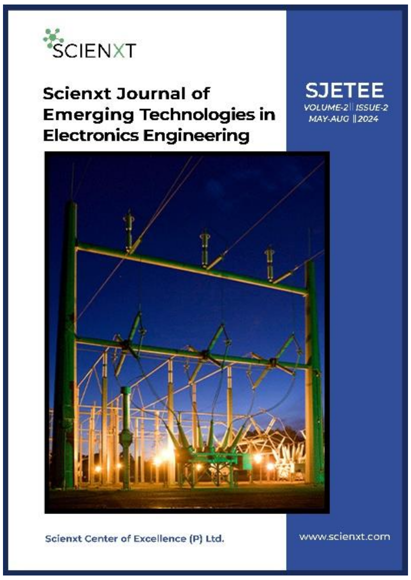

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'Harmonic deduction using single phase active power filters controlled by a hysteresis current controller devices'

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Abstract:

This article describes the use of power filters to apply negative feedback to one-time plans. Harmonics are produced when the PCC is connected to a nonlinear load. Single stage active power filter reduces harmonics. In order to prevent elect ronic products from being damaged by harmonic injection, electronic filters are used to suppress harmonics generated by nonuniform components. This unique si ngle-stage power filter uses a half-bridge with shared capacitors. To compensate for the harmonics in the field current, the generator usually uses parabolic pulse width modulation (PWM) to control the two power supply voltag es. Unlike parabolic PWM, the harmonic current is reduced using a hysteretic mechanism. Circuits of both controllers, including active filters and single- phase networks, are modeled in MATLAB Simulink and their time plans are created.

Keywords:

Power factor enhancement; harmonics suppression; shunt active power filter; parabolic pulse width modulation.

1. Introduction:

Filters are networks with the ability to selectively pass signals of a desired frequency while rejecting or dampening those of other frequencies. Pass bands refer to the frequencies that make it past the filters, whereas stop bands refer to the frequencies that are completely blocked or muted. The cut-off frequency is the dividing frequency between the pass band and the stop band. Working properties, area of application, connection between arm impedances, frequency characteristics, etc. are only few of the criteria used to categorize filters.

These filters are broken down according to their respective fields of use:

(1) Passive filters

(2) Active filters

(3) Hybrid filters

Power quality might vary in the following ways since it is difficult to obtain a perfect power source in the actual world:

1.1. Voltage:

(1) Voltage sag and swell, or fluctuations in peak and RMS values

(2) Flickering: sudden, obviously occurring shifts in brightness that result in intermittent or cyclical voltage fluctuations.

(3) Voltage spikes, impulses, or surges: momentary, extreme increases

(4) When the nominal voltage dips below 90% for more than 1 minute, this is known as "under voltage."

(5) When the nominal voltage stays at or above 110% for more than a minute, an overvoltage condition has occurred.

1.2. Frequency:

(1) frequency variations

(2) Non zero low-frequency impedance

(3) Nonzero high-frequency impedance

(4) Harmonics at lower frequencies

(5) Inter harmonics at higher frequencies

1.3. Waveform:

(1) Voltage and current fluctuations typically take on the shape of a sine or cosine function. However, flaws in generators or loads may cause these patterns to deviate from the norm.

(2) Harmonics are voltage and current aberrations that are faster than the normal frequency and are often caused by generators and loads, respectively.

(3) Total harmonic distortion (THD) refers to the degree to which harmonics cause a waveform to deviate from its ideal form.

(4) Vibrations, buzzing, losses, and overheating May all result from these distorted waveforms.

1.4. Some examples of filters are as follows:

Band pass filters are electronic circuits that allow communications between two specific frequency bands to flow through while blocking all other frequencies. These filters, known as active band pass filters, need an external power source and active components like transistors in order to function. However, passive band pass filters don't need any kind of power supply.

Using a signal filter, you may get rid of any extra noise in the signal. Some of the frequencies are eliminated while others are kept in order to improve efficiency and get rid of noise.

A well-implemented sinusoidal filter is widely used in engines and has several advantages. The engine's lifespan may be extended by minimizing harmonics and cutting power consumption. The engine will be more efficient and have less heat buildup. Additionally, it dampens vibrations and dampens voltage spikes.

2. Passive filters:

Harmonics may be tamed with the help of passive filters, which are made up of inductance, capacitance, and resistance components tuned to certain specifications. Passive filtering methods based on the utilization of:

(1) Filters with a low impedance route to harmonic currents, either singly or doubly tuned.

(2) High or band-pass filters (damped filters) that may remove harmonics from a specified frequency range.

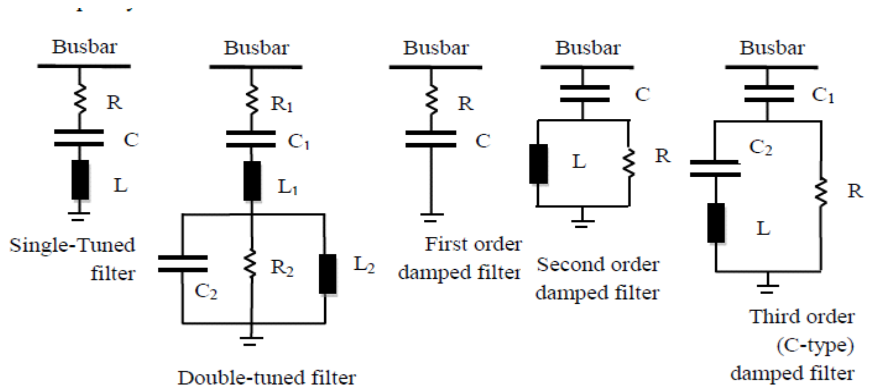

Figure. 1: Passive filters

When compared to other methods, passive filters for lowering harmonic distortion are cheap. However, there is a risk that they may disrupt the electricity grid, therefore it is important to test for any unintended consequences before putting them into operation. The passive control filter is seen in Fig. 8.

Harmonic generators (nonlinear loads) are closer to where passive filters perform best. If the load causes any substantial harmonics or other frequency components, the resonant frequency must be far out of their way. For security reasons, filters are often adjusted somewhat below the harmonic frequency. Since passive filters are vulnerable to overloading, which may quickly lead to excessive overheating and thermal failure, designers must account for projected increases in harmonic current sources or load reconfiguration. Due to the fact that passive filters may provide reactive compensation, depending on the size of the volt-ampere and the voltage of the capacitor bank utilized, they can do double duty by delivering both the filtering operation and the power factor at the correct level. It's important to keep in mind that a certain amount of reactive compensation would be offered by both filters if more than one were utilized, such as a set of 5th and 7th or 11th and 13th divisions.

A capacitor and an inductor connected in parallel make up the passive filters of the series. They exhibit a high impedance on the load side of all harmonic currents and a simple frequency impedance. Harmonic current may be prevented from permeating to the remainder of the grid by using shunt passive filters with low impedance to the harmonic frequencies. Power systems often use shunt passive filters instead of series passive filters due to the former's advantages. Shunt filters must let harmonic currents to flow in the load but block them in the utility. If the load's harmonic currents are prevented from flowing, as they are by series filters, the resulting load voltage will be unbalanced. Single tuned filters and high pass filters are the most typical passive shunt filter types. The largest currents are often seen at the lower order harmonics. This necessitates the use of very low-impedance filters operating at the relevant frequencies. A

Single-tuned filter is a series LC circuit tuned to a specific harmonic frequency, such as the third, fifth, seventh, eleventh, or thirteenth. As can be seen in Fig. 1.1, we have a regular passive filter set to low frequency harmonics.These filters are made with a low impedance route to facilitate the passage of harmonic current in the load. If the source impedance, Ls, was likewise very low, then the LC components by themselves would be ineffective. By connecting an inductor Lf in series, the LC segments take on the role of preferred low-impedance path for the resulting harmonics. The total amount of energy saved may be calculated using simple current division by knowing the value of Ls for each harmonic. At the fundamental frequency, the Lf reactance should be rather small, but at higher frequencies, the impedance should be quite large. As the ratio of the inductive or capacitive reactance to the resistor at resonance, the value of the resistor R determines the quality factor Q of each tuned filter. Q values typically range from 15 to 80 for filters used in commercial and industrial settings.

Since the higher-order harmonics are of lesser amplitude, it is usually not cost-effective to utilize several tuning filters to get rid of them. The high-pass passive filters exhibit low resistance throughout a broad frequency range, including the 17th and higher harmonics. Fig. 1.2 depicts four distinct types of high-pass filters. Due to its high power loss at the fundamental frequency, the first-order version with a large capacitor is seldom used. The second and third order kinds are easy to implement and provide effective filtering results. The third order kind has reduced losses at the fundamental frequency but is less effective as a filter. The purpose of the new circuit, designated as type C, was to lessen the power loss of the older kids 2 and 3. To get around the resistor (C2-L), a simple frequency-tuned arm is used in this filter. This circuit has smaller losses, but is more sensitive to frequency fluctuations due to its fundamental frequency tuning.

Historically, passive filters' primary function has been to limit the flow of harmonic currents in distribution systems that are specifically designed for that purpose. However, their output is limited to only a few harmonics, and they may cause resonance in the electrical grid. The passive filters use reactive storage devices like capacitors and inductors. Passive filters, especially shunt LC filters and shunt low pass LC filters, are ubiquitous. Its simplicity, longevity, low cost, and effective operation are just a few of its advantages. Problems with tuning and possible detuning are also present, as are resonances introduced into the ac supply and the filter performance, which is a function of the device's overall setup.

3. The limitations of passive filters:

While passive filters may seem simple in concept, they actually exhibit several limitations during operation. To name a few:

(1) Filtering qualities are highly dependent on the impedance of the source, and passive filters cannot account for variations in the network or the filter's components due to things like temperature or wear and tear.

(2) On the source side, harmonic currents may be amplified at a certain frequency if the passive filter components and the network impedance resonate in series or parallel.

(3) Since passive filters act as a current sink for the output harmonic voltage, they may be easily overpowered by a large harmonic voltage at the source.

(4) To get a low THD, passive filters are expensive and cumbersome.

3.1. Active power filter:

Parallel to the load is where you'll often find an active power filter, also referred to as a shunt active power filter. The nonlinear load's harmonics are cancelled by injecting counter-harmonic currents into the string. Harmonic cancellation for power efficiency improvement.

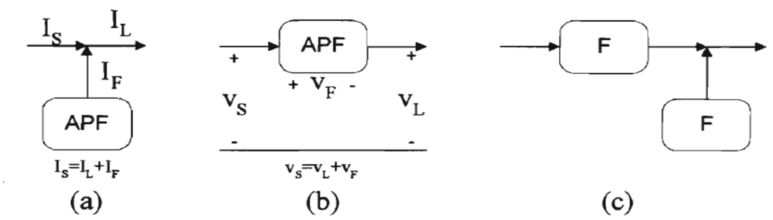

Figure. 2: Active power filter (a) Shunt (b) Series (c) Hybrid filter

3.2. Single phase active power filter:

The fundamental layout of a single-phase shunt and series APF with a capacitor (an inductor may also be used) for energy storage. The shunt active power filter (APF) load current harmonics are detected by the filter controller seen in Fig. 3.2a, which subsequently injects comparable anti-phase components into the system. Finally, when we improve power efficiency, we see promising outcomes and enhanced dependability.

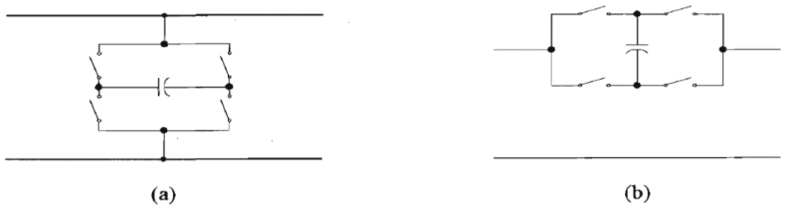

Figure. 3: (a) Single phase Shunt filter (b) Single phase Series filter

The voltage harmonic isolator function of a single-phase series APF is shown in Figure 3.3b. If a voltage distortion occurs to the right side of the filter, this compensation will prevent it from passing through to the left. In the event of a malfunction, they would provide the whole short circuit current, necessitating a swift safeguard to protect the filter and its parts.

3.3. Three phase active power filter:

There are two categories of three-phase SPF. One category of three-phase, three-wire filters does not include a neutral. However, in the alternative kind, known as three-phase four-wire systems, the neutral conductor is present.

The active control filters in the distribution system employ a three-phase, three-wire configuration. It cancels the 5th and 7th harmonics, etc., but not the triple harmonics since there is no neutral link to the inverter. This filter may be added in one of two ways to three-phase, four-wire systems. The first method uses three neutral, side-related single-phase filters. This approach is straightforward to implement if the single-phase filter has already been developed, but it requires the use of insulation in each filter or, alternatively, three single-phase inverters supplied by three isolated buses. Recent years have seen the introduction of a number of alternative power sources (APFs) that are compatible with 3-phase, 4-wire grids.

3.4. Active power filter with three wire phase conversion:

The absence of the neutral conductor in a three-phase, three-wire design that is inherently balanced prevents the flow of third-, ninth-, and fifteenth- harmonic currents, among others. The fundamental goal of filtering in such a distribution system is to eliminate fifth-, seventh-, eleventh-, thirteenth-, etc.-order harmonic components.

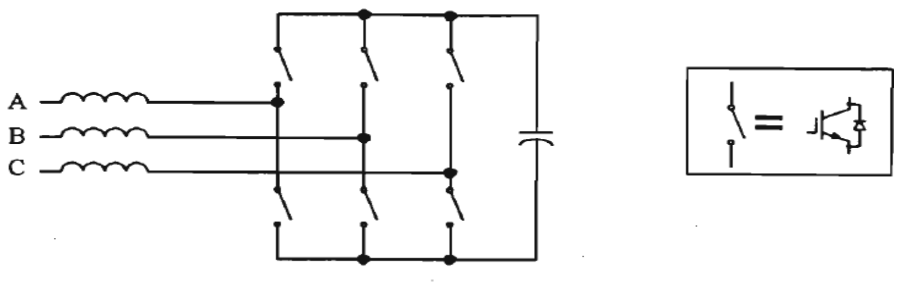

Figure. 4: Three phase three wire APF

The three-phase, three-wire APF is seen in Fig. 3.4. This kind of active power filter inverter supplies the 5th, 7th, and so on harmonic currents required by the load. If the nonlinear load and filter combination is not asymmetrical, it will act as a unit power factor load to the utility. Source impedance, the inverter control loop, unit component rating, and the accuracy and phase shift of the current sensor are just a few of the many factors that affect the useful degree of filtering. Many authors recommend this sort of voltage source inverter because of its superior efficiency.

3.5. Quadratic phase-changing power filter:

A three-phase, four-wire system provides power to residential and commercial loads in realistic settings. The third harmonic component represents a significant amount of the total harmonic current used by power electronics converters, which are often used in several applications that run on single- phase power. Triple harmonic currents are phase-aligned in three-phase systems. As a consequence, they fortify rather than dispel, leading to an excessive neutral current. The neutral current at 22.6% of the locations studied was more than 100% of the phase current, according to a recent study. The following issues may arise due to this abnormally high neutral current:

(1) An electrical fire caused by a too-small neutral conductor.

(2) Disturbance and insulation failure in the transformer as a consequence of harmonic currents causing the transformer to overheat.

(3) Excessive voltage between the neutral and ground caused by neutral current created by voltage drop.

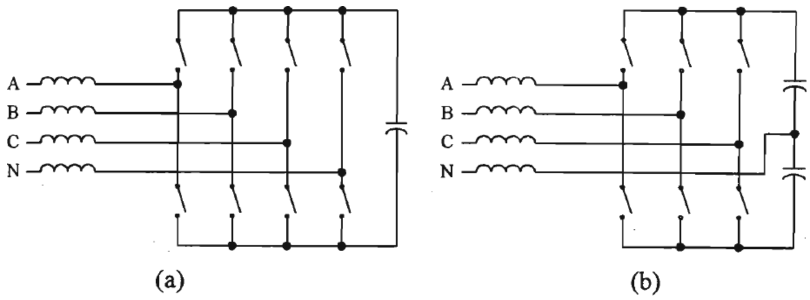

Figure. 5: (a) Four leg topology for APF (b) Capacitor-midpoint topology for APF

3.6. Advantages of active power filter:

Following are the advantages of Active power filters

(1) Continuous measurement and rejection of current and voltage harmonics; no real power consumption beyond that required to account for intrinsic flaws in the switch and inductor; zero power usage overall.

(2) They can adapt to different loads and different situations.

(3) Their quick reaction time and high bandwidth allow them to effectively cancel out any harmonics that may be present in the system.

(4) They are compact, lightweight, and space-efficient because they use cutting-edge semiconductor power devices.

3.7. Filter of active power, shunt series:

The series-shunt active filter, as the name suggests, is a hybrid between the series-shunt active filter and the shunt active filter. The shunt-active filter is situated on the load line and is used to cancel out the load's harmonics. However, the series component at the source acts as a filter that suppresses harmonics. This configuration is known as a Unified Power Consistency Conditioner. The series section acts as a harmonic oscillation blocking filter and a damper for the power grid, mitigating the effects of harmonics in the supply voltage and voltage imbalances. Harmonic load current, reactive power, and unbalanced load current may all be canceled out thanks to the shunt component.

3.8. Filter active power hybrid:

Since power supplies generally have low impedance, correcting voltage harmonics is not a major problem, therefore the passive filter was designed to exclusively deal with the source current harmonics. Commonly, stringent requirements for total harmonic distortion (THD) and voltage regulation are imposed at the point of connection. Making ensuring the supply is perfectly sinusoidal is a difficulty when trying to compensate for voltage harmonics. Devices used to ensure the safety of the electrical grid and store superconducting magnetic energy are particularly sensitive to harmonic voltage, making this a pressing concern. The impedance of the line is the link between voltage and current harmonics. While current harmonics may be reduced with voltage harmonic correction, the latter is still necessary.

A wide variety of solid-state power converters, such as diode bridge rectifiers, thyristor converters, etc., are utilized in transmission/distribution networks and industrial applications. All of these types of power converters are nonlinear, which causes severe current harmonics issues, poor power factor, inefficient devices, irregular supply voltage, and a heavy load of reactive power. As a result, there has been a surge in research on power quality management systems that might limit demand in the face of such critical issues.

4. Waveform distortion:

The spectral content of a steady-state divergence from a perfect power frequency minus wave is the primary identifier of waveform distortion. Here are three examples of waveform distortion:

4.1. Harmonics:

Sinusoidal a steady-state energies or currents exist whose frequencies are integer multiples of the fundamental frequency, a phenomenon known as harmonics. Harmonic distortion is caused by the nonlinear nature of power grid systems and loads. Technological devices such as computers, uninterruptible power supplies (UPSs), variable frequency drives (VFDs, etc.

4.2. Inter harmonics:

There exist voltages and currents whose components have frequencies that aren't whole number multiples of the fundamental frequency; this phenomenon is known as interharmonics. Some examples are arcing systems, induction motors, cyclo-converters, and static frequency converters.

4.3. Noise:

Superimposed or detected on neutral wires by device voltage or current, noise is electrical having a wireless spectral content of less than 200 kHz.

5. The PI controller:

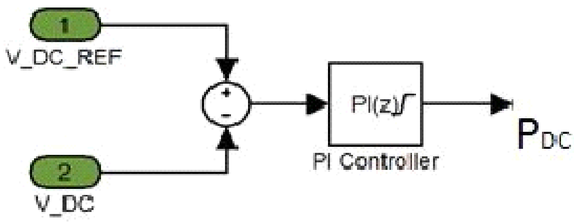

Figure. 6: PI Controller

Implementing a discrete PI controller requires a discrete sample period and the discrete PI equation form necessary to approximating the integral of error, both of which are common in digital electronics. It is often used to non-integrating processes, or those where the same result is achieved regardless of the inputs or disturbances applied.

The PI controller uses both proportional and integral modes to effectively cancel out any innate offsets. Its mathematical representation is as follows:- $P = K_p e_p(t) + K_p K_i \int e_p(T)dT + P_i(0)$

Where,

(1) P =PI controller output

(2) Ki = Integral gain

(3) Kp= Proportional gain

(4) Pi(0)= Initial value of integral term

(5) ep(t) = Controlled variable's desired value - measured value

If the error is zero, the controlled variable will fluctuate sporadically around the target value, and the integral will eventually get it there by canceling out the error.

The controller shortens the rise time to attain maximum output under the current load circumstances if the error is greater than zero. The key benefit of using a PI controller in this situation is that it can be readily applied to fast-response processes and significant and frequent load fluctuations, and that it eliminates steady-state errors.

5.1. Hysteresis PWM for current control device:

As shown in Fig. 4.5, the output current generated by the filter can be made to mimic the waveform of the reference current with the help of hysteresis current control, which involves generating the necessary triggering pulses by comparing the error signal to that of the hysteresis band.

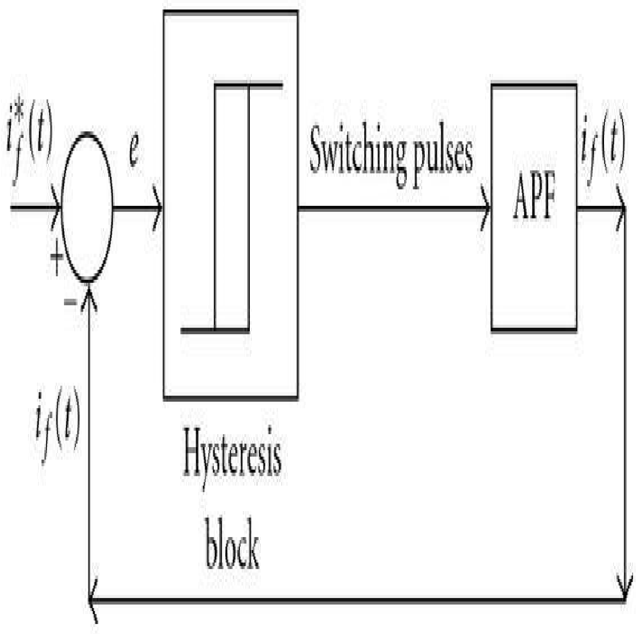

Figure. 7: Hysteresis control device

This technique employs an asynchronous control of the switches in the voltage source inverter to ramp the current through the inductor in order to track the reference current. In practice, the most fundamental kind of control is hysteresis current control. Hysteresis band voltage controllers are quick, have good dynamics, and need little hardware, making them an attractive option.

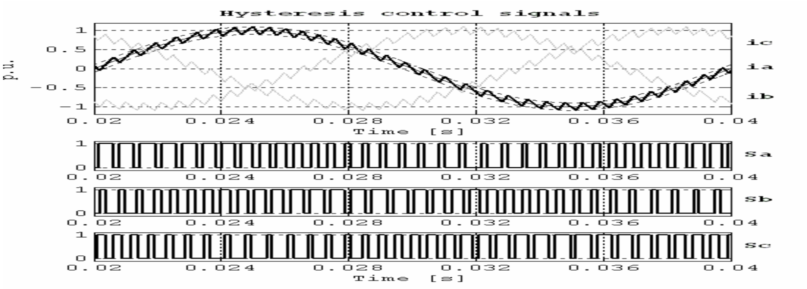

Figure. 8: control signals of Hysteresis-Band PWM

To minimize the current ripple at the output side, the suggested method uses a hysteresis band with a constant value (H) in the open loop and a variable value (H') in the closed loop. It will lead to high switching frequency and significant power loss during switching. It also necessitated sophisticated controls for optimal performance in.

Hysteresis current controllers are beneficial because to their speed and precision, as well as their ease of use. However, there may be significant variation in the switching frequency throughout the fundamental period, leading to inverter irregularities.

6. Current control algorithm:

6.1. Hysteresis band technique:

Limits for the upper and lower hysteresis bands must be established before this kind of control can be used. If the load is fluctuating, the output DC voltage will fluctuate when using an open loop control technique, while a tight loop strategy will provide a consistent output. In closed-loop control, the current signal at the output is compared to a known reference current signal. Which one reduces output errors while still producing the required results? PI controllers can regulate the gate pulses that are produced. For power switching devices, these signals are generated when the upper and lower hysteresis bands are surpassed. If a critical fault occurs, this method will prevent the power switching devices from being activated. For PID controller tuning, the Ziegler-Nichols approach may be used. This technique involves contrasting the load current with the specified band limit. Switches are closed when the current reaches the upper band limit and opened when it reaches the lower band limit.

7. Simulation result and discussion:

MATLAB (R2016) is used to put the suggested technique into action. The signal processing toolbox allows us to apply the many Windows, shifting, scaling, and other MATLAB Library operations to our work.

7.1. Simulation software:

MATLAB (matrix laboratory) is a high-level language designed specifically for numerical computation. Matrix operations, graphing of functions and data, algorithm development, user interface design, and interfacing with programs written in other languages like C, C++, Java, and FORTRAN are all possible with MATLAB, a tool developed by Math Works.

Although MATLAB is mainly designed for numerical computation, it does provide access to symbolic computing via the usage of the MuPAD symbolic engine inside an optional toolbox. Simulink is a supplementary software that provides Model-Based Design and graphical multi-domain simulation for real-time and embedded systems.

Around one million people in business and education used MATLAB in 2004. Users of MATLAB come from a wide variety of disciplines, including engineering, science, and economics. The application of MATLAB extends well beyond the realm of industry, into the realms of academia and research.

To every engineering grad, the name "MATLAB" is instantly recognizable. Since its beginnings in the early 1990s, MATLAB has been extensively used as a scientific computing tool. Originally confined to the realm of academia, it has now become a staple of Electrical and Electronics Engineering curriculums.

The MATLAB software package combines numerical and graphical analysis with a visual programming environment. There are several built-in functions, and other toolboxes are available (e.g., for signal processing) to do even more complex tasks.

7.2. System parameter:

Table. 1: Parameter used in simulation

Parameter	***Value***
AC Voltage	220V
Branch inductance L	1mH
Branch Capacitance C	300 µF
Resistance	100 Ω

Phase Locked Loop (PLL) Minimum Frequency	37.5 Hz
Voltage (Vdc)	300 V
Proportional (Kp)	0.005
Integral gain (ki)	0.00023

8. Result analysis & discussion:

Description 1**:** The suggested concept of a single-phase grid-connected shunt active power filter and half bridge voltage source inverter with two MOSFET switches T1 and T2. C1 and C2 on the opposite leg serve as a DC bus and aid in current compensation. Parabolic pulse width modulation (PWM) controller with source voltage feedback coupled to phase lock loop (PLL) for synchronization of pulses to grid voltage. It has a quick reaction time and a stable output current. We see SAPF's Hysteresis PWM controller in action. The MOSFET switches are alternately driven by a NOT gate, making this controller simpler to build and more responsive than a parabolic PWM controller.

The DC voltage read from the diode bridge rectifier at the load end (nonlinear load). It can withstand 325V with a 15% ripple.

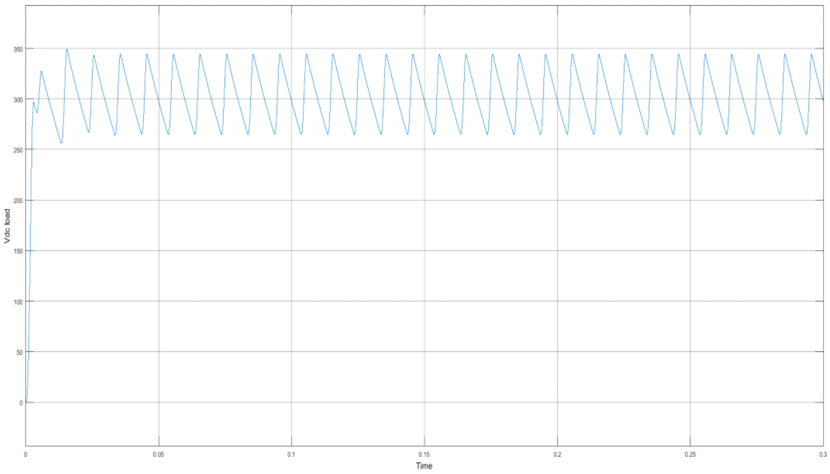

Figure. 6: DC side load voltage

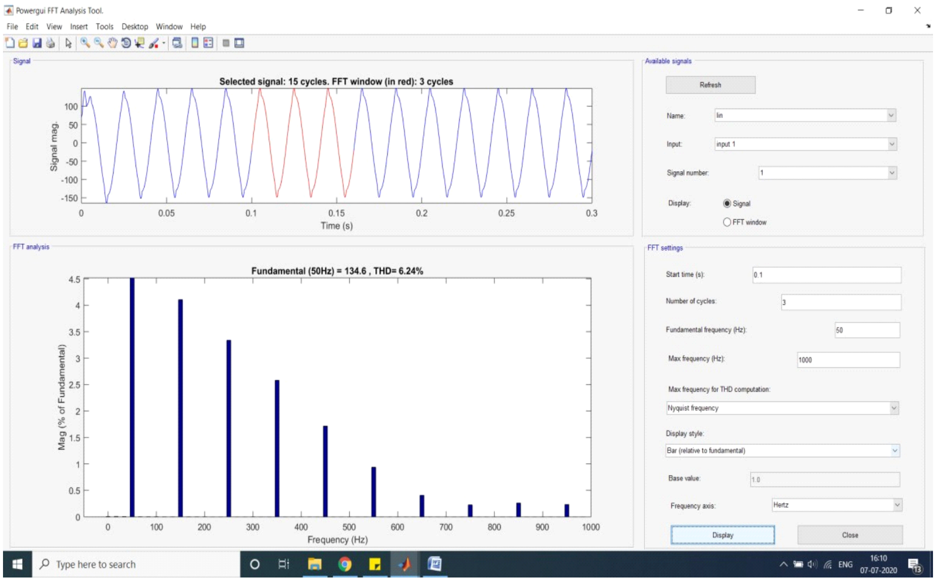

Figure. 7: FFT analysis of source current with parabolic PWM active power filter

Table.

S.No.	***Controller***	***Harmonics Percentage***
1	Before Connecting active filter	140.46%
2	Parabolic pwmActive Filter	6.24%
3	Hysteresis PWM Active Filter	3.98%

Figure. 8: Hysteresis PWM active power filter FFT study of source current Parabolic Pulse Width Modulation Active Power Filter vs. Hysteresis Pulse Width Modulation Active Filter

9. Conclusion:

The preceding FFT analysis findings and comparisons indicate that the source current THD is around 140% when SAPF is not present. The similar THD reduction occurs when a parabolic PWM operated SAPF is fitted. If a PWM controller with hysteresis is added to the SAPF, the value drops to roughly 3.98%. The non-linear loads' harmonics are reduced by the SAPF linked at the PCC, safeguarding the whole system from disruption. In MATLAB, the 'Power GUI' block of the Simulink environment is where you'll find yourself using the FFT analysis tool.

10. Future scope:

In order to further reduce harmonics in the grid, adaptive controllers or fuzzy logic controllers may replace the presently utilized PI controller for the DC bus voltage regulation, which is used to calculate the current magnitude. Hybrid active power filters combine the advantages of active and passive filters to reduce harmonic distortion to levels below 1%. Using parabolic pulse width modulation (PWM) and hysteresis pulse width modulation (HPWM), the same single-phase active power filter may be converted into a three-phase active power filter with two levels of VSI linked to the three-phase grid.

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