POWER QUALITY ENHANCEMENT FOR A GRID-CONNECTED PHOTOVOLTAIC SYSTEM USING FONF CONTROL THEORY

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ABSTRACT

The creation of a fractional order notch filter (FONF) for a grid-connected solar photovoltaic (PV) system is the subject of this research. The voltage source converter (VSC) in a photovoltaic (PV) system uses gating pulses to operate because the proposed FONF control technique estimates basic active elements from the distorted load currents. The goal of this control strategy for grid-connected solar PV systems is to feed the active power demand of the load or grid and address power quality concerns linked to current at a common connecting point, among other goals. The system's reactive power load, harmonic distortion, and unbalanced connected loads are the power quality concerns that are taken into account. A modified integer order notch filter construction is suggested by the FONF-based control. The fixed integrator and differentiator terms restrict the integer order filters. The FONF allows for the modification of the integrator power in a notch filter based on the specific application needed to get an accurate response from the system. IGBTs-based VSC are used in the lab to construct a prototype of the grid-connected solar PV system that shows how the FONF-based control behaves. Results from simulations with variations in solar irradiation are achieved for both unbalanced and steady state loads. The system's harmonic distortions are noted in accordance with IEEE-519.

Index Terms: Power quality, harmonics, notch filter, solar photovoltaic generating, fractional order control.

1. INTRODUCTION

Renewable energy sources have seen an increase in popularity due to growing concerns about global climate change and rising electricity consumption (RESs). The solar photovoltaic (PV) energy conversion system is the recommended option among several renewable energy sources (RESs), including wind power, biomass, biogas, fuel cells, and small/micro-hydro. These factors include its affordability, ease of installation, availability, and environmental friendliness. Large-scale grid-connected solar PV producing station installations are becoming increasingly common in both developed and developing nations. The Indian government has also set a target of installing 100 GW of solar PV power by 2022. A voltage source converter (VSC) connects the PV array to the grid in a grid-connected photovoltaic system. For the purpose of obtaining the most amount of power from the PV panel, these systems often include maximum power point tracking (MPPT) control installed.

This may be done by adjusting the duty cycle to regulate the semiconductor device's on and off states in the DC-DC converter that interfaces with the photovoltaic array. Moreover, the utility is now concerned about power quality due to a rise in the use of nonlinear loads and the existence of highly inductive loads. Distortion in the grid voltages is caused by nonlinear loads, which also cause distortion in the grid currents. Massive, heavy inductive loads that use electricity at low power factor put extra strain on the grid. In addition, a three-phase distribution network imbalance may cause a high neutral current to flow through the neutral conductor, potentially damaging it. Several power conversion stages, or power converters, are needed to integrate RESs with the utility grid. These power converters increase harmonic distortions in the supply system. As a result, the grid integrated solar PV system should be able to mitigate power quality concerns in addition to providing actual electricity to the grid or load.

Using an active shunt compensator is a simple way to solve power quality issues including harmonics, feeding lead/lag reactive power, and load unbalancing. Active shunt compensators are a highly interesting alternative to passive compensators for load compensation because of its small size, quick response time, and steady functioning. When the same VSC is appropriately regulated to meet the dual aims of providing actual as well as reactive power, the method becomes even more appealing and economical. The literature has listed a number of studies that have been conducted to achieve these two goals in grid-connected solar photovoltaic systems. Arab al. have suggested a sturdy linear quadratic regulator with an additional integral action controller to achieve a variety of solar PV system tasks, including voltage stabilization, power line conditioning, and active power regulation. In order to accomplish the dual goals of a grid-tied solar PV system—maximizing power extraction from the PV array and delivering it to the load—Modi invented the WidrowHoff algorithm. This algorithm also enhances power quality at the distribution system. Miranda has looked at a hybrid control to mitigate power quality concerns like harmonics and power factor correction while also achieving an uninterrupted supply despite the intermittent nature of solar PV arrays.

With the use of appropriate control techniques, the PV array fed grid connected VSC may combine the properties of an active shunt compensator. The literature has reports on many control strategies for these kinds of applications. Typical methods include instantaneous p-q theory, which employs the Clark transformation ($\alpha\beta0$) to convert three-phase voltages and currents into a stationary reference frame of $\alpha\beta0$. Additionally, power balance theory and instantaneous symmetrical component theory (ISCT) are also utilized. The latter was designed to operate dual VSC in order to improve power quality in microgrid operations.

Designed for three phase PFC rectifiers, the hybrid one cycle control (HOCC) combines the best features of symmetrical pulse width modulation (PWM) with a control block that may be used in both SPWM and space vector PWM (SVPWM). For grid-tied PV systems, a plethora of artificial intelligence-based controllers have been developed. These are based on T-S fuzzy controller, adaptive neuro fuzzy based inference system, and artificial neural network (ANN). Because they eliminate the need to adjust and adjust several parameters in real time, adaptive theory-based controls have drawn a lot of attention in the last ten years. An automated tuning aid in achieving goals more successfully.

A large number of adaptive controls have been documented in the literature; they include adaptive differential evolution control, least mean square Adaline based adaptive neuro-fuzzy controller, adaptive Laguerre filter-based control, and multilayer fifth order generalized integrator, among others. Other contemporary notch filter-based control strategies include amplitude adaptive notch filter and adaptive notch filter (ANF) driven multifunction control for grid-connected RES systems.

The notch filter and its comparison with the integer order notch filter design are included into the adaptive control approach. These controllers have a drawback in that they can only produce a symmetric gain curve. The asymmetrical gain curve around the notch filter's core frequency cannot be produced using an integer order integrator. By offering a high gain at a particular frequency, the notch filter is often intended to reject all undesirable frequencies from the signal and choose an interesting frequency.

Notch filters are utilized as selector or rejector circuits in a variety of applications since they essentially fall within the band pass or band reject filter category. Because of its fixed integrator or differentiator term, an integer order notch and other filters have their own constraints. Due to the flexibility and advantages of fractional order control theory, fractional order filters have emerged as a means of changing the fixed structure of an integer order filter. A traditional notch filter's integrator power may be adjusted by the designer to get a more desired and precise response during operation using fractional order control theory.

Unlike the integer order notch, the fractional order notch filter generates the gain term between 0 db/decade and ±20 db/decade or ±40 db/decade. The ability to generate an asymmetrical gain response curve—something that is not achievable with a regular notch filter—is another benefit of using a fractional order notch filter. In the realm of signal processing, there have been a few restricted studies and study reports in the literature about the functioning of fractional order filters; however, there has been no noteworthy work in the area of power electronics control. This research develops a unique notch filter structure specifically for grid integration solar PV system operation.

The basic weight component of the distorted load currents is extracted using this fractional order notch filter (FONF). Using FONF control, the active power needs of the load/grid are shown, together with characteristics of the active shunt compensator such as load unbalancing, reactive power burden reduction, and harmonic mitigation. Test findings and comparison simulation research verify significant benefits for an accurate control by lowering the system's total integral square error. The following is a summary of this paper's major contributions. development of grid-integrated solar photovoltaic (PV) systems using fractional order notch filters (FONF). The FONF controller was created to separate the essential active components from the distorted load currents and to address PQ issues including load unbalancing, harmonics, and the system's reactive power burden. Grid-integrated PV system created in the lab put into practice in real time.

• A created prototype is used to verify the FONF controller's performance.

Testing the system's performance in a variety of settings, such as during the day when the sun is present. In addition to providing active power to the grid or load, it does a few PQ-related auxiliary functions. Additionally, the device handles various PQ concerns at night by acting as a power quality compensator. The normalized least mean square (NLMS), normalized least mean fourth (NLMF), and integer order notch filter (IONF) based control approaches are compared with the performance characteristics of FONF control for solar PV systems. It is shown that the suggested control performs better in terms of sampling time, harmonics compensation, fundamental weight convergence, integral square error, and computational complexity.

2.INVERTERS

2.1 DC- AC CONVERTER (INVERTER)

An electrical device called an inverter changes direct current (DC) to alternating current (AC); with the right transformers, switching, and control circuits, the converted AC may be at any desired voltage and frequency. Solid-state inverters are utilized in many different applications, ranging from big electric utility high-voltage direct current applications that transmit bulk power to tiny computer switching power supplies. They are made without moving components. When supplying AC power from DC sources, such solar panels or batteries, inverters are often used.

2.2 CIRCUIT DESCRIPTION

2.2.1 BASIC DESIGNS

DC electricity is linked to a transformer in a single basic inverter circuit via the main winding's center tap. To enable current to return to the DC source via two distinct paths—through one end of the main winding and then the other—a switch is quickly shifted back and forth. Alternating current (AC) is created in the secondary circuit by the transformer's main winding's change in current direction.

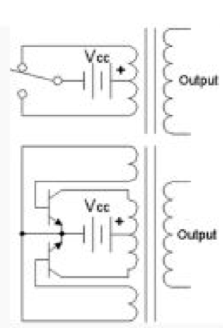
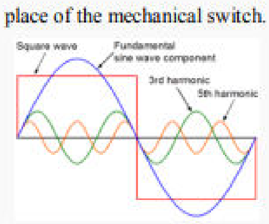


Fig 2.1: Simple inverter circuit shown with an electro-mechanical switch *and automatic equivalent*

auto-switching device implemented with two transistors and split winding auto-transformer in place of the mechanical switch.



Square waveform with fundamental sine wave component, 3rd harmonic and 5th harmonic

The switching device's electromechanical form has a moving contact supported by a spring and two stationary contacts. The mobile contact is held against one of the stationary contacts by the spring, and it is pulled to the opposite stationary contact by an electromagnet. The switch's function interrupts the current flowing through the electromagnet, causing it to quickly flip back and forth repeatedly. Known as a vibrator or buzzer, this kind of electromechanical inverter switch was first used in vacuum tube car radios. Tattoo guns, buzzers, and door bells all employ a similar mechanism. Transistors, among other forms of semiconductor switches, have been used into inverter circuit designs when they became available with sufficient power ratings.

2.3 TYPES OF INVERTERS:

Generally, inverters are of Two Types:

1. VOLTAGE SOURCE INVERTER (VSI)

2. CURRENT SOURCE INVERTER (CSI)

3.RENEWABLE ENERGY SOURCES

3.1 INTRODUCTION

This chapter provides a short discussion of the project's nonconventional energy sources, including the wind, hydro, photovoltaic, and battery systems, along with the essential vocabulary and background knowledge.

3.2 BLOCK DIAGRAM

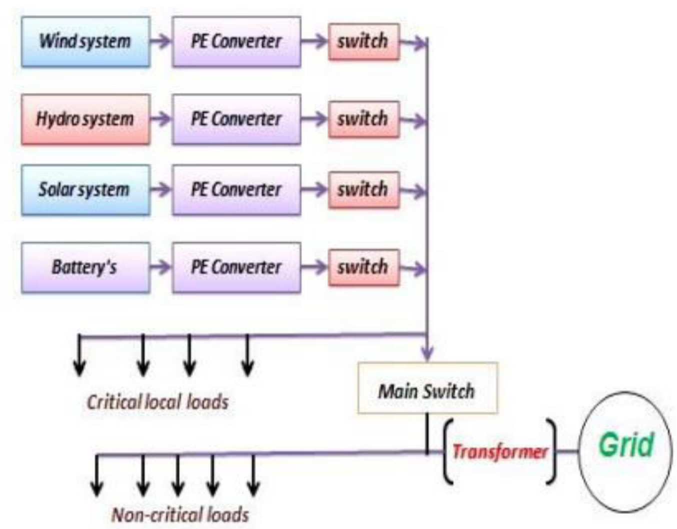


Fig.3.1: Block diagram

3.3 SOLAR PHOTOVOLTAICS

3.3.1 Introduction

Becquerel was the first to notice the photovoltaic effect, which converts solar energy. It is usually understood to mean that when light is shone on a solid or liquid system, an electric voltage appears between two electrodes linked to the system. Solar cells are energy conversion devices that employ the photovoltaic effect to transform sunlight into electrical current.

3.3.2 Basics of Solar Cells

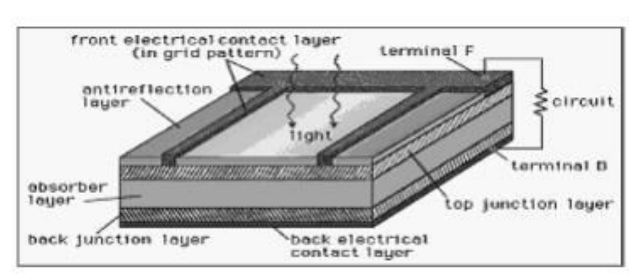


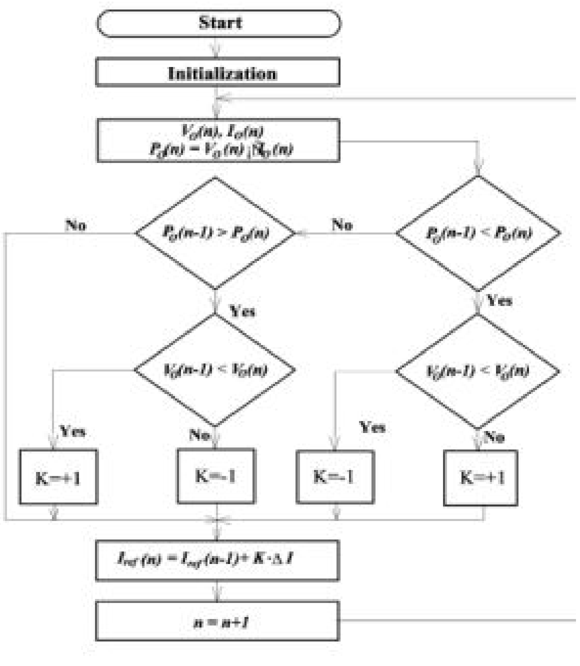
Fig.3.2: Solar cell

4.MAXIMUM POWER POINT TRACKER

4.1 PRINCIPLE OF MPPT

A high-efficiency DC to DC converter known as a maximum power point tracker, or MPPT, presents the ideal electrical load to a solar panel or array and generates a voltage appropriate for the load. PV cells have a single operational point when the cell's voltage (V) and current (I) values provide the highest possible power output. These numbers represent a specific load resistance, which Ohm's Law states is equal to V/I. The maximum power point (MPP) of a photovoltaic cell is found at the knee of the curve, when resistance equals the negative of differential resistance ($V/I = -dV/dI$). PV cells have an exponential connection between current and voltage. In order to find this point and enable the converter circuit to draw the most power possible from a cell, maximum power point trackers use some kind of control circuit or logic.

4.2 ALGORITHM OF PERTURB OBSERVE METHOD



5.SYSTEM CONFIGURATION

5.1 SYSTEM DESCRIPTION:

The linear and nonlinear loads connected to the three-phase AC mains with modest line impedance (Rs-LS) are fed by them. The 1.5 kW rated power capacity solar PV array is linked to the VSC DC connection. Through the use of interface inductors (Lf), the AC side of the VSC is connected to the point of common coupling (PCC). The purpose of the small ripple filter (Rf-Cf), which is linked at the PCC, is to suppress the high frequency components produced by switching semiconductor devices. Hall-effect voltage and current sensors are used to detect the following: PCC voltages (vs), grid currents (is), load currents (il), DC link voltage (Vdc), PV array voltage, and PV current (VPV and IPV). The dSPACE DS-1202 MicroLabBox is used to build the FONF based control algorithm, and the controller interface box's analog to digital converter (ADC) channels are used to input detected voltages and currents.

5.2 BLOCK DIAGRAM:

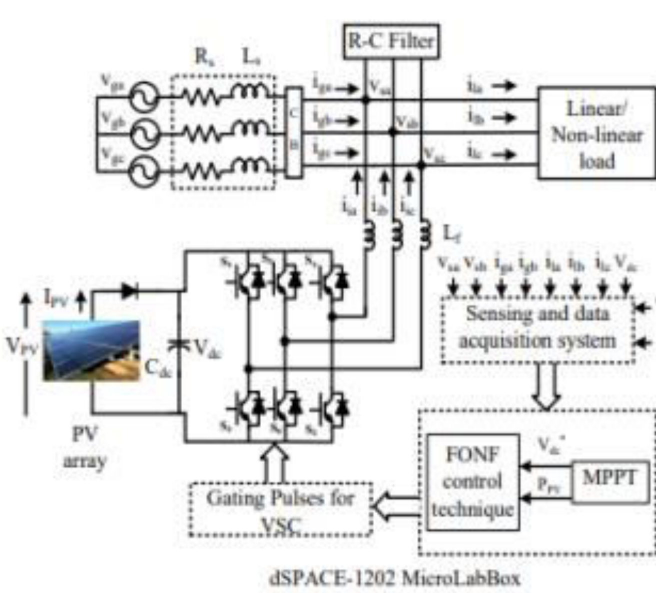


Fig.5.1: System configuration of grid connected solar PV system.

6.SIMULATION

6.1 SIMULATION CIRCUIT:

There are three requirements for our endeavor.

1. Over voltage Condition.

2. A low voltage situation.

3. There is no PV voltage.

Case 1: Over Voltage Condition Simulink Circuit

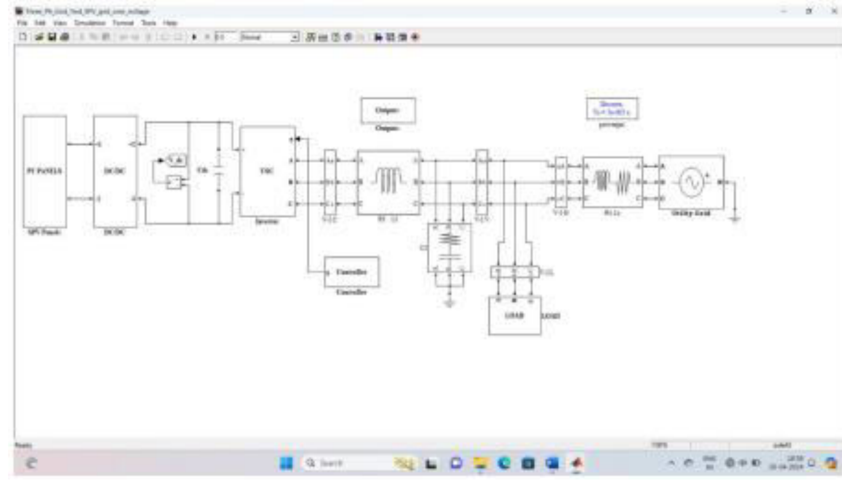


Fig.6.1-Simulink circuit of Over voltage Condition

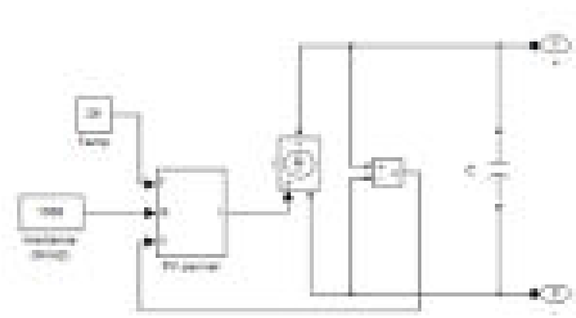


Fig.6.2- PV cell

DC-DC Boost Converter

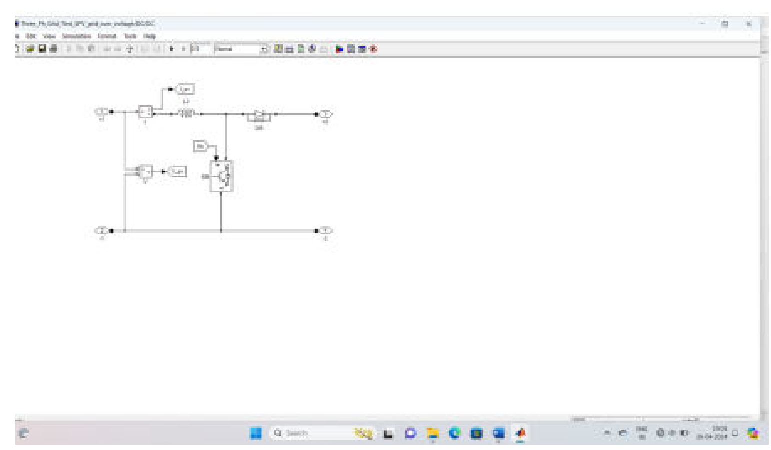


Fig.6.3- DC-DC Boost Converter

VSC (Voltage source converter)

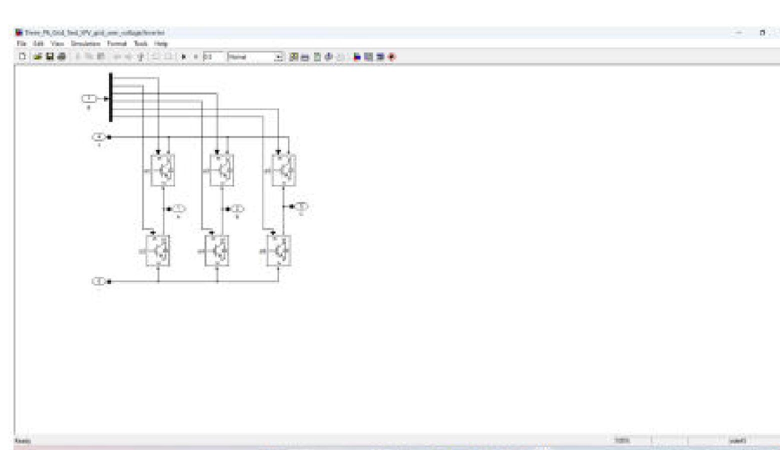
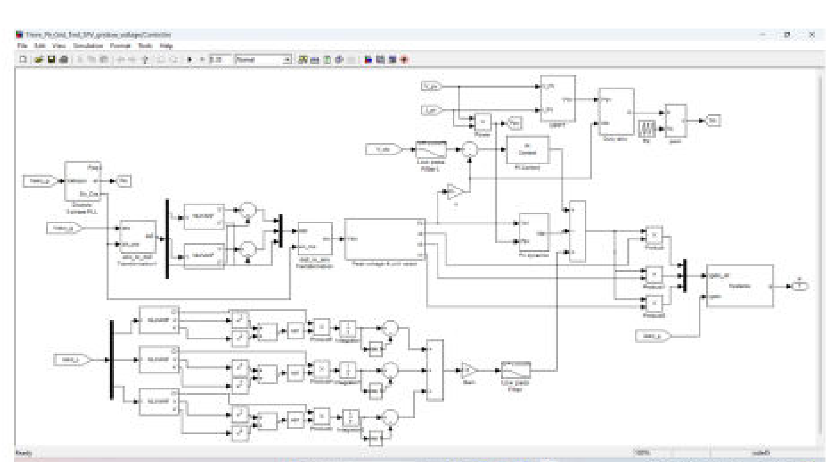


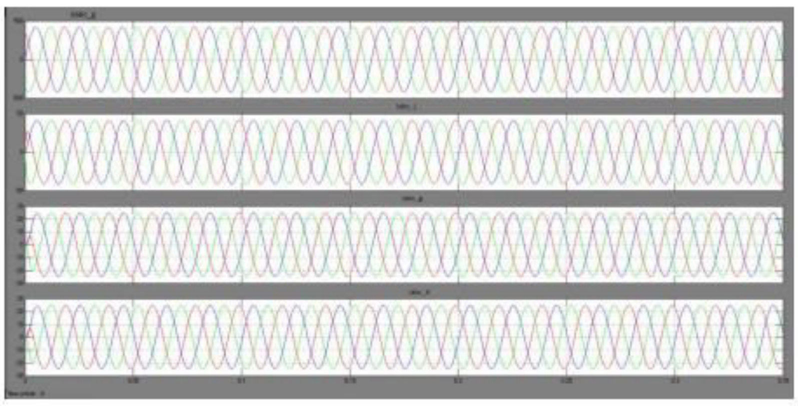
Fig.6.4- Voltage Source Converter (Inverter)

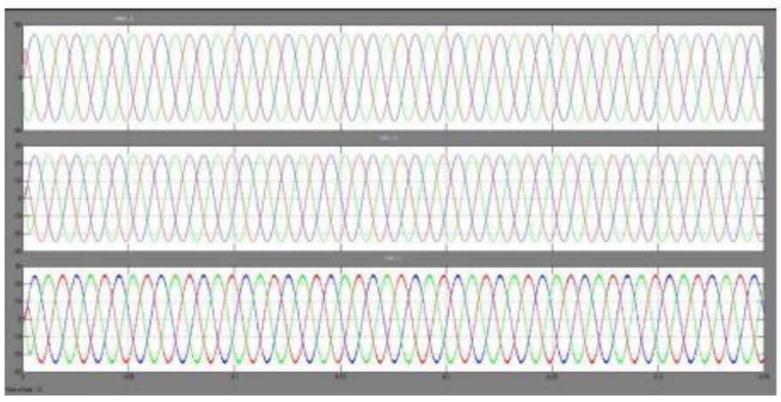
FONF CONTROLLER:

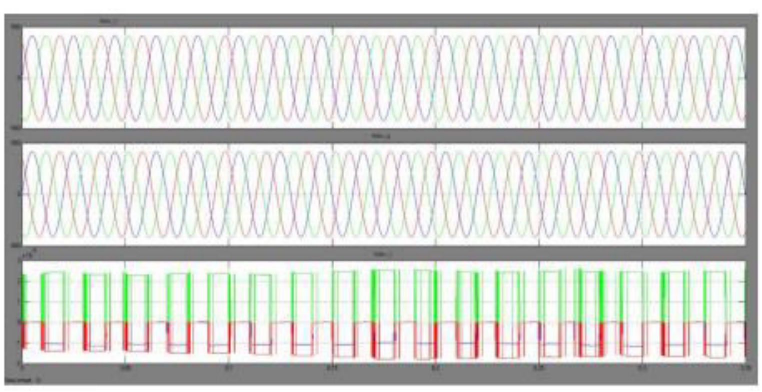


WAVEFORMS:

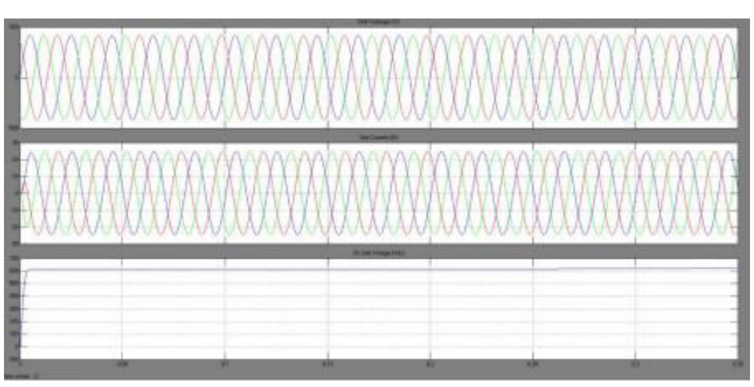
INPUTS:

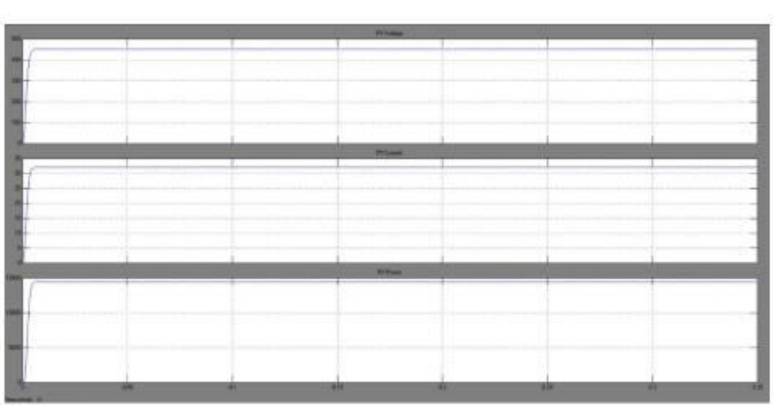




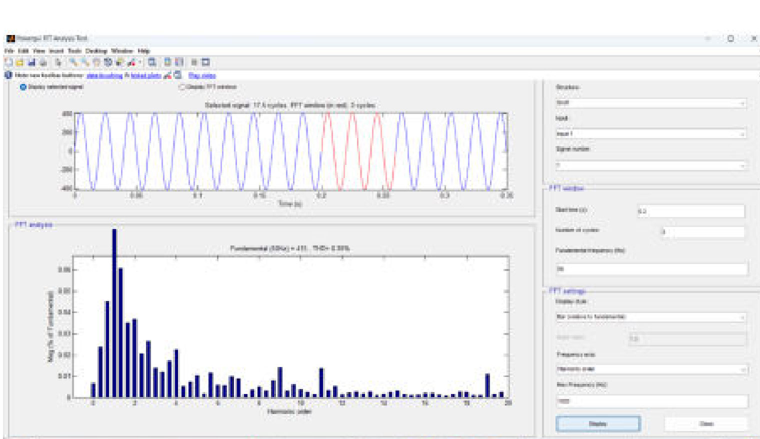


OUTPUTS:





THD (Total Harmonic Distortion):



7.CONCLUSIONS

This paper proposes a three-phase grid-connected solar photovoltaic system with FONF-based control. The grid-connected PV system's dual goals of providing active electricity to the load and grid and resolving current-related power quality concerns at PCC are the reasons for the design of the FONF control. The created control system has resolved a number of power quality concerns, including harmonic distortion in the grid current, reactive power consumption of the load, and unbalancing load currents. Given its ability to modify the power of the integrator used in the notch filter and create an asymmetrical gain response curve—something that is not achievable with an integer order notch filter—the FONF control has been determined to be appropriate. It has been observed from the Bode plot that sharpness of developed FONF does not alter by increasing the value of damping ratio once fractional gains are appropriately decided. Moreover, this control presents fast response when compared with integer order notch filter. Performances of FONF controller have been confirmed at steady state and unbalanced load along with variation in solar irradiance considered. The results demonstrate performance of FONF controller in maintaining 0.35% THD in the grid current.

8.REFERENCES

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