Three Phase Transformerless Shunt Active Power Filter with Intregated Photovolatic Array & Reduced Switch Count For Harmonic Compensation

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ABSTRACT: In recent years, traditional electrical power networks have been rapidly transformed into smart grids and next-generation power systems. The utilization of power electronics is an important aspect of these developments. Recent improvements in power electronics have hastened the integration of renewable energy sources, power storage, and contemporary loads into a hybrid microgrid linked to the smart grid. This study describes a Photovoltaic Array integrated into active power filter that includes harmonic correction and active power injection. The most effective solution for nonlinear loads, current harmonics, and power quality concerns is a shunt active power filter. Active power filter topologies for harmonic correction are wasteful because they depend on a large number of components with high power ratings. To reduce the power rating of voltage source inverters, hybrid topologies combining low-power ratings Active power filters and passive filters have been deployed. In hybrid APF topologies, a transformer with a large number of passive components is employed to power high-power systems. This paper presents a unique four-switch two-leg Voltage source inverter design for a three-phase Shunt active power filter with the goal of lowering system costs and footprint. The recommended topology includes a two-arm bridge design, four switches, coupling inductors, and two sets of LC PFs. By eliminating the power switching devices, the third leg of the three-phase VSI is deleted, enabling the phase to be directly linked to the dc-link capacitor's negative terminals. When compared to standard Active power filter topologies, the proposed approach enhances harmonic compensation and allows for total reactive power compensation. Since the photovoltaic array is linked to the DC connection, active electricity is fed into the network and absorbed by the load. The test system's findings are examined using the MATLAB Simulink program.

Keywords:Harmonics,hybridtopology,nonlinearload,powerquality(PQ),Transformer less inverter, Grid-connected system.

1. INTRODUCTION

Voltage and current harmonics are produced in the power distribution system due to the growth of nonlinear characteristic loads. Current harmonics affect power quality, reactive power, transformer losses, voltage harmonics, and harmonic resonance at the distribution level.Active technology, such as shunt active power filters (SAPFs) and hybrid active power filters (HAPFs), may assist to address these concerns. The passive and active components of these filters are connected in series or shunt. These filters also limit the harmonic flow of current into the power distribution system to comply with rigorous harmonic standards. [1]

A typical APF consists of a three-leg bridge voltage source inverter (VSI) and a dclink capacitor. Traditional APF topologies are wasteful because they need a matching transformer and a large number of active switching devices, such as the insulated gate bipolar transistor (IGBT). These problems result in a system that is cumbersome and costly, which is undesirable. Power quality refers to the energy grid's ability to provide clients with consistent, optimum, and non-tolerant electricity. Power quality problems may be classified into many categories. Originally, it simply meant the availability of electrical power, as well as voltage and frequency control within a certain range. As electrical equipment get more sensitive, consumers become more aware, and power quality pollution in the system increases, so does attention to power quality. In addition to initial needs, power quality must address harmonic distortion, short-term transients, disruptions, interrupts, and flashes. [2] Power electronic devices may negatively impact grid characteristics, power quality, and system reliability. These devices, which are often used in contemporary networks, have a direct influence on the distribution network's power quality. These pollutants include inverter-based DGs, which link to the grid via power electronic equipment.

The most important element is that the usage of DG is growing increasingly prevalent, both among consumers and among energy utilities. However, in standalone applications, the output current and voltage of DGs may be increased in the generating source by using specific inverter switching techniques. It is vital to note that multilevel inverters are among the most intriguing inverters for applying these switching techniques, such as harmonic elimination approaches, owing to their diverse capabilities. Power quality concerns are becoming more important as the number of DGs in today's grid rises, therefore paying attention to this subject is vital. Several studies have been undertaken to reduce the negative impacts of power electronic-based DGs in microgrids that employ DGs; nonetheless, this seems to be the first iteration of the multi-functional DGs idea, and more work has to be done in this area. [3]

While several devices have been classified as PQI, each has its own set of limitations, highlighting the need for more research in this field. Although the use of power electronic-based converters and nonlinear loads may compromise power quality, multifunctional DGs are one of the novel solutions to the power quality problem. The microgrid enables us to fix certain system faults, improving the grid's dependability and safety. Microgrids were first presented in the 1990s, and scholars started to pay more attention to them thereafter. It includes distinguishing characteristics that will improve power quality, one of which is the presence of several DG units of various types to strengthen overall system dependability. Because the majority of DG units employ power electronics-based converters, such energy sources might help to enhance power quality.[4] Even though it serves some of the same roles as a traditional converter, each power electronics-based converter used in microgrids has the potential to improve power quality. Numerous researches have been undertaken on the issue of increasing power quality in distributed power systems, but they have mostly concentrated on a specific region and hence are not comprehensive.

1.1. RENEWABLE SOURCES

Renewable resources are natural resources that are infinite and can be replenished in a short period of time. Renewable energy is energy derived from renewable natural resources such as sunlight, wind, rain, waves, and geothermal heat (naturally replenished).

The sun is the planet's principal source of endless free energy (solar energy). New ways are now being utilized to generate power from solar energy collected. These technologies have previously been proven and are widely employed as renewable energy sources for non-hydro technology across the globe. [5]

Another key part of solar research is the current attempt to decrease global carbon emissions, which has emerged as a major environmental, social, and economic concern in recent years. The installation of 113,533 residential solar systems in California, for example, led in a reduction or avoidance of 696,544 metric tons of CO_2. As a consequence, adopting solar technology would significantly reduce and relieve issues such as energy security, climate change, unemployment, and so on. It is also anticipated that, since it does not need the use of gasoline, it will play an important role in the transportation sector in the future.

Policies, investments, and support (such as research funding) for solar technology from a number of governmental and non-governmental organizations have all helped to establish a solid basis for the usage of this renewable energy source. Although rewards and rebates may be effective motivators for market expansion, there are growing efforts to reduce the financial impact of these regulatory incentives.In contrast, several countries have already curtailed solar power subsidies, possibly impeding the industry's development. Policies are moving to encourage the development of solar power systems for large-scale electricity production in order to avoid this possible decline. Additionally, residential solar producers should get bigger subsidies than utility-scale generators. [6]

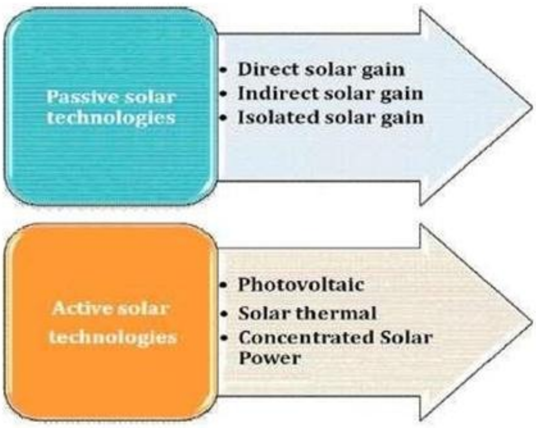

Figure1.1ClassificationOfThePresentSolarEnergyTechnologies

1.2. PhotovoltaicSystemForPowerGeneration

Photovoltaic systems are presented in the graphic as a simple example of how they might be incorporated into the grid. Solar energy is converted to direct current (dc) electricity by the PV array, which is directly influenced by the amount of insolation. The array's produced power can only pass to the power conditioner with the help of a blocking diode. A blocking diode prevents the battery from being discharged back into the solar array during periods of low sunlight. A maximum power point tracker (MPPT), a battery charger, and a discharge controller are all included in the power conditioner.

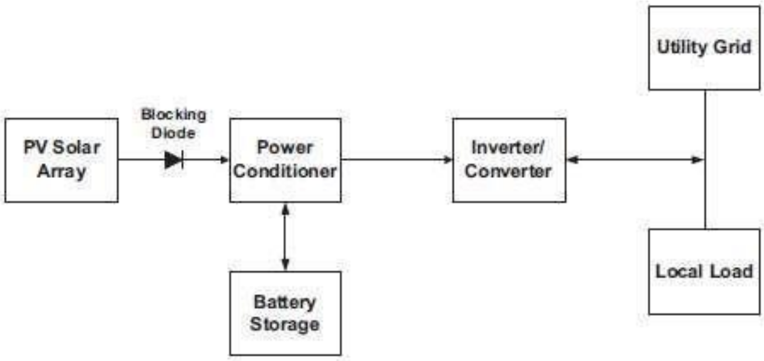

Figure1.2ATypical PhotovoltaicSystem

Because the batteryvoltage is steadyenough to ensure near-maximumpower collection from the PV module in small PV systems, the inclusion of MPPT circuitry is often deemed unnecessary. There is no grid connection for a stand-alone system.

The use of PV systems as "distributed energy sources (DERs)" to harvest electricity from non-conventional energy sources with minimal environmental implications has been the subject of much study in recent years, both experimentally and virtually.

2. ClassificationofPowerQuality

Power qualities are divided into three generations that have evolved over the previous fifty years. The first generation of PQ devices has a simple and effective structure and typically does not cost a lot of money; these devices comprise passive, active, as wellas hybrid power filters. [7] The second half of this research explains the operating principles, benefits, and drawbacks of the second generation of PQIs, which are currently the most popular PQIs in power systems.

2.1. ShuntActivePowerFilter

It substitutes for current harmonics by infusing a harmonic current with almost the same magnitude as the harmonic current but 180 degrees phase difference. As a result, harmonic current isadjusted,therefore grid current isalmost sinusoidaland phase-locked to the source. Additionally, if correct control mechanisms are applied, an active power filter can also be used to compensate reactive power. A parallel active power filter having nonlinear load appears to be a linear load from the grid's perspective. [8]

Asdemonstrated,APFcompensates for nonlinear load current byinfusing the same nonlinear current from the grid that the load consumes, resulting in a sinusoidal grid current. Novel controlmethodsforshunt activepowerfilters,aswellasnewapplicationsforshuntAPFs,are the focus of current research in this topic. In, a more in-depth examination of the main topologies of shunt active power filters is carried out.

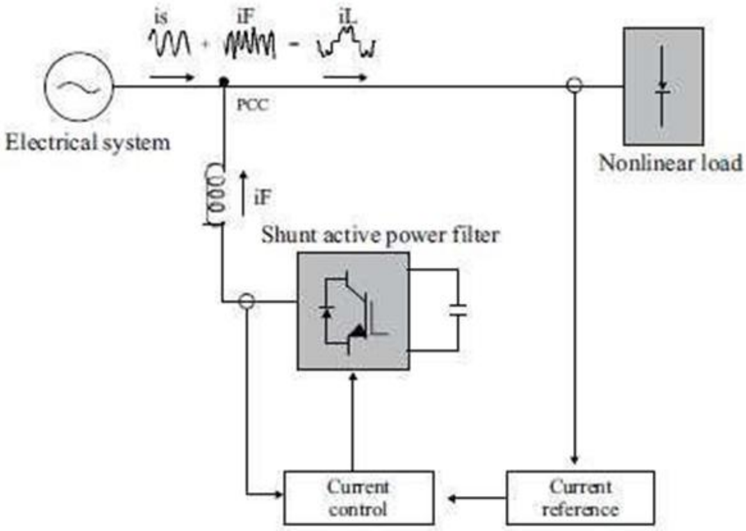

Figure2.1ShuntActivePowerFilter

2.2. Non-LinearLoad

Whenthe input current into electricalequipment doesnot followthe impressedvoltageacross the device, it is said that the equipment has a nonlinear input voltage as well as input current relationship. Nonlinear loads include any equipment that uses some form of rectification. Nonlinear loads produce current and voltage harmonics, which can cause problems for equipment that is designed to operate as a linear load. Because of the harmonic producing sources (nonlinear loads) to which transformers bringing power into an industrialenvironment are attached, they suffer increased heating losses. [9]

The non-linear load is athreephase bridgerectifierconnectedtothegrid bythe meansofline inductor (*Ll, Rl*) feeding an inductive load (*Rdc, Ldc*) as shown in figure shown below:

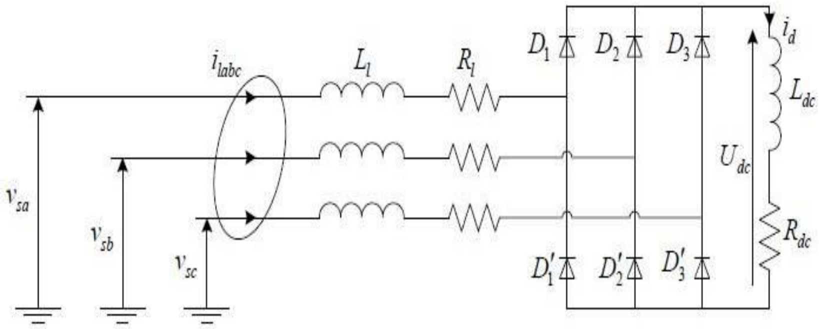

Figure2.2Non-linearLoad

2.3. Harmonics

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 ofpower converter equipment connectedtothe distribution power systemwhich 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.TheCommitteeEuropeandeNormalizationElectrotechnique(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, commercialand industrial) in the American Electric Power Distribution System.[10]

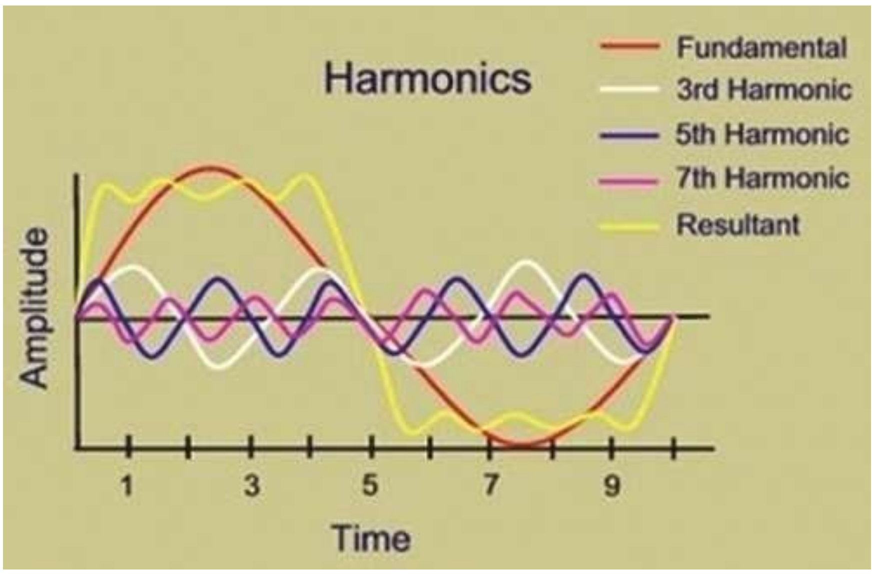

Figure2.3:HarmonicsinPowerSystem

2.4. MitigationofHarmonics

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 qualityconditioners). In between nonlinear load and also the distribution system, the series APLC acts as a voltage regulator as well as harmonic isolator.The seriesactive filter infusesa voltage component inserieswiththe supply voltage, making it a controlled voltage source that compensates for voltage sags as well as surges on the load side. The injected harmonic voltages are added or subtracted, to / from thesource 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 seriesAPLC, it can operate as a harmonic isolator betweenthe 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.[11]

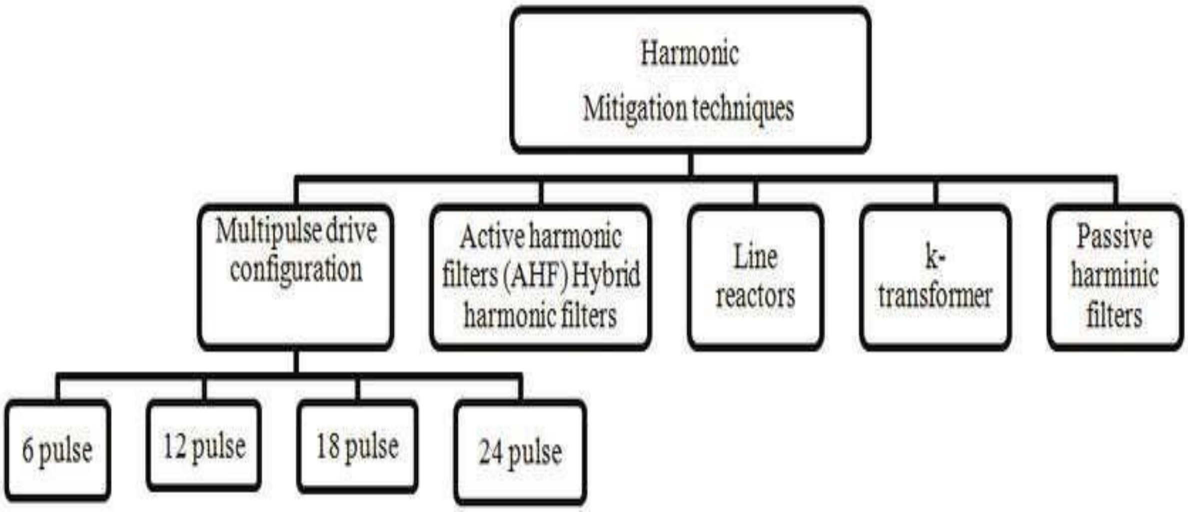

Figure2.4HarmonicMitigationTechnique

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.

3. FourSwitchTwoLegVSITopology

For a three-phase SAPF, a novel four-switch two-leg VSI architecture is suggested in this research to reduce system cost and complexity. As illustrated in the image below, the suggested SAPF is made up of a three-phase two-leg bridge version of a four-switch inverter.

A two-arm bridge construction, 4 switches, coupling inductors, and sets of LC PFs are all included. For a good switching scheme, the sinusoidal PWM (SPWM) modulation strategy was used in this work. To design the reference signals, the carrier signal is compared to the comparators with a single alteration. By removing the set of power switching devices, the third leg ofthe three-phase VSI is eliminated, allowing the phase to be connected directly to thenegativeterminalsofthedc-linkcapacitor.Theremovalofasinglephase-legcausesa voltage imbalance or voltage variations in the dc-link. To prevent imbalance charging of the dc-link capacitors, link the detached leg terminal to the negative terminal of the dc-busPWM-VSI. Additionally, the ac film capacitor holds decoupling power ripples to give regulatedoutput voltage and current,thus stopping the flow ofdecoupling powerripples. The new circuit is developed from the six-switch full-bridge inverter shown in, unlike other previous topologies. In comparison to traditional full-bridge topologies, the novel model improves harmonic filtering as well as reactive power correction. [12]

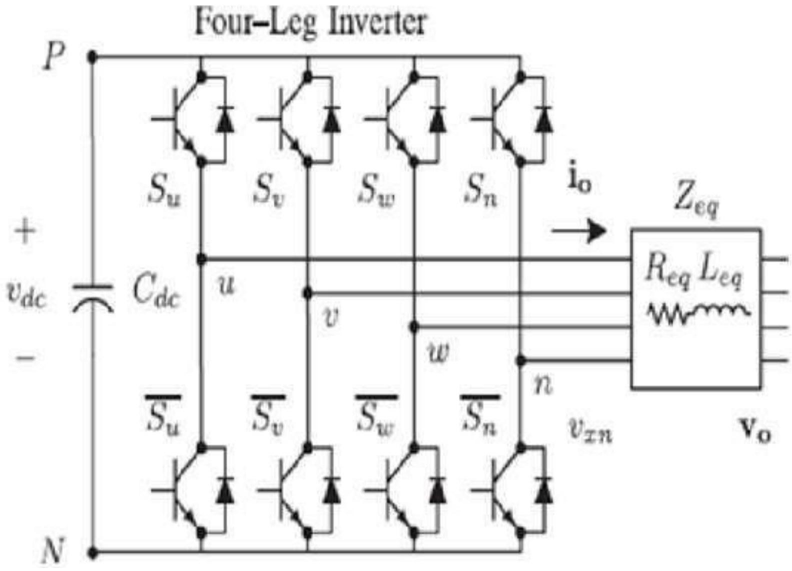

Figure3.1FourSwitchTwoLogeVSITopology

4. ControlStructureAndFunctioningofShuntActivepowerFilter

The SAPF topology is primarily made up of two parts: a typical VSI fed by a DC-link capacitor and a controller. To account for the unbalanced real power that arises in dynamic operation, the voltage source inverter (VSI) systematically controls and creates the filter current if used as injection current.Furthermore, if the ripple content in the injected filter current is high, a filter inductor is utilized to reduce it. The harmonics are injected into the electrical grid system current by the nonlinear load through PCC. Adjustable speed drives (ASD), arc furnaces, switch-mode power supplies (SMPS), as wellas power electronic loads are a few illustrations of realistic nonlinear loads. Uncontrolled rectifier bridge load is commonly employed in research contexts (simulation and laboratory), despite its substantial current harmonic distortions. The bridge rectifier is often coupled to one of three types of loads:(1)RL(resistor–inductor)seriesload,alsoknownasinductiveload;(2)RC(resistor– capacitor) parallelload, also knownascapacitive load;and (3) simple resistive load. Figure 3 depicts SAPF's typical control structure. [13]

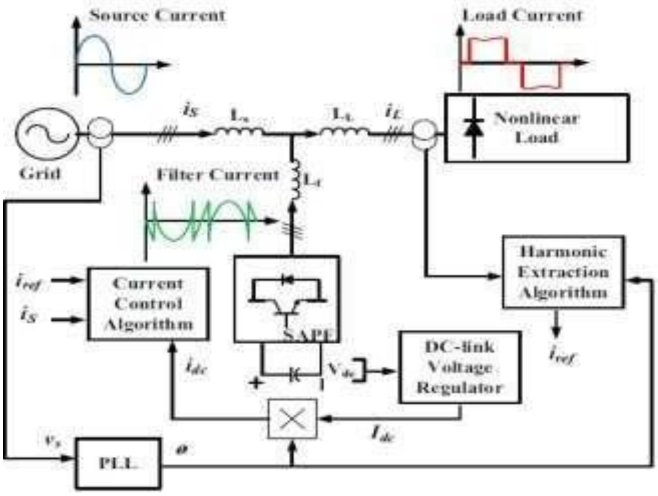

Figure4.1TypicalControlStructureOfSAPF

4.1. TRANSFORMERLESS APF WITH PV ARRAY

The SAPF is implemented in different load scenarios using MATLAB/SIMULINK in this research. Essentially, there are two simulations: one with non-linear load and the other with SAPF attached. A transformer-less SAPF architecture based on a four-switch two-leg arrangement isin this work. The new circuit is developed from a six-switch full-bridge inverter, unlike previous current topologies. In comparison to traditional full-bridge topologies, the novel model improves harmonic filtering and reactive power correction. [14]

The suggested design primarily intends to provide greater compensating capabilityand a less complex system for three-phase applications without expanding the number of powers switching components. By minimizing the use of PFs, sequential ac-coupling inductors overcome the fixed reactive power compensation. Due to the extreme balanced voltages and currents, the new topology delivers better overall performance than the dc-bus midpoint connection design in terms of harmonic compensation capabilities.

As a result, the constraint of voltage balancing across the dc-link capacitor is reduced thanks to asimpler structureaswellasconnection betweenthetransmission lineaswellasthedcbus terminal. This solution also avoids the requirement for an additionalcontroller &transformer to ensure magnetic saturation between the LC PF and also the filter inverter. As a consequence, the design configuration is less expensive, has a smaller volumetric dimension, and is lightweight. [15]

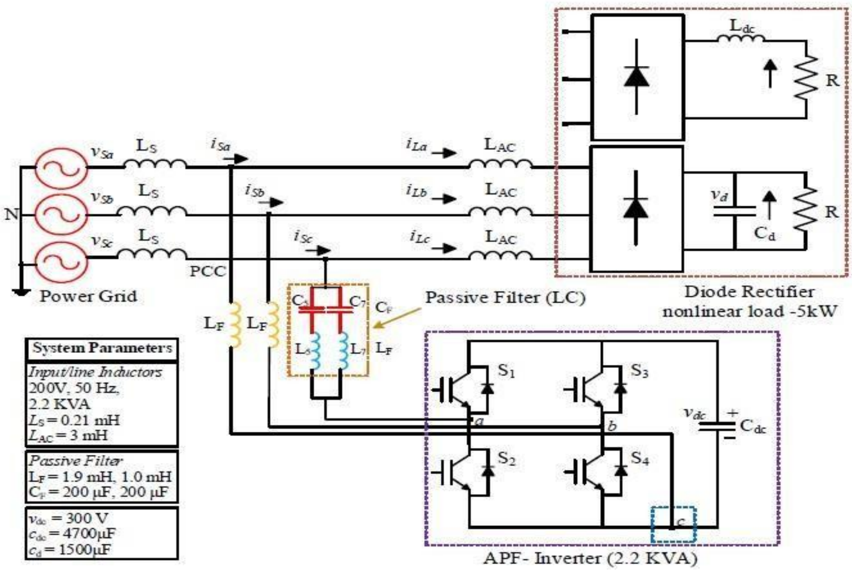

Figure4.2TransformerLessAPFSystem

5. RESULTS AND DISCUSSION

Table 5.1. SimulationParameterOfSystem

Name	UnitandValue
LinetoRmsVoltage	200V
Grid Frequency	50Hz
OutputRmsVoltage	200
Frequency	50Hz
SupplyInductor(L)	0.21mH
ACLoadInductor	3mH
Non-LinearLoadResistance	40Ω
SwitchingFrequency	20000Hz
DCVoltageofactiveFilter	300V
HPFCutoffFrequency	50Hz
DampingRatio	0.707

5.1. ResultAnalysis

Simulation studies are carried out in the MATLAB/Simulink environment to validate the efficiency of SAPF with the suggested controller. This section contains the electrical parameters of the SAPF that were used in simulation experiments. In simulation investigations, two scenarios for steady state and transient state circumstances are explored, and the SAPF MatLab/Simulink Model is shown in figure.6.1 in this simulation model anovel four-switch two-leg VSI topology for a three-phase SAPF isfor reducing the system cost and size. The SAPF is composed of the three-phase two-leg bridge version of the fourswitch inverter, as shown in Fig.5.1. It comprises a two-arm bridge structure, four switches, coupling inductors and sets of LC PFs. The adopted modulation strategy in this study is the sinusoidal PWM (SPWM) for a proper switching scheme. The carrier signal is compared with the comparators with single modification to pattern the reference signals

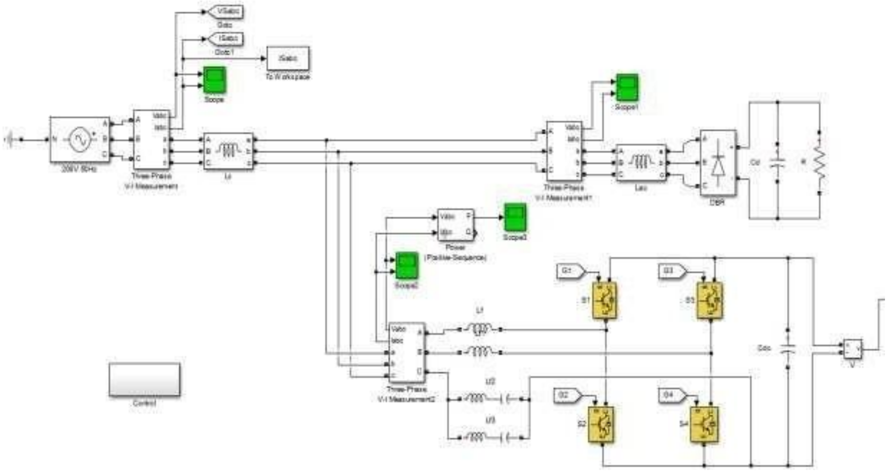

Figure5.1 TransformerLessShuntActivePowerFilterSystem

Figure 5.1 depicts the test system's modeling, which includes a three-phase source feeding a nonlinear load that introduces harmonics. The harmonics are corrected by the SAPF coupled to the test system's PCC.

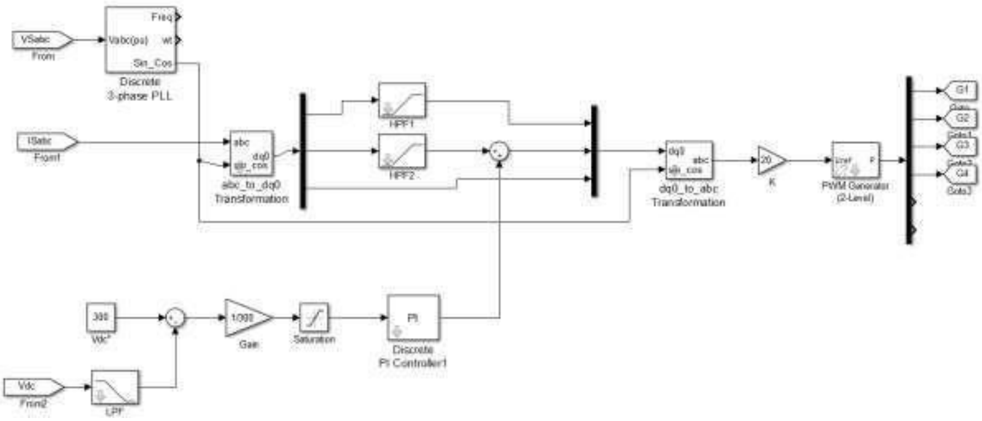

Figure5.2ControlModeling

Figure 5.2 depicts the modeling of the control structure for regulating the four SAPF switches using the sinusoidal PWM approach. The three phase voltages and currents of the source are shown below when the system is not linked to SAPF.

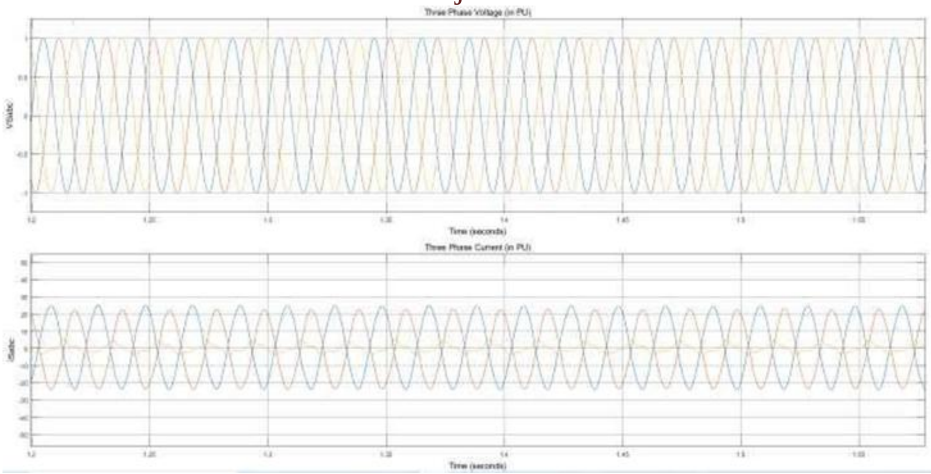

Figure5.3SourceVoltagesandCurrentWithSAPF.

Figure 5.3 shows source voltage (VSabc) vs. time and (ISabc) using SAPF (shunt active power filter). There are no harmonics in the voltage source vs time graph or the source current (ISabc) vs time graph, and the total harmonic distortion (THD) has been reduced from 32% to 2% with the use of a shunt active power filter (SAPF). We now have nearly a sinusoidal current wave. We may claim that 2% harmonics is quite low, thus we can assume there are no harmonics in the source current (ISabc).

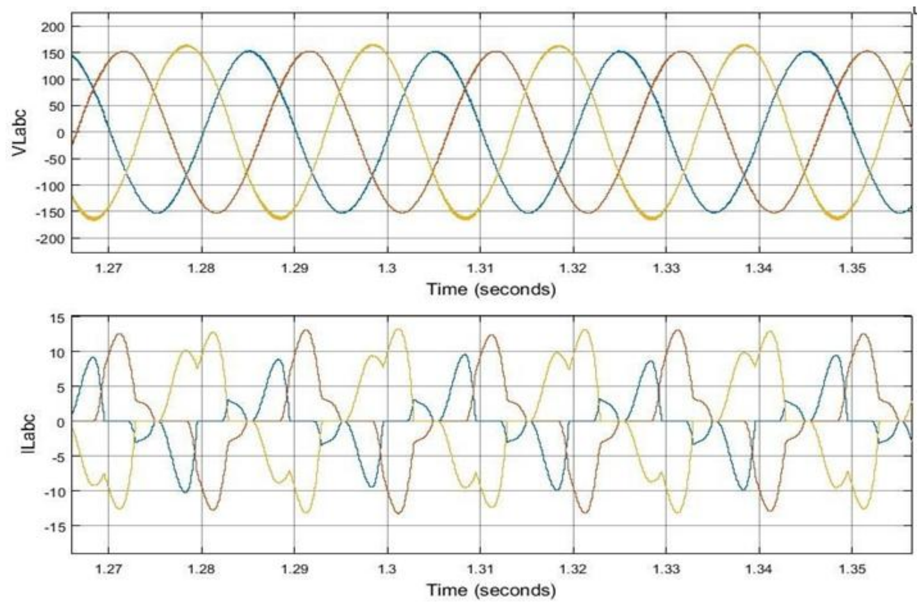

Figure5.4LoadVoltagesandCurrentsSAPF

Figure 5.4 shows load voltage (VLabc) vs. time and (ILabc) using SAPF (shunt active power filter). There are no harmonics in the voltage load vs time graph or the load current (ILabc) vs time graph, and the total harmonic distortion (THD) has been reduced from 32% to 2% with the use of a shunt active power filter (SAPF). We now have nearly a sinusoidal current wave. We may claim that 2% harmonics is quite low, hence we can assume there are no harmonics in the load current (ILabc).

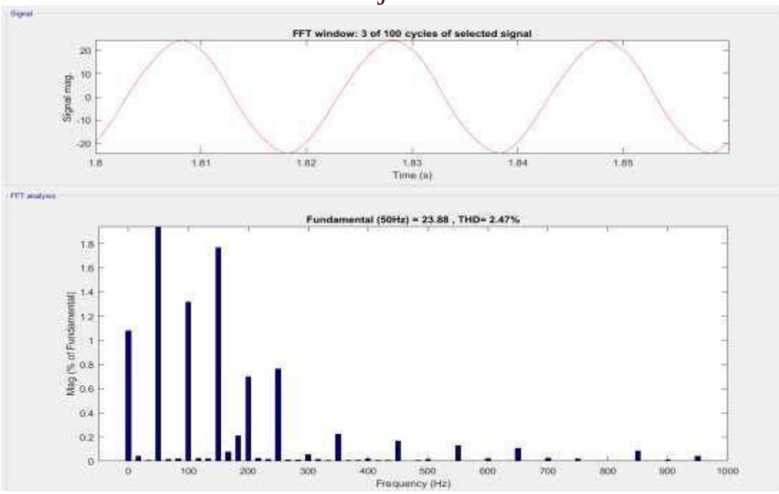

Figure5.5THDOfSourceCurrentWithSAPF

Figure 5.5 depicts the FFT (Fast Fourier Transform) analysis of the source current to calculate the THD (total harmonic distortion) with SAPF connected to the grid. Total harmonic distortion is decreased to 2%, indicating that the signal wave is sinusoidal.

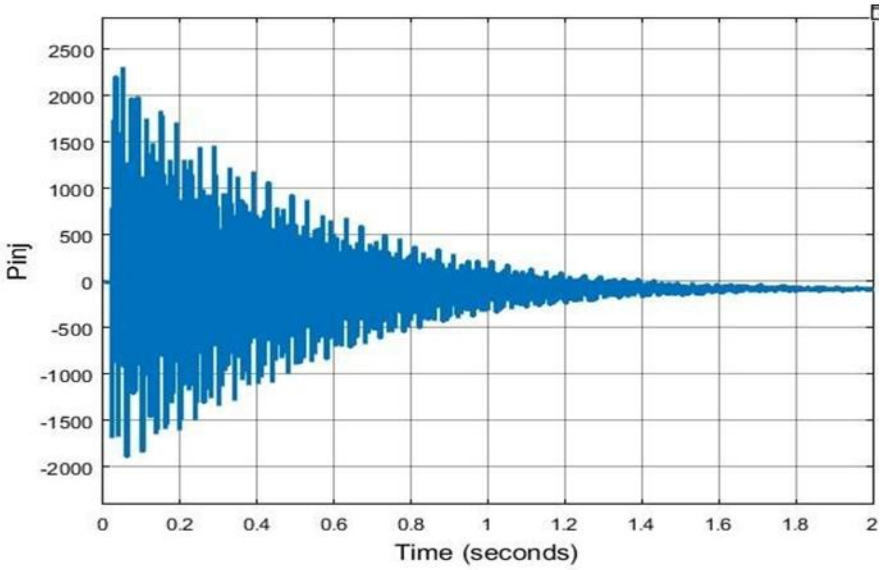

Figure5.6InjectedActivePowerofOnlySAPF

TheFig5.6representstheActivepowerafterconnectedwithonlySAPF (excluding PVA). After that, we get zero active power as output in above graph.

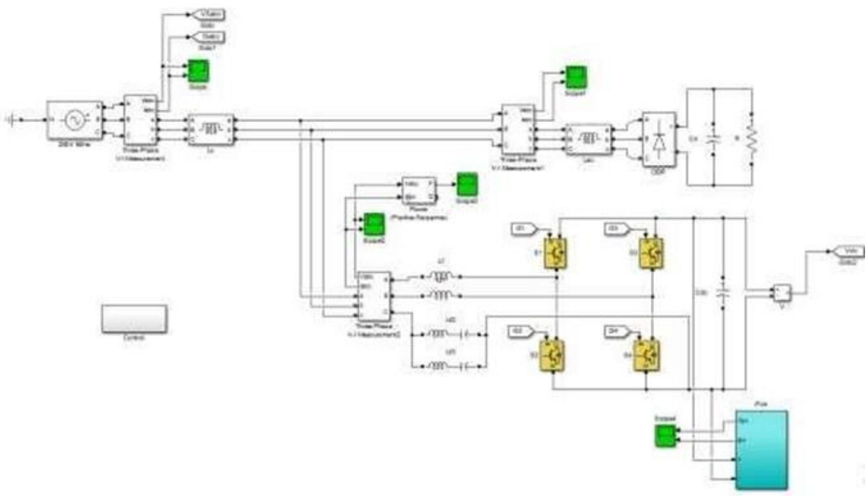

Figure5.7TransformerLessShuntActivePowerFilterSystemWithPVA

The test systemis updated withPhotovoltaicArrayconnected atthe DC link inparallelto the DC capacitor for renewable source power sharing.

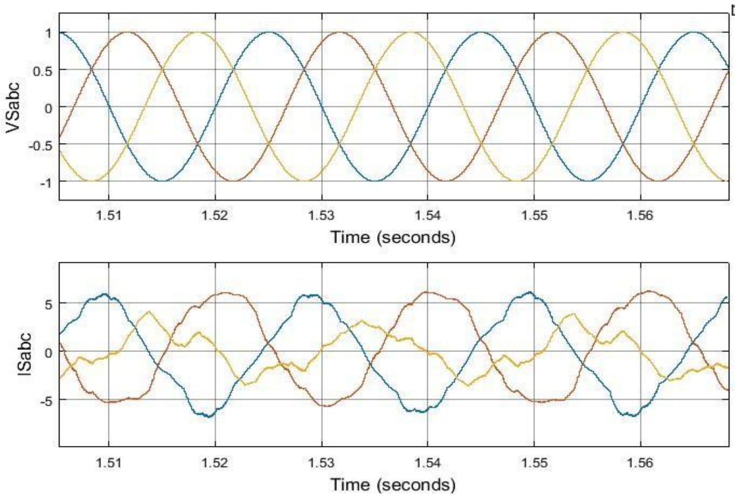

Figure5.8SourceVoltagesAndCurrentWithSAPFConnectedToPVA

Figure 5.8 depicts the three-phase source voltages and currents for the test system with PVA integrated SAPF, whereas figure 5.9 shows the load voltages and currents.The voltage source vs time graph is a perfectly sinusoidal wave, but the source current vs time graph is distorted sinusoidal.

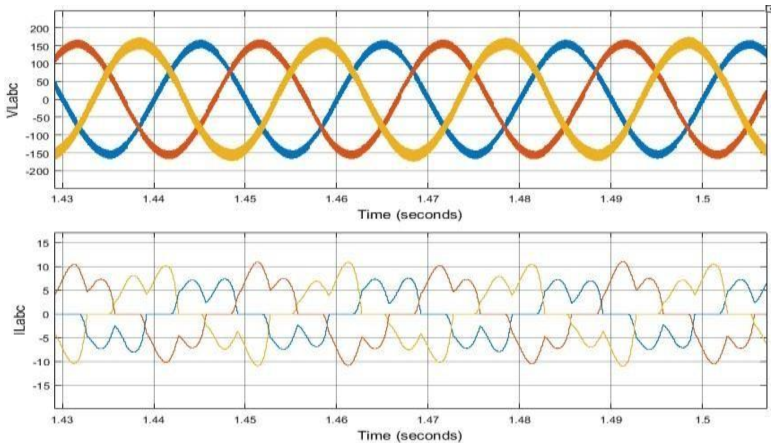

Fig5.9LoadVoltageAndCurrentWithoutSAPFConnectedToPVA

Figure 5.9 depicts the load voltages and currents for the same. The voltage source vs time graph is a perfectly sinusoidal wave, but the source current vs time graph is distorted sinusoidal.

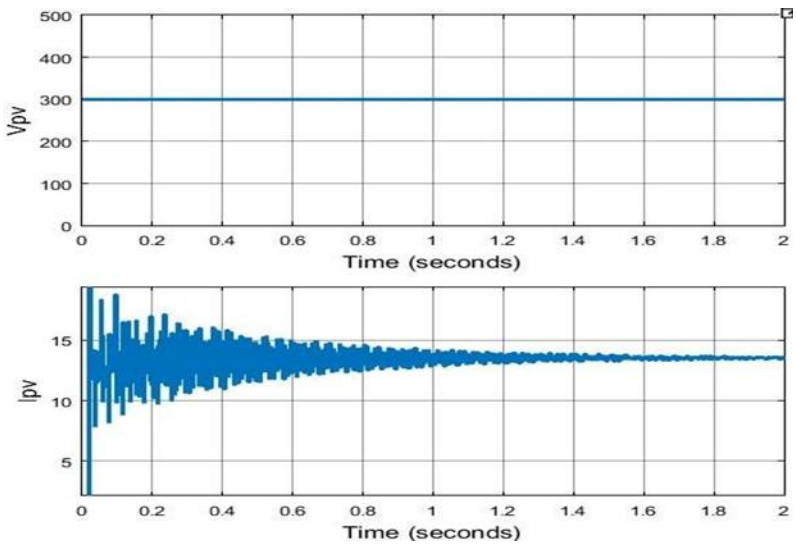

Figure5.9PVAVoltageandCurrent

Figure 5.10 depicts the PVA voltage and current shared to maximize sun radiation. After connecting PVA to SAPF, we obtained a voltage of roughly 300 volts and a current of around 14 amps. The grid receives voltage and current from outside sources.

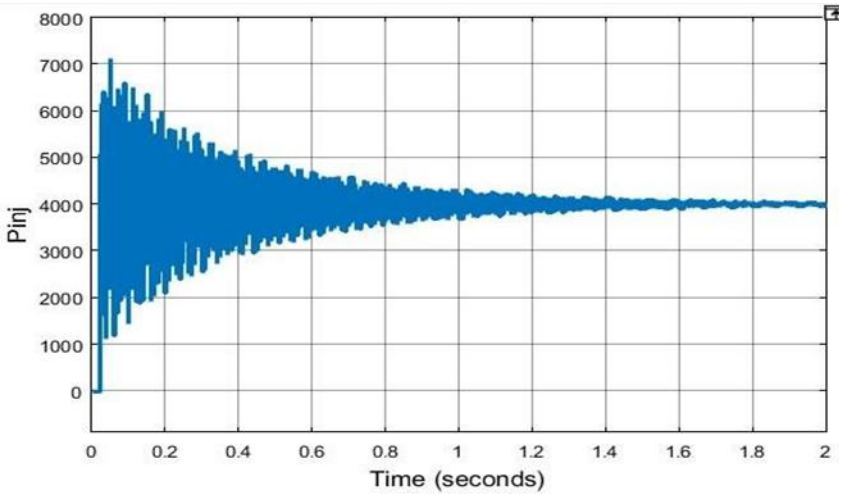

Figure5.10InjectedActivePowerof SAPFConnected toPhotoVoltaicArray

Figure 6.15 depicts the total active power injected by the PVA-integrated SAPF into the grid system. The total amount of electricity pumped into the grid is roughly 4 kW. When Shunt Active Power is linked to the grid at PCC, the THD of the source current falls from 34.68% to 2.47%. The Photo Voltaic Array Integrated Shunt Active Power Filter module also provides active power injection of 4kW of electricity. The APF system is more resilient, efficient, and stable, which improves the power distribution system's practicality and harmonic propagation.

6. Conclusion

When Shunt Active Power is linked to the grid at PCC, the source current's THD decreases from 34.68% to 2.47%. Additionally, the Photo Voltaic Array Integrated Shunt Active Power Filter module provides an active power injection of 4kW. The APF system is more resilient, efficient, and stable, enhancing the practicality and harmonic propagation of the power distribution system. A detailed examination of both the active filter inverter and the passive filter is offered, including active power capabilities and filtering properties. The control algorithm ensures that the power distribution system has controlled sinusoidal voltage, phase amplitude, and minimal THD, as well as dc-link voltage management. The whole simulation is carried out in the Simulink environment of MATLAB software, with graphs made using the powergui toolkit.

6.1. FutureScope

The traditional PI controller may be substituted with sophisticated controllers such as adaptive, artificial neural networks, or optimization approaches to better stabilize the outputs for any given disturbance in the system. Along with PVA, numerous renewable sources may be linked at the DC link to increase renewable active power sharing to the grid, lowering power consumption from conventional sources.

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