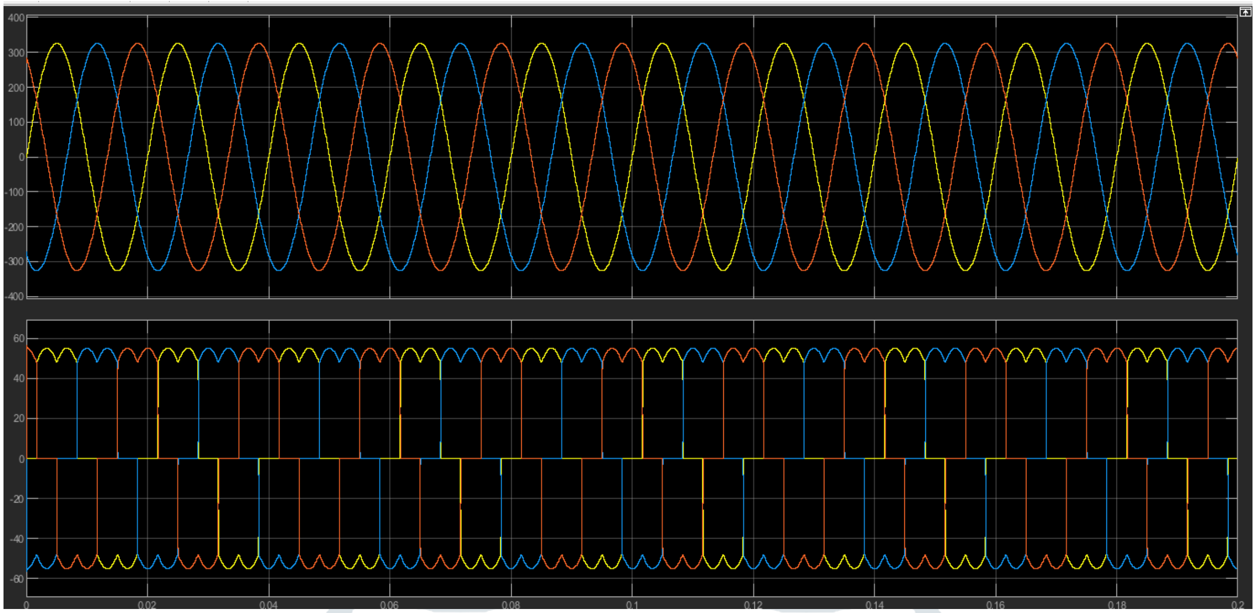


Figure No. 5 Obtained waveform containing harmonics distortion

PROPOSED METHODOLOGY

An unbalanced three-phase resistive load is attached to simulate the impact of unbalance on system power quality. These loads are responsible for generating harmonics in the system. The system often carries both linear and non-linear loads. Nonlinear load (changing frequency driving) is the source of power quality issues. Our asynchronous motor's integrated load is a nonlinear load that has grown over time to accommodate loads in both home and commercial settings. These include harmonic distortion, voltage fluctuations, and noise. Harmonic distortion in low-voltage distribution networks can cause power losses, device heating, insulation failures, communication system interference, and even breakdown of the power system. For the sake of both the utility and the customer, power quality issues must be resolved.

THD(%)=√($ID2 + ID2 + ID2+. . . ID2$) 2 3 5 n

Total harmonic distortion (THD) refers to the cumulative impact of harmonics on a network's voltage or current waveform.

$$THD_v(\%) = \frac{1}{V_1}\sqrt{\sum_{h=2}^{\infty} V_h^2 \times 100}$$

$$THD_i(\%) = \frac{1}{I_1}\sqrt{\sum_{h=2}^{\infty} I_h^2 \times 100}$$

Non-linear loads produce harmonics, resulting in a total harmonic distortion (THD) of 30.23%. To reduce harmonics, a shunt APF is added to the transmission system at the PCC.

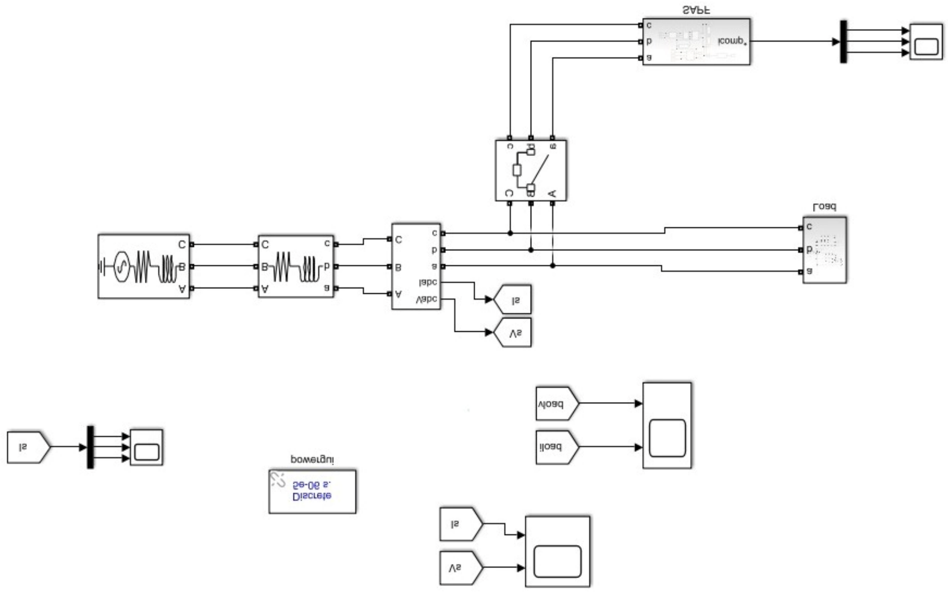


Figure 6. Proposed model for power quality improvement

APF is the best solution for power quality issues as it utilizes a voltage source inverter and offers benefits such as better filtering accuracy, fast dynamic response, and flexibility. This makes it The Shunt Active Power Filter (SAPF)'s harmonic mitigation relies on a compensation control algorithm and detecting reactive and current harmonics.The PQ theory and harmonic current compensation methods employed in PWM-based voltage source inverters significantly impact harmonic current compensation efficiency.

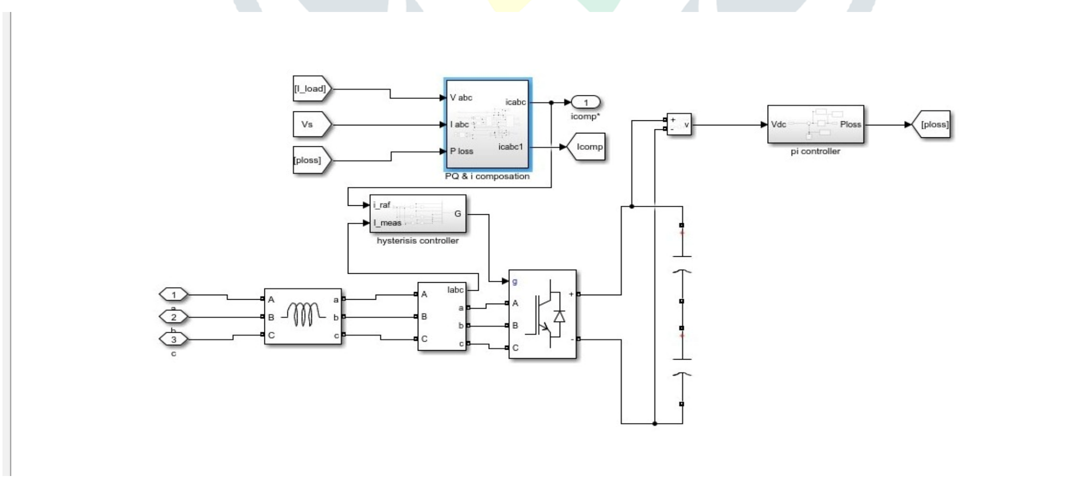


Figure 7. Proposed model of Shunt APF

It makes use of supplied by a DC-link capacitor and a VSI along side PWM. The control circuit continuously observes the harmonic current variation in order to estimate the instantaneous reference compensation current. It then perfectly synchronizes the power circuit to generate the necessary harmonic current. The efficiency of harmonic current compensation is heavily influenced by P&Q theory and the harmonic current compensation techniques employed in PWM-based voltage source inverters. PQ theory is based on Clarke's Transformation, which converts stationary a-b-c coordinates to oscillatory 0-$\boldsymbol{\alpha}$-$\boldsymbol{\beta}$ coordinates. In our study article, we ignore zero sequence values due to load The following formulas are used in the Clarke Transformation to convert three phase current and voltage from a-b-c coordinates to $\boldsymbol{\alpha}$-$\boldsymbol{\beta}$ coordinates.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Next, we have determined the fundamental instantaneous active power and reactive power values for the three-phase system using the following formulas Then, for the three-phase system, we have calculated the value of fundamental instantaneous active power and reactive power as follow

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

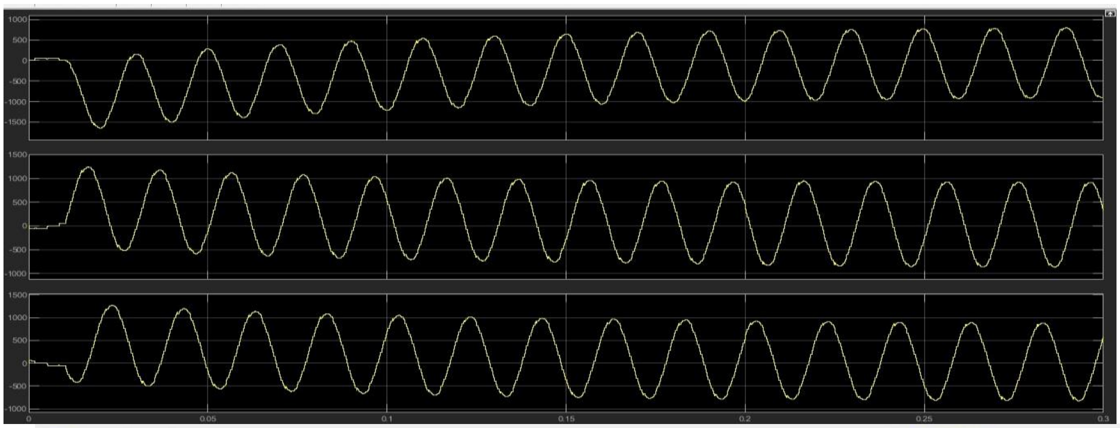
In $\boldsymbol{\alpha}$-$\boldsymbol{\beta}$ frames, the fundamental reactive power and instantaneous , P and Q, will exhibit a DC signal, whereas harmonic-infused P and Q will appear as ripples. Then, using the inverse Clarke Transformation, reference current is created. Harmonic components were obtained. The oscillating bits of P and Q were retrieved using a low pass filter (LPF). The complex sum of P and Q can be expressed in $\boldsymbol{\alpha}$-$\boldsymbol{\beta}$ coordinates as:

$$P = \overline{P} + \widetilde{P}$$
$$Q = \overline{Q} + \widetilde{Q}$$

The adjusted currents in $\boldsymbol{\alpha}$-β coordinates are calculated without considering zero sequence value. Using the inverse Clarke Transformation, we can calculate the values in a-b-c coordinates based on the $\boldsymbol{\alpha}$-$\boldsymbol{\beta}$ coordinates. The hysteresis controller generates the switching signal for the Voltage Source Inverter (VSI) based on the above parameters. The VSI switches are turned on and Considering the variation between the related reference currents to detect errors. Maintain the real current inside the hysteresis band. These inverters provide required correction for transmission lines. The above procedure continues in the DC-link loop, reducing harmonics.

RESULT

The waveform below displays the compensation current used to compensate for harmonics.



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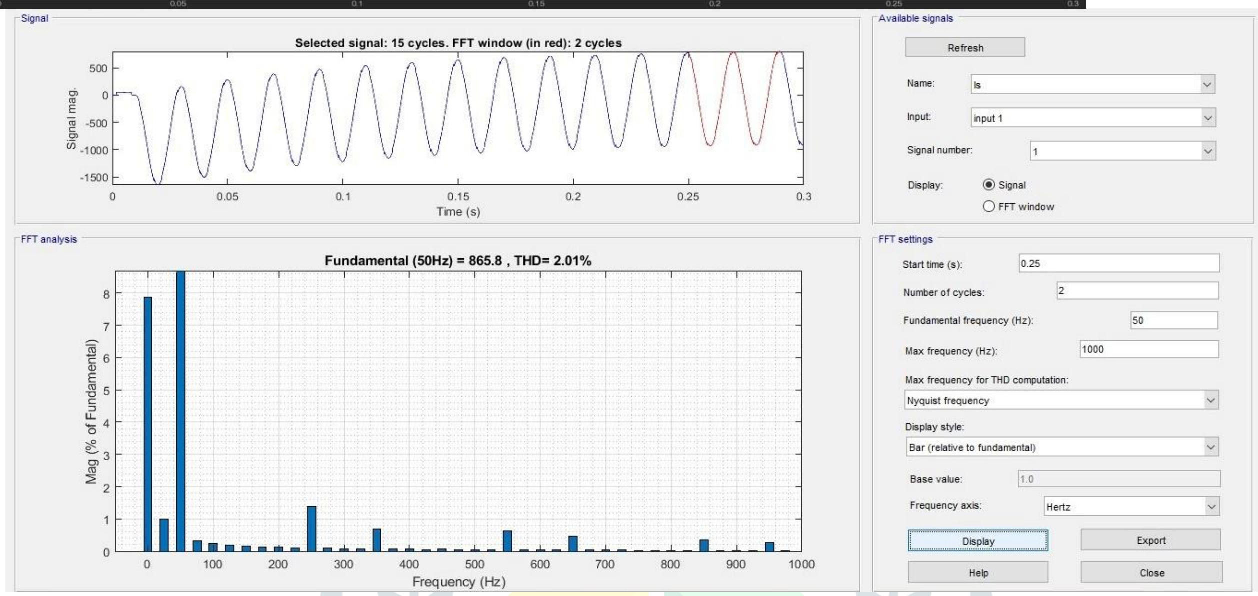

Figure 8waveform of compensation current

Figure 9. Fast fourier transform analysis illustrating the harmonics' magnitude in relation to the fundamentals

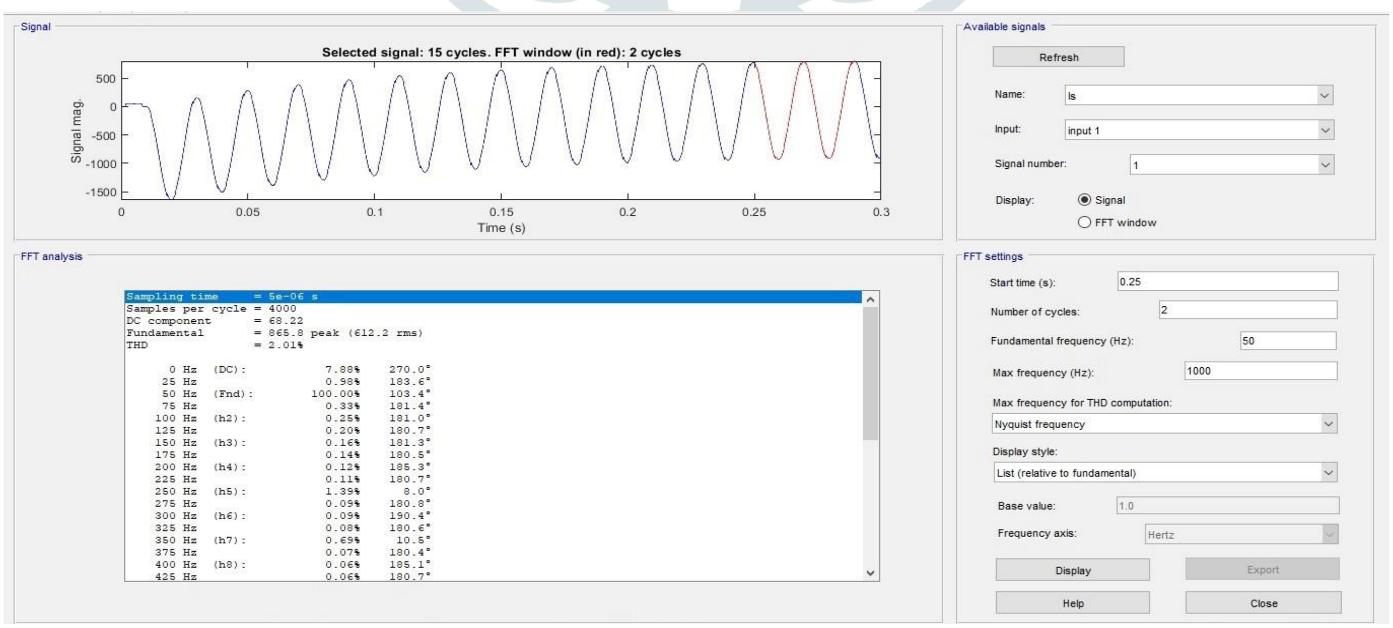

Figure 10. The FFT analysis shows the percentage of each harmonic's distortion in relation to the fundamentals

Filtered source and load current waveforms are produced by the proposed Shunt APF when it is connected in a shunt configuration to the load at the point of common coupling (PCC). As can be seen from the FFT analysis, adding the Shunt APF produced a lowers the system's Total Harmonic Distortion (THD). Adding the Shunt Active Power Filter reduced the THD from 30.23% to 2.01% of the fundamental value. Comparing the system to the baseline, the THD decreased by 93.43%. Furthermore, every harmonic component were lessened by The fifth, seventh, and eleventh harmonics showed increases of 93%, 94%, and 94%, in that order. from each's starting values.

CONCLUSION

According to FFT analysis, the THD was reduced from 30.23% to 2.02% under the impact of balanced and unbalanced non-linear loads (rectifier and unbalanced three-phase resistive load), which is a 93% reduction from its initial value. worth. The 93% efficiency rate indicates that the system can effectively reduce low order harmonics. and 94% mitigation in the major harmonics' fifth and seventh harmonics, respectively. elements in charge of the poor power quality. The system's power quality is therefore enhanced.

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