Modelling and Simulation of Power Grid Connected PV Generation System Using MATLAB/Simulink

A DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

CONTROL AND INSTRUMENTATION

SUBMITTED BY:

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CANDIDATES DECLARATION

I, Suryansh Dubey (2K19/C&I/11) student of MTech., Control and Instrumentation Engineering at Delhi Technological University hereby declare that the dissertation titled "**Modelling and Simulation of power grid connected PV generation system using MATLAB/Simulink** " which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not plagiarized from any source without proper citation. This work has not previously formed the basis for award of any Degree, Diploma, Associateship, Fellowship, or any other similar title or recognition.

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SUPERVISOR CERTIFICATE

I hereby certify that the project Dissertation titled "**Modelling and Simulation of power grid connected PV generation system using MATLAB/Simulink**" which is submitted by SURYANSH DUBEY, 2K19/C&I/11, ELECTRICAL ENGINEERING DEPARTMENT, Delhi technological university, Delhi, in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree to this University or elsewhere.

PLACE: DELHI

Date:13-07-2023

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Place: Delhi

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ABSTRACT

These days the Power Quality has become the key issue in electrical distribution power systems. Customers are critical to the energy industry's long-term growth. In this thesis comparative study of a system with a 10-kW grid- connected photovoltaic system and a PID controller with and without MPPT is simulated in Simulink. The Perturb and Observe (P&O) approach is utilised to increase the power output of a photovoltaic array. The tuned output of the PID controller is provided to the inverter through IGBT switching devices. The inverter is a three-level inverter with a Neutral Point Clamped architecture. The MPPT monitors maximum power point and provides improved output power from the photovoltaic system. The inverter's converted output is then routed to 15 kW and 20 kW local loads, respectively. The loads are switched at intervals of 0.5 seconds, and the linked power grid meets the remaining demand of the loads. Additionally, a dynamic model of a photovoltaic system is built in order to compare the output from the photovoltaic array to the inverter with and without MPPT. Also, power is compared from the inverter to the loads to confirm the usage of NPC and HCC.

LIST OF ABBREVIATIONS

PV	Photo Voltaic
AC	Alternating Current
DC	Direct Current
FIT	Feed In Tariff
I(k)	Short Circuit Current
MPPT	Maximum Power Point Tracking
VSI	Voltage Source Inverter
SPWM	Sinusoidal Pulse Width Modulation
P& O	Perturb & Observe Algorithm
Kwh	Kilo Watt hour
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
PVSYST	Photovoltaic System
HCC	Hysteresis Current Control
NPC	Neutral Point Clamped
IGBT	Insulated-gate bipolar transistor

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

By converting the direct current (DC) electricity produced by solar panels into alternating current (AC) power, the inverter is a key component of grid interactive system. The electrical grid is then immediately supplied with this AC power, allowing for its integration and utilization. Any excess energy generated by renewable energy sources, like solar panels, beyond the building's electricity needs is returned to the electrical grid in grid interactive systems. Other grid-connected users can make use of this extra energy. Utility providers may give system owners credits for the extra energy they feed back into the grid. These credits can be used to reduce future electricity costs, which encourages the use of renewable energy sources [1]

Grid-connected photovoltaic systems offer reliable performance and demonstrate the efficiency of the control system. Photovoltaic systems are popular due to their lightweight nature, environmental friendliness, and ease of installation. However, in order to guarantee a high-quality electric power system, connecting these systems to the grid requires a number of prerequisites.

Under normal circumstances, the inverter maintains the battery in a fully charged state, preparing it for use during power outages. When the grid goes down, the grid interactive inverter seamlessly converts DC power from both solar panels and batteries into usable AC power to operate specific loads. Throughout the day, the system charges the batteries using power from the solar panels, and if necessary, from a generator. The generator can be intelligently controlled by the grid interactive inverter so that it only runs when necessary to replenish the batteries. As a result, the generator runs for shorter periods of time, makes less noise, and uses less fuel.

Under Typical conditions , the inverter in a grid interactive system ensures that battery remains fully charged , thereby keeping it ready for utilization during power outages .In the event of a grid failure, the grid interactive inverter seamlessly converts the direct current (DC) power derived from both the solar panels and batteries into Alternating Current(AC) power .This AC power is then employed to operate specific loads , enabling the continued functionality of electrical equipment even when grid is down .These solar inverters' efficiency, dependability, and safety characteristics are essential for a PV system to function properly.

1.1 OBJECTIVES

The objectives of grid interactive inverters address the urgent need to reduce reliance on fossil fuels, which currently account for 60% of energy consumption and result in the emission of large volume of CO2. With nonrenewable resources being depleted at an alarming rate, renewable sources such as solar energy and wind energy emerges as potential solution. However, to integrate the variable power output and ensure compatibility with the existing transmission grid in terms of voltage and frequency, grid interactive inverters play a crucial role.

Over the past few decades, solar arrays and power converters have become much more affordable because to developments in the photovoltaic (PV) sector. Electricity generation from PV arrays is now more feasible and cost-effective thanks to government incentive programs like tax credits and rebates. Policies like as Net Metering, Feed-in Tariffs, and Renewable Portfolio Standards (RPSs) can help the solar industry change. Utility interactive inverters are at the Centre of this change. Grid interactive inverters are complicated pieces of equipment that control the behavior of the entire system. The effectiveness of a PV system depends on its components' efficiency, dependability, and safety features.

Grid-interactive inverters should successfully export electricity produced by PV arrays to the utility grid while preserving the system's integrity and safety. To ensure these grid contact capabilities, all inverters must adhere to IEEE 1547 specifications. The primary focus of this talk is on the design components of a solar inverter that comply with IEEE 1547. A number of important control procedures are covered, such as managing current harmonics, addressing uncommon grid circumstances. The presentation also considers potential applications for these inverters to enhance grid stability and security in the future.

1.2 MATHEMATICAL MODELING OF A PHOTOVOLTAIC MODULE

Modelling serves as the foundation for computer simulations of real systems, providing a theoretical analysis of the various physical processes and factors that influence these processes. Mathematical models are developed to describe the characteristics of the system and are then translated into computer codes for use in the simulation process. For academics and experts in the subject of photovoltaics, models are essential in explaining the behavior of photovoltaic cells. The single diode circuit model, which depicts the electrical behavior of the pn-junction, is the most widely used model for estimating energy generation in solar cell modelling.

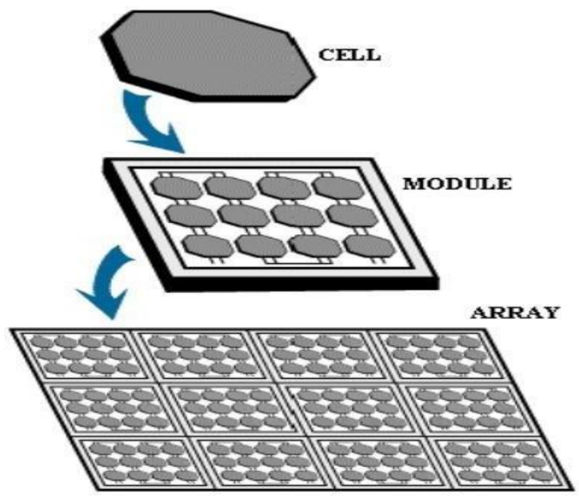

Fig 1.1 Solar PV Cell, Module and Array

Fig 1.1 illustrates the working principle of a photovoltaic system. The PV panel can be considered as an energy conversion system. The inputs (such as the amount of solar radiation G, the load current I, and the temperature T) and outputs (such as the output voltage U of the PV panel) of the model are shown in a block diagram in Fig 1.1.

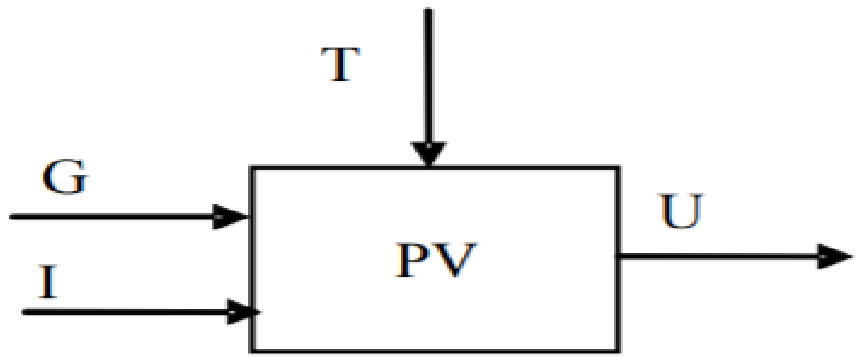

Fig. 1.2 Block diagram of PV panel

The PV model can be expressed by function which has current I, Voltage U, Irradiance G, Temperature T

The short-circuit current I_k is constrained by the open-circuit voltage U_o when the voltage is limited, and G stands for the conductivity of the solar panels. Conductivity and temperature parameters in a photovoltaic (PV) model exhibit nonlinear behaviour, which results in nonlinear behavior in the model's output voltage. Based on the aforementioned relationships for the PV module, we can approximate the PV voltage and current using equations 1 and 2. The voltage U_p is a linear approximation of the output characteristics, with coefficients p_0 as offset and p_1. For a specific range of q values and a constant temperature of 20°C, the coefficients are p_0 = 18.6 and p_1 = 2.35.

$$U = U(q) = p_o + p_1.q + p_o.q/(1-q) \quad (1)$$

$$I = q.(1 + \frac{1}{U} - U_p) \quad (2)$$

Likewise, the open-circuit voltage U_0 and short-circuit current I_k can be developed and approximated as

$$U_0 = U_p - 1 = p_1.q + p_o - 1 = 2.35.q + 17.6 \quad (3)$$

$$I_k = q(1 - \frac{1}{U_p}) = q(1 - \frac{1}{p_1.q + p_o}) = 0.96q - 0.003 \quad (4)$$

Fig. 1.3 represents the relationship between photovoltaic voltage and current represented by theeffect of the solar radiation intensity q.

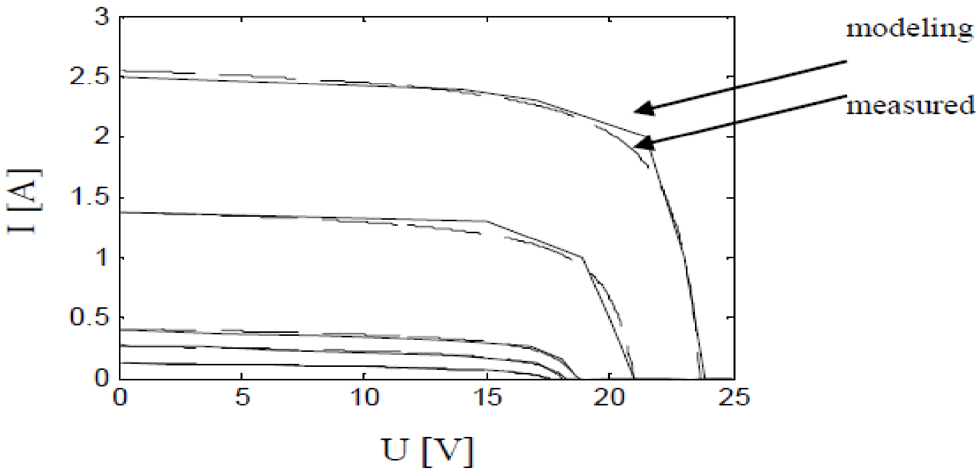

Fig 1.3 I-V characteristics of PV (mathematical modelling)

In Fig 1.3 we observe the comparison between the measured PV Curve and the output obtained from I-V PV Characteristic modelling using aforementioned formulas. A solid line depicts the modelling results, whereas a dotted line shows test results. It is clear that the modelling strategy produces positive outcomes, demonstrating that equations 1 or 2 can accurately describe the PV Model. Moreover, to enhance the accuracy of the model, an extended mathematical representation of the PV System is presented below. This enhanced model incorporates an additional parameter, r, which corresponds to the conductivity, further refining the model's predictive capabilities

$$I = I(U, q) = q.(1 + \frac{1}{U} - U_s) + r.U \ \ = q\left(1 + \frac{1}{U} - s_o - s_1.q\right) + r.U \quad (5)$$

$$U = U_s + k.\frac{q}{.1} - k.q - r.U \quad (6)$$

where U_s is a linear approximation.

$$U_s = s_o + s_1.\mathrm{q} \quad (7)$$

Then the open-circuit voltage U_o and short-circuit current I_K are given by:

$$U_o = U_s - k.\left(\frac{q}{k}\right).q + r.U_s \quad (8)$$

The output characteristics of the PV system can be linearly approximated using Equation 7, where the coefficients s_0 = 18.8, s_1 = 2.3, and r = -0.003. Fig 1.3 represents the results of the mathematical modeling of the I-V PV characteristics using the aforementioned equations. It is clear that this enhanced approximation yields outcomes that are superior to and more accurate than those produced by the prior approximation. It is important to keep in mind that the first approach might be preferable in terms of making the hardware implementation of the maximum power point tracking (MPPT) algorithm simpler. The mathematical modeling's predictions are well supported by the experimental verification, confirming its accuracy and showing improvements over the earlier approximation. As an alternative, the initial strategy might be advantageous in terms of streamlining the hardware implementation of the MPPT algorithm. Notably, the experimental results closely match the mathematical modeling's predictions, confirming the methodology's usefulness and correctness.

1.3 CONNECTING PV SYSTEM WITH GRID

PV systems connected with grid are widely utilized, for utilizing abundant and cost-free solar energy. However, the high cost of photovoltaic cells contributes to the initial high expenses of solar energy adoption. The solar cell is a PV system's primary component responsible for converting solar irradiance into direct current (DC). A synchronized converter is necessary to convert the low MPPT Voltage into AC in order to connect a PV system to the grid. Modeling and simulation of the system are necessary to ensure its desired functionality and investigate its performance under different conditions.

Models are essential in the field of photovoltaics because they help professionals and researchers understand the behavior of photovoltaic cells. The single diode circuit model is the most used model for predicting energy generation in solar cell modelling because it illustrates the electrical behavior of the pn-junction.

1.4 COMPONENTS INVOLVED IN PHOTOVOLTAIC CONVERSION

The principle schematic diagram of a grid connected PV system with voltage source inverter is shown below in Fig. 1.4

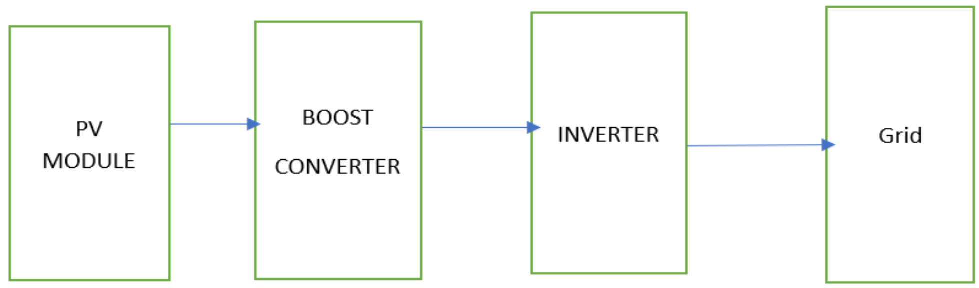

Fig.1.4 Grid connected PV system block Diagram[16]

A photovoltaic conversion system typically consists of several crucial parts, as indicated in Fig.1.4, including solar modules, converters, the utility grid, DC and AC loads, and inverters. A grid-connected system without battery backup, often known as this design, is frequently utilized in PV standby power supply units.

1.4.1 PV MODULE

The main power source in every photovoltaic installation is the solar panel. It is made up of a number of solar cells coupled in parallel and series. Solar irradiance is directly converted into DC power by the semiconductor materials of PV cells when sunlight interacts with them. The equivalent circuit of a PV cell is depicted in Fig 1.5 which enables the derivation of its nonlinear I-V characteristics.

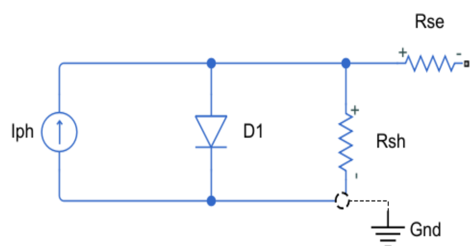

Fig 1.5 Equivalent circuit of photovoltaic cell [16]

1.4.2 DC-DC BOOST CONVERTER

An important factor in maximizing a solar installation's overall efficiency and functionality is the boost converter's positioning. It enables various control mechanisms within the system. The solar panels can provide either the greatest amount of energy that is accessible to the system or the amount of energy that is ideal for their functioning by using the proper laws. The grid-tied inverter receives electricity through the boost converter from the solar panels, which serves as a means of power transmission. This process involves the utilization of four essential components: an inductor, electronic switch, diode, and output capacitor.

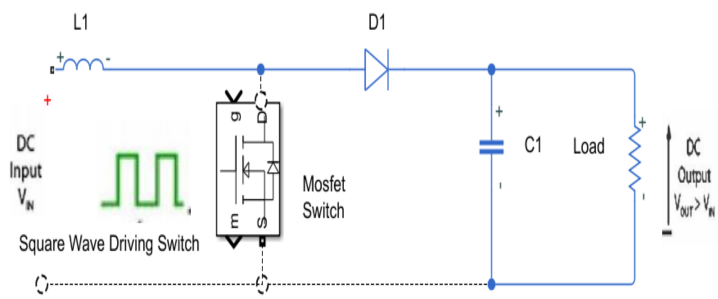

Fig 1.6 Basic Boost Converter Circuit[16]

As the switch is closed (time t1), the inductor current rises, increasing the amount of energy the inductor L can store. In contrast, the inductor current decreases when the switch is left open for time t2 because energy from the inductor is passed through the diode D. Since the output voltage is greater than the input voltage, equation (9) can be used to quantitatively explain this phenomenon. Here $0<a<1$.

$$\frac{V_{out}}{V_{in}} = 1/(1-a) \qquad (9)$$

1.4.3 INVERTER

The inverter serves as a crucial component within the system, comprising semiconductor switches that are controlled by a dedicated controller. The primary function of the inverter is to convert the DC power generated by the photovoltaic system into AC power that can be utilized by various devices.

The photovoltaic (PV) array produces direct current (DC) electricity, which the inverter converts into alternating current (AC) power to match the utility grid criteria for voltage and power quality. The voltage source inverter (VSI) has been used as inverter topology in this design. The VSI consists of a three-phase configuration with six switches, denoted as S_1 through S_6. Fig 1.7 illustrates a schematic representation of this VSI, where the middle section of each "inverter leg" is connected to each respective phase output

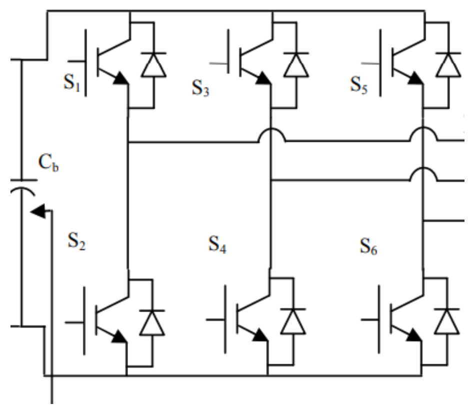

Fig 1.7 Topology of Three Phase Inverter[16]

Controlling the switch's conduction intervals has a direct impact on the form and quality of the AC output waveforms. The resulting AC waveform can be precisely controlled in terms of its phase, magnitude, and frequency thanks to SPWM. To achieve the desired output waveform, the process involves utilizing the use of other related techniques, a high frequency triangular waveform known as carrier signal, three reference sinusoidal waveforms of the same frequency

The magnitudes of the sinusoidal and triangular waveforms are compared during the modulation process. The top switch in the corresponding phase leg (as shown in Fig 1.4) is engaged when the magnitude of the modulating signal is greater than that of the carrier signal. By doing this, the output voltage is brought into balance with the DC link voltage and vice versa.

1.4.4 BAND PASS FILTER

A bandpass filter is utilized to take harmonic components out of the inverter's output. It is connected to the grid between the inverter and make sure that harmonics are properly controlled. A specific type of filter utilized is the bandpass filter, which is centered at 50 Hz and designed with a narrow bandwidth. This configuration aims to comply with the harmonic introduction limits specified by the IEEE 519 standard for the power system

1.4.5 OTHER DEVICES

To enhance performance, the implementation of a filter can be considered, which can contribute to improved outcomes. Additionally, the utilization of a meter is recommended to accurately measure and monitor the energy being consumed from or supplied to the local power grid

1.4.6 LOAD

This component plays a crucial role in the process of converting this energy into useful work.

It is a 3-phase series R-L-C Load

1.5 PERTURB AND OBSERVE MPPT ALGORITHM

By regulating the voltage, the MPPT algorithm is used to continuously optimize the power production of PV systems. The Perturb and Observe (P&O) algorithm is one of many MPPT approaches for solar PV applications, and it is popular because of its straightforward design and implementation as well as its effective performance.

The P&O algorithm measures the PV characteristics and perturbs the PV module's operating point to cause a shift in direction in order to track the Maximum Power Point (MPP). A slight increase in PV panel voltage is used to identify the direction towards the MPP; if the change in power is positive, the system is going in the direction of the MPP. By increasing the perturbation step ('), the perturbation in this instance is continued in the same direction. The sign of the perturbation is inverted and the perturbation step (') is reduced if the change in power is negative, which denotes that the system is moving away from the

MPP.

Until the maximum power point is attained, this iterative process is repeated. The reference point (Vref) is the voltage at which the MPP is achieved. The PV system is capable of continually functioning at its maximum power output by dynamically altering the operating voltage depending on the P&O algorithm.

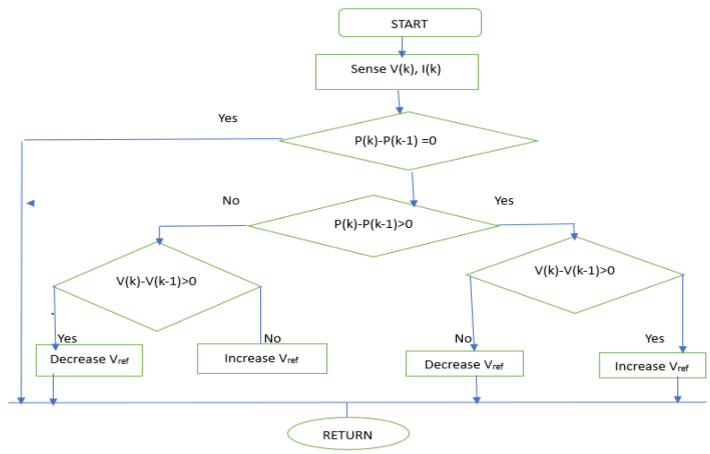

Fig 1.8 Flowchart of P and O algorithm[16]

1.6 GRID MODELLING

The unit formed by the energy transport line and all the connection transformers between the various voltage levels, will be indicated by network in Fig 1.9. It has load which

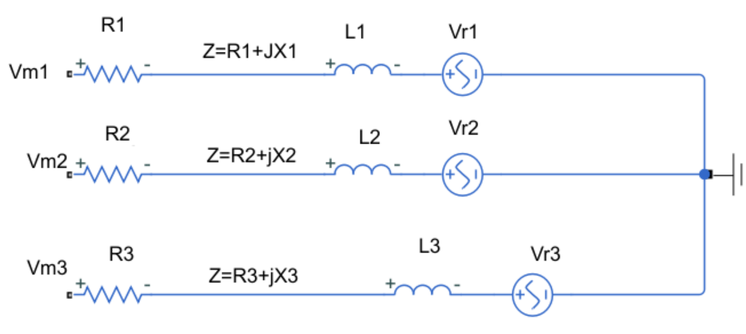

Fig 1.9. Grid equivalent circuit[16]

1.7 THESIS ORGANISATION

This thesis consists of six chapters.

Chapter 1 provides an introduction to renewable energy, with a focus on PV (photovoltaic) systems. It includes discussions on PV selection, the research objectives, which involve mathematical modeling of PV systems and grid interconnection.

Chapter 2 presents a comprehensive literature survey, summarizing relevant research papers that are related to the thesis topic. Additionally, the chapter addresses the problem formulation, highlighting the key challenges and issues.

Chapter 3 focuses on the materials and methods employed in the project. It outlines the components utilized, such as PV panels, boost converters, maximum power point tracking (MPPT) techniques, PID controllers, and the grid. A block diagram is also provided to illustrate the system architecture.

Chapter 4 centers around the simulation and MATLAB work conducted in the project. The chapter includes discussions on the obtained results, along with the presentation of relevant tables and graphs derived from the simulations.

Chapter 5 concludes the thesis and provides insights into future work. It summarizes the main findings and outcomes of the research, while also addressing the original aim of the thesis.

Overall, the thesis encompasses various aspects of renewable energy, PV systems, mathematical modeling, interconnection with the grid, literature review, experimentation, and future direction.

CHAPTER 2
LITERATURE SURVEY

2.1 INTRODUCTION

A literature review refers to the compilation of published information within a specific subject area, often within a defined timeframe. It serves as a concise summary of relevant sources, research methods employed, and the overarching thesis topic.

The purpose of a literature review is to present existing studies in a fresh perspective, incorporating new approaches or combining previous methodologies with novel ones. It provides an overarching view of the research landscape in a given field, serving as a basis for new contributions. While a literature review synthesizes and summarizes the arguments and ideas of others, it does not introduce original findings.

Essentially, a literature review acts as a valuable guide on a specific topic, aiding researchers in developing new insights and conducting further investigations. In some cases, a literature review may even constitute a research paper in itself, presenting a comprehensive analysis of existing literature and scholarly discourse.

2.2 LITERATURE SURVEY

A study on the operational evaluation of an Indian solar photovoltaic power plant with a 190 kWp capacity was undertaken in 2013 by Vikrant Sharma et al. [1]. The final yield, reference yield, and performance ratio were among the several criteria that the researchers evaluated. The results showed that the reference yield varied between 2.29 and 3.53 kWh/kW-day, the ultimate output ranged from 1.45 to 2.84 kWh/kWp-day. The study's performance ratio was between 55% and 83%.

In a study conducted by M. Gohul et al. [2] in 2011, the authors discussed the increasing interest in photovoltaic (PV) generation as an abundant and readily available energy resource. They categorized PV systems into two main types: stand-alone (or off-line) systems and grid-connected systems. Stand-alone systems are commonly used in rural areas and as backup systems when the grid is unavailable due to natural disasters or disruptions. Grid-connected systems, on the other hand, are installed in areas with a reliable grid infrastructure capable of accepting energy from PV systems. To operate a renewable system in parallel with an electric grid, special inverters are required They conducted performance analysis and experimental tests, which demonstrated that the proposed system significantly reduced energy consumption while providing reliable support to the grid. Overall, the study highlighted the importance of grid-connected PV systems and the role of specialized inverters in achieving efficient energy utilization and integration with the grid. The experimental results provided evidence of the system's effectiveness in reducing energy consumption and supporting grid operations

The cost of solar arrays and power inverters has significantly decreased as a result of improvements in the photovoltaic (PV) sector, according to a 2008 paper by Anil Tula Dhar et al. [3] They emphasized how government incentive programs, such tax breaks and rebates, helped make electricity generation from solar panels profitable. Grid interactive inverters were a major component of these solutions. Solar panels are pricey, but grid interactive inverters are high-tech devices that control how PV systems behave. Their effectiveness, dependability, and safety features are essential for a project's success. Overall, the paper highlighted the significance of grid interactive inverters in the PV industry, emphasizing the importance of meeting IEEE 1547 requirements and addressing key control features for efficient and safe grid integration

In a paper by B. Kavya Santoshi et al. [4] in 2019, the authors conducted a comprehensive review of Solar Photovoltaic (PV) systems and their integration with power grids. The paper highlighted the increasing use of inverter-fed PV grid topologies to address the challenge of meeting growing electricity demands. The review concentrated on developments in PV-Grid Tied Inverters, including the benefits, drawbacks, and key characteristics of each topology. Multiple inverters used in the literature were presented and analyzed within the context of PV grid integration. Reactive power, an important ancillary service provided by PV systems, was discussed the article suggested the injection of reactive power from the inverter into the grid as a means of compensating for reactive power in localized networks. This practice, taking into account grid codes and requirements, has been adopted in numerous countries.

In a 2012 work by Prashant et al. [5], the authors used MATLAB to analyze the performance of photovoltaic inverters with boost converters. The study concentrated on using a boost converter to couple a series of solar panels to a single-phase inverter. The boost converter was employed to increase the voltage without the need for a transformer. The authors utilized MATLAB for the analysis, allowing for simulations and performance evaluations of the photovoltaic inverters with boost converters. The study's objectives were to evaluate the suggested system configuration's efficacy and efficiency and find areas for improvement. Overall, the paper presented a performance analysis of photovoltaic inverters with boost converters, showcasing the use of MATLAB for simulation and evaluation purposes.

A report on the performance optimization, system dependability, and operational effectiveness of smart grid systems was given by M. Natsheh et al. [6]. A PV/WT (solar/Wind Turbine) hybrid system with a smart grid connection was created by the authors. It included a solar array, a wind turbine, an asynchronous (induction) generator, a controller, and converters. The MATLAB/SIMULINK software set was used to implement the model. As a Maximum Power Point Tracking (MPPT) technique, the Perturb and Observe (P&O) algorithm was used to maximize the generated power. Under various operating situations, the proposed model's dynamic behaviour was examined. Real-time inputs for the created system came from a 28.8kW grid-connected solar power system located in the heart of Manchester. These inputs included solar irradiance, temperature, and wind speed. The proposed model and its control method, according to the authors, were a useful instrument for enhancing the performance of the smart grid.

In another paper by S. Narendran [7] published in 2013, an overview of grid-tie inverters (GTIs) was provided. There was discussion of the many MPPT system types, such as Fixed Duty Cycle, Constant Voltage, Perturb and Observe (P&O), Modified Perturb and Observe, Incremental Conductance (IC), Modified Incremental Conductance, Ripple Correlation, and System Oscillation techniques. The paper highlighted how these methods contribute to achieving efficient power output from PV arrays to the grid system. A study on a Grid Interactive Solar Photovoltaic System erected in the BNLT building of Integral University, Lucknow, was undertaken by Ekta Maurya et al. Data on the system's current, voltage, power, energy, and temperature were gathered for the paper. Based on data from January to April, it assessed the reference yield, actual yield, and performance ratio. The findings showed that the average performance ratio for those months was poor, pointing to the need for modifications such altering the tilt angle, maintenance, and perhaps even the deployment of concentrating panels and CPC to increase the system's effectiveness.

The ideal design of a grid-connected solar photovoltaic power system for a residential building in Jabalpur city, Madhya Pradesh, India, was the topic of Animesh Patel,A.Paranjape [8] study. The study designed and analyzed a residential power system that included a grid-connected solar PV-based system with battery storage using the Hybrid Optimization Model for Electric Renewable (HOMER) software. The analysis took into account variables like energy cost, payback period, and environmental emissions in both grid-connected and stand-alone modes. In order to optimize the system under various circumstances, the performance of each component—including the battery, inverter, and rectifier—was assessed.

The design of a control module for a grid-connected photovoltaic system was presented by Krishna K.R. et al. [9]. The research emphasized the requirement for a DC-DC boost converter to connect a solar array's highly nonlinear output to the utility grid. An inverter was used to convert the converter's output to AC, and a digital control module oversaw both devices. The control module included an MPPT module to ensure maximum power point tracking and a PI controller to stabilize the output PWM signal. The system was implemented using DSPIC30f and MATLAB.

M. Ganga Prasanna et al. [10] discussed the financial feasibility of a 100-kW rooftop solar PV system for an Indian educational facility. In the financial analysis, the study took into account variables including solar insolation variations, financial interest rates, and operating and maintenance expenditures. The result of the feasibility analysis was presented, highlighting the life cycle cost of energy and the various parameters affecting the system's economic viability.

V. Indra Gandhi et al. [11] focused on grid-connected solar inverters' effects on the quality of the power. The study detailed a solar grid-tied inverter system made up of a photovoltaic array, a single-phase/three-phase converter, a DC-to-DC converter and an AC source. Photovoltaic cells' DC power was converted by the inverter into AC power, which was then given to attached AC loads. The paper proposed the design of a 281.6 kW grid-tied solar power generation system.

A grid-tied solar inverter (GTSI) based on a microcontroller was created by Md. Nahid Hossain et al. [12] The GTSI synchronized the output voltage with the grid voltage and used

MOSFET switching to increase the efficiency of the DC to AC conversion. A 24 V lead-acid battery, which could be swapped out for a maximum power point tracker, was used by the system to store solar PV power. The output was applied to a step-up transformer, and the resulting AC power was filtered.

A single-stage inverter for solar PV systems was proposed by K. Prasad Rao et al. [13] that enhances energy capture through voltage management. A DC link voltage control loop and a current control loop were used in their cascaded control structure. In response to rapidly varying irradiation levels, the authors introduced a robust maximum power point tracking controller that adjusts the reference voltage. Under a variety of weather situations, the suggested technique considerably lowers power losses brought on by dynamic tracking errors. The effectiveness of the method was demonstrated through simulations and experiments.

Karuna Chaudhari et al. [14] centered on incorporating renewable energy sources, specifically PV power with the electric grid using a smart grid architecture. They developed a 3.5 kW PV-based solar inverter system that could operate on both solar power and AC mains, depending on the load requirements. For effective solar power generation, the system included a single-stage, high-performance maximum power point tracker (MPPT). Simulation results showcased the effectiveness of the design in reducing grid dependence and providing reliable power supply.

Chinmay D Shukla [15] highlighted the growing popularity of solar photovoltaic systems for electricity generation. Inverters are essential for transforming the DC electricity generated by solar panels into AC power for electrical loads, they emphasized. The control of the inverter was crucial for satisfactory grid-connected operation, including phase measurement of grid voltage and current, pulse generation, and meeting international power quality standards. Various control techniques, such as PLL, hysteresis current control, and ZCD circuits, were discussed.

AY. Mohammed [16] study's objective is to investigate a sizable three-phase grid-connected inverter system with an emphasis on the construction and operation of the inverter. Through the use of power electronic DC-DC converters and inverters, the PV systems in this configuration are continuously connected to the grid. The functionality and design of these power electronic converters have a big impact on the performance and characteristics of the PV generation. Maximum power point tracking (MPPT) technology is used in the power plant under study to ensure precise and quick reaction. The DC-DC converter incorporates this MPPT technique, which enables it to precisely track and maintain the PV panels' maximum power point.

CHAPTER 3

PV SOLAR

3.1 Why PV Solar?

Global warming is accelerating and the world urgently needs a shift to clean and renewable energy like solar energy, wind energy. Due to increasing population dependency on renewable energy source is justified especially the solar energy which is developed through PV cells. PV Solar is accounted for global electricity generation and it is easily accessible Government is giving subsidy for solar power generation. Many domestic households have become independent in terms of electricity generation through solar PV.

3.1.1 Abundantly Available

The quantity of sunlight that reaches the surface of the Earth in just 40 minutes is equal to the amount of energy used worldwide for an entire year. This highlights the solar energy's enormous potential as a big and plentiful resource. For instance, the southwestern part of the United States receives an astonishing 4,500 quadrillion BTU of solar energy per year, covering an area of around 250,000 square miles.

To generate 3000 GW of power, a relatively small area of around 30,000 square miles would be required for the installation of photovoltaic arrays. It is worth noting that this land requirement for solar energy generation is actually smaller than what is required for a coal-powered plant.

These numbers demonstrate how effective and expandable solar energy is as a clean and sustainable energy source. With its abundant availability and potential to harness vast amounts of energy, In the shift to a more sustainable and ecologically friendly energy system, solar power presents a viable answer.

3.1.2 Benign in Nature

Photovoltaic (PV) solar energy is recognized for its minimal carbon dioxide (CO_2) footprint. These systems operate silently without any moving parts, ensuring a noise-free operation. Unlike other energy sources, PV solar does not require water consumption as it directly converts sunlight into electricity. This feature makes it environmentally friendly and conserves water resources. An important advantage of PV solar energy is its emission-free nature, as it does not release harmful pollutants during operation, contributing to improved air quality and reduced environmental impact. Moreover, PV solar exhibits fewer geographical restrictions compared to other energy sources, enabling flexible installation options in various locations. Overall, PV solar energy is regarded as a pollution-free and sustainable option that supports a greener and more sustainable future

3.1.3 Thermal Requirements

To ensure the optimal performance of a solar inverter system in various outdoor operating conditions, it is crucial to design a thermal system that can effectively manage temperature levels. The goal is to prevent any overheating, fire hazards, or damage to insulation. It is important to maintain the junction temperature of switching components below the maximum allowable value, such as 120°C. Since solar inverters are typically installed outdoors, they must be capable of withstanding extreme temperature ranges, from -40°C to 50°C.

Considering that solar power generation is not constant throughout the day, it is not necessary to run the cooling system continuously. To enhance efficiency, it is recommended to implement a cooling system control mechanism based on the power output. This control strategy will ensure that the cooling system operates only when required, optimizing the overall performance of the solar inverter system.

3.2 PV Specific Performance Requirements

To comply with the National Electrical Code (NEC) and Underwriters Laboratories (UL) requirements, several control and protection features need to be integrated into the design of PV systems. These include:

Auto-Wakeup: Implementing a mechanism that allows the system to automatically wake up and start operation when sunlight is available.

Maximum Power Point Tracking (MPPT): Incorporating MPPT algorithms to ensure the PV system operates at its maximum efficiency and extracts the maximum power from the solar panels.

DC Bus Over Voltage Handling: Including protective measures to handle situations where the DC bus voltage exceeds the specified limits.

DC Bus Over Current Handling: Implementing safeguards to address overcurrent situations within the DC bus of the PV system.

Optimum Efficiency Operation: Designing the system to operate at the most efficient points, taking into account varying solar conditions and load demands.

Remote Monitoring: Integrating remote monitoring capabilities to enable real-time monitoring and control of the PV system's performance and parameters.

This information can be valuable for system optimization and performance analysis.

3.2.1 Maximum Power Point Tracking

IV / Power characteristics of a 170 W Sharp polycrystalline panel.

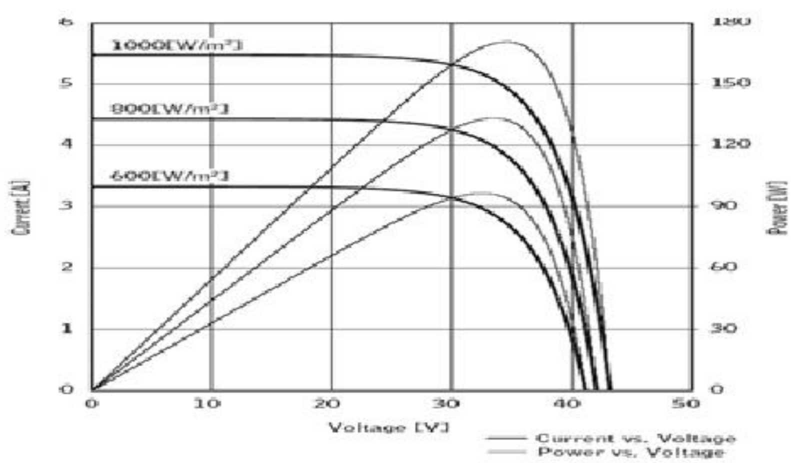

Fig 3.1 Current, Power vs Voltage Characteristics

The IV (current-voltage) curve of a photovoltaic (PV) system exhibits a unique characteristic where the available power varies with changes in output voltage and current. This power variation can be visualized as a straight line on the IV curve, with a distinct maximum power point. It is important to note that the IV curve undergoes changes throughout the day due to fluctuations in the level of sunlight, also known as insolation. Moreover, the temperature of the PV cell has an impact on the characteristic curves, although this aspect was not represented in the previous diagram.

As the day progresses, the maximum available power from the PV system fluctuates. To fully harness the capacity of the solar panel, the control algorithm of the inverter should continually track and optimize the system's operating point, aligning it with the maximum power point. This ensures that the PV system operates at its highest possible efficiency and extracts the maximum power from the solar panels, accounting for the varying solar conditions. By continuously adjusting the operating point, the inverter maximizes the power output of the PV system, leading to improved overall performance and energy generation.

a) Desired Features of an MPPT Algorithm

The Maximum Power Point Tracking (MPPT) algorithm plays a critical role in efficiently maximizing energy extraction from a photovoltaic (PV) system. To achieve this, the MPPT algorithm should possess an appropriate speed that allows it to closely track changes in insulation, enabling efficient energy capture. However, it is crucial to strike a balance and avoid excessive tracking speed that could lead to system instability.

A key consideration is to prevent tracking along the left slope of the power curve. This region can introduce instability in the system and should be actively avoided. The MPPT algorithm should be designed to ensure that it operates within the stable region of the power curve, optimizing power extraction without compromising system stability.

When operating at lower power levels, the MPPT algorithm should take into account the grid voltage. It is important to maintain a balance between the DC bus voltage and the grid voltage. If the DC bus voltage drops too low while the grid voltage remains higher, it can negatively impact the quality of the current supplied to the grid. The MPPT algorithm should consider this aspect to ensure stable integration with the grid and maintain a consistent power output.

Furthermore, the MPPT algorithm should not lock onto a local maximum on the IV curve but instead sweep the entire curve to accurately locate the global maximum. By accurately identifying the global maximum power point, the MPPT algorithm ensures that the PV system consistently operates at its highest power generation capability, maximizing energy extraction.

In summary, an effective MPPT algorithm should possess the appropriate speed to closely track changes in insolation, avoid tracking along the unstable region of the power curve, account for the grid voltage during lower power levels, and accurately locate the global maximum on the IV curve to consistently achieve the maximum power point.

3.2.2 AUTO WAKE UP

When the power available from the photovoltaic system (PV) system surpasses the total losses within the inverter system, it becomes crucial for the PV inverter to become active or operational. Premature activation could lead to reverse power flow from the grid, adversely impacting energy production. On the other hand, delayed activation would hinder energy production as well. Given that the available power fluctuates due to weather conditions, it is necessary for the wake-up algorithm to possess adaptability in order to address these variations effectively.

3.2.3 DC BUS OVER CURRENT PROTECTION

During extremely cold conditions, a combination of grid failure and increased solar intensity can create a scenario where a DC overvoltage situation may occur. To ensure the integrity and safety of the inverter system, it is crucial to implement appropriate measures.

In the event that the DC voltage exceeds the specified maximum voltage threshold the inverter should start a shutdown process as a protective action. Additionally, the solar array must be promptly disconnected from the DC bus. This action is essential to prevent potential damage to the DC bus capacitors, disconnects, and wire insulations.

By implementing these protective measures, the inverter system can effectively manage and mitigate the risks associated with DC overvoltage during extremely cold conditions. Ensuring the safety and reliability of the system is of utmost importance to avoid any potential damage or operational issues caused by excessive voltage levels.

3.2.4 DC BUS OVER VOLTAGE PROTECTION

An overcurrent condition in a PV inverter can arise from several factors, including but not limited to excessively low DC bus voltage, transient spikes in AC grid voltage, intensified solar conditions, hardware failures or short circuits in the DC bus circuitry, incorrect DC bus connections, or sudden in-rush current to the DC bus capacitor (which can occur when connecting an already voltage-generating array). To mitigate the risks associated with overcurrent situations, it is crucial for the inverter to promptly respond by initiating a shutdown process and isolating itself from both the grid and the PV array.

The shutdown process is essential to protect the inverter and the associated components from potential damage caused by excessive current flow. By isolating itself from the grid and the PV array, the inverter prevents the overcurrent condition from propagating further and causing harm to the system. This protective action ensures the safety and integrity of the PV inverter, reducing the risk of hardware failures, circuit damage, and other related issues.

Implementing reliable and responsive protection mechanisms is vital to maintain the robustness and reliability of the PV system. By promptly detecting and addressing overcurrent situations, the inverter can effectively safeguard itself and prevent any potential hazards or damage that may arise from such conditions.

3.2.5 REVERSE DC PROTECTION

Ensuring the safe operation of a PV inverter requires the capability to detect and alert the installer about reverse polarity in the DC connection. When reverse voltage is detected, the inverter should enter a sleep state, disabling further operation until the polarity is corrected. This protective measure is crucial in preventing potential damage to the capacitors and mitigating the risk of excessive current flow within the DC circuit.

Reverse polarity in the DC connection can have detrimental effects on the operation and longevity of the PV inverter. By promptly detecting the reverse voltage, the inverter can avoid any unintended consequences that may arise from incorrect DC polarity. The sleep state acts as a safety precaution, ensuring that the inverter remains inactive until the polarity is rectified to the correct configuration.

Detecting and warning about reverse polarity in the DC connection is an important feature that enhances the safety and reliability of the PV inverter. It helps to prevent potential hazards, protects the components of the inverter, and minimizes the risks associated with improper DC wiring. By incorporating this capability, the PV inverter can ensure the correct and safe operation of the system, providing peace of mind for the installer and maintaining the overall integrity of the PV installation.

GROUND FAULT

In a grounded PV system, a ground fault can occur when the DC terminal of the PV array makes contact with the chassis or any other grounded surface. This can create a path for current to flow through the ground, starting from the negative terminal and passing through the PV cells to reach the positive terminal. To detect such ground faults, a current sensor is typically installed on the wire connecting the negative terminal and the ground.

When a ground fault is detected, the PV inverter should promptly initiate a shutdown sequence, disconnecting itself from both the grid and the PV array. This immediate disconnection is crucial for preventing any further flow of current through the fault. The ground fault current should be effectively interrupted to ensure the safety of the system.

3.2.6 REMOTE MONITORING

The ability to remotely monitor the status of PV inverters offers several advantages as we can easily measure current and voltages over extended durations, valuable economic insights can be obtained.

Remote monitoring allows for the collection of weekly, monthly data. This data can be analyzed to understand the performance of the PV system, identify trends, and make informed decisions regarding energy optimization and efficiency improvements. By monitoring parameters consistently, potential issues or anomalies can be detected early, enabling proactive maintenance and minimizing system downtime.

Moreover, remote monitoring facilitates troubleshooting and issue diagnosis. Comprehensive information surrounding specific events or performance deviations can be accessed, aiding in the identification and resolution of problems. Remote monitoring provides real-time data and alerts, allowing for prompt response to any issues that may arise.

The economic benefits of remote monitoring are significant. It enables the optimization of energy production, identifies areas for improvement, and helps in evaluating the return on investment of the PV system. By remotely monitoring the performance of PV inverters, system owners and operators can make informed decisions, optimize energy usage, and ensure the long-term efficiency and profitability of their PV installations.

In summary, remote monitoring of PV inverters offers advantages such as economic insights, proactive maintenance, issue diagnosis, and the ability to optimize energy production. It enables efficient management of PV systems, enhances troubleshooting capabilities, and contributes to the long-term success and performance of the installations.

3.3 IMPACT ON GRID SAFETY

i) Possible Islanding Operation.

ii) Single Phase Open Detection.

iii) AC Over current condition

i) ANTI ISLANDING CONTROL AND SAFETY

During the Grid Link mode of operation, ensuring the safety and stability of the grid is of utmost importance. When the output power of the inverter matches the total load on the grid, it is crucial to prevent significant fluctuations in voltage or frequency in the event of grid failure. Power-exporting inverters should have the capability to promptly detect grid failure and cease exporting power to the grid within a maximum of 2 seconds.

Voltage and frequency drift can have adverse effects on the stability of the grid and the devices connected to it. To prevent such issues, inverters are designed to actively monitor the grid's voltage and frequency. If any deviations beyond acceptable limits are detected, the inverter takes protective measures, such as disengaging from exporting power and initiating a shutdown process, to prevent further complications.

By actively monitoring the grid's voltage and frequency, inverters can detect any abnormalities and respond accordingly. This ensures that the inverter operates within safe limits and prevents any detrimental effects on the grid and connected devices. The ability of inverters to promptly disconnect from the grid in the event of grid failure helps maintain grid stability and protects against voltage or frequency-related issues.

By implementing these safety measures and adhering to the specified response times, inverters contribute to the overall stability and reliability of the grid. They play a crucial role in maintaining a stable grid operation and safeguarding the integrity of the connected devices.

ii) SINGLE PHASE OPEN DETECTION

It is essential to detect any phase loss in the grid and start the proper inverter processes in order to assure safety and avoid any risks. Current sensors on each phase can be used to identify phase loss. If the output transformer is separate from inverter, it is important to observe the single -phase open condition on both sides of the transformer

As per the new requirements, it is necessary to detect a single-phase open condition at 5% of the full load or above the minimum current level. This ensures that even under low load conditions, where the current may be below the minimum level, a single-phase open condition can still be detected.

When a loss of phase is detected, the inverter should initiate a shutdown process to prevent any potential safety hazards. This protective action ensures that the inverter ceases operation and avoids any further issues that may arise from the loss of a phase in the grid.

By implementing the detection of single-phase open conditions and incorporating the necessary shutdown mechanism, the inverter can maintain safe and reliable operation, contributing to the overall stability of the grid and the safety of connected devices

iii) AC OVER CURRENT DETECTION PROTECTION

Grid transients or faults can lead to overcurrent conditions in the system. In addition, faults in transformers or line filters can also cause overcurrent situations. Furthermore, faulty switching devices can result in dead short circuits, which can also lead to overcurrent faults. To ensure the safety and integrity of the system, it is necessary to promptly respond to overcurrent conditions. When an overcurrent fault is detected, the inverter should initiate a shutdown process and disconnect from the grid. This protective action prevents further damage or risks associated with excessive current flow.

By promptly detecting and responding to overcurrent faults, the inverter safeguards the system components and helps maintain a stable and reliable operation. The disconnection from the grid during such faults is essential to prevent any potential hazards and ensure the overall safety of the system and the connected grid

3.4 SITE COMMISSIONING

Proper grounding is essential in PV systems to ensure safety and protect against electrical hazards. The grounding should be done in accordance with the relevant standards and regulations to maintain proper electrical bonding and minimize the risk of electrical shocks.

AC and DC disconnects should be conveniently located near the inverter. This allows for easy access and quick disconnection of the AC and DC power sources when necessary. The placement of disconnects in close proximity to the inverter enhances safety during maintenance or emergency situations by effectively isolating the system from the power sources.

Matching the PV capacity with the inverter capacity is important for optimal system performance. The capacity of the PV array should be closely aligned with the rated capacity of the inverter. This ensures that the inverter can efficiently convert the generated DC power from the PV array into AC power without operating beyond its limits. Proper matching of capacities also helps maximize the energy production and overall system efficiency.

By implementing proper grounding, placing disconnects near the inverter, and ensuring a close match between PV and inverter capacities, the PV system can operate safely, efficiently, and reliably. These measures contribute to the overall performance and longevity of the system while adhering to industry standards and regulations.

CHAPTER 4

BLOCK DIAGRAMS

4.1 SIMULINK MODEL OF GRID INTERACTIVE SOLAR

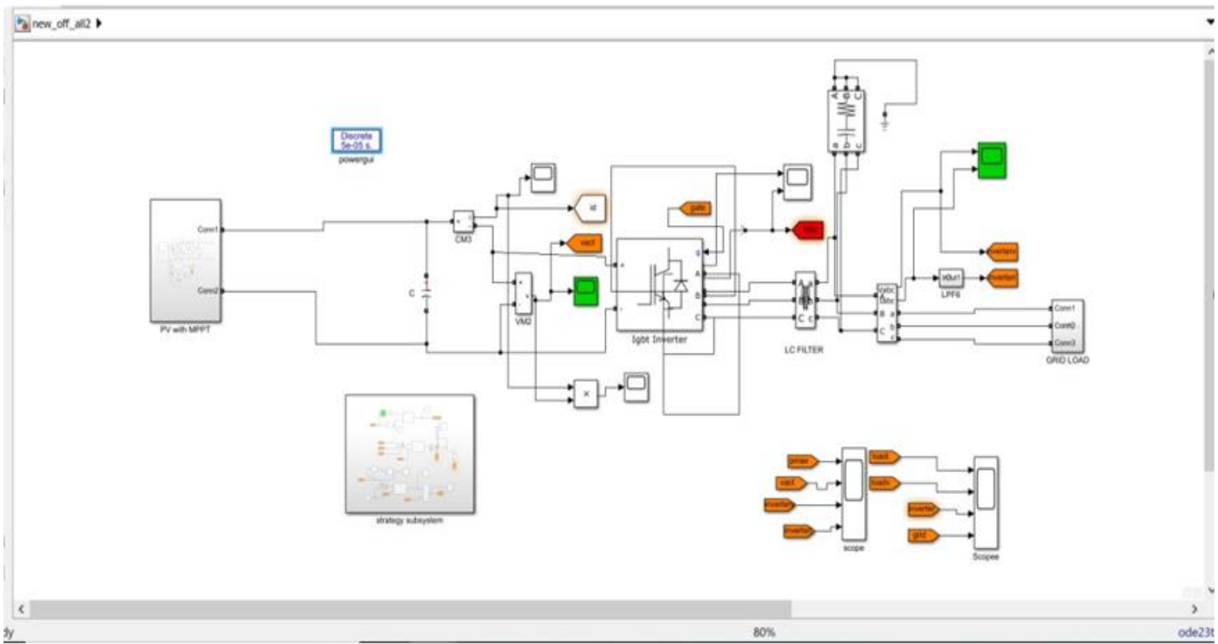

Fig 4.1 Model for integrating PV and the grid

The MATLAB Simulation model for the grid interaction of photovoltaic modules is depicted in Fig 4.1 and includes a number of subsystems, including the PV, PV MPPT, inverter, and load subsystems. The PV plant's intended output is 8KW. The PV plant is expected to meet the load requirement up to 8 KW under the system's design, with the grid providing any additional power needed above that.

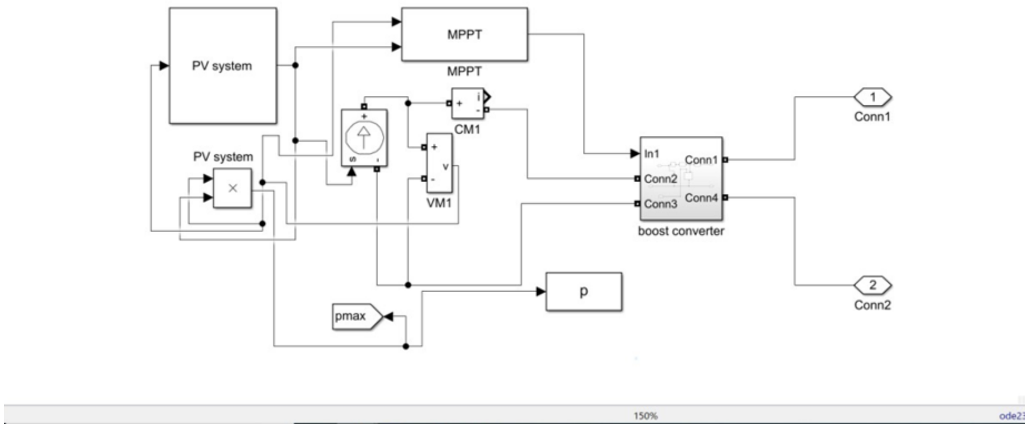

Fig 4.2 MPPT-equipped PV module subsystem

The PV module subsystem with a boost converter is shown in Fig 4.2. The PV MPPT subsystem produces the gating pulses for the boost converter, as shown in Fig 4.3. The Perturb and Observe (P&O) MPPT approach is used to maximize the efficiency of the PV cells by optimizing the power extraction from them

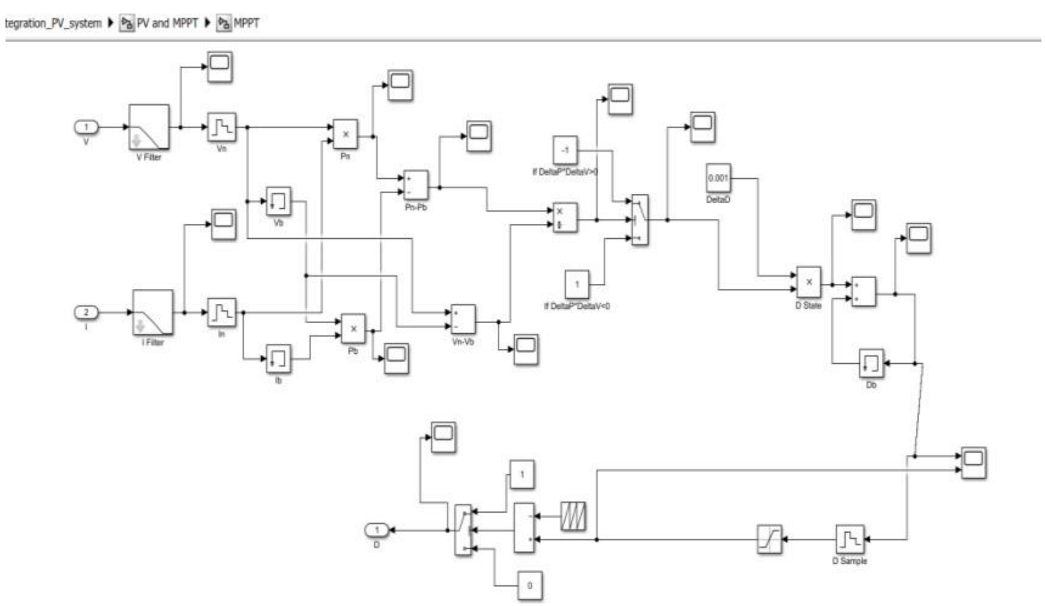

Fig 4.3 PV MPPT subsystem

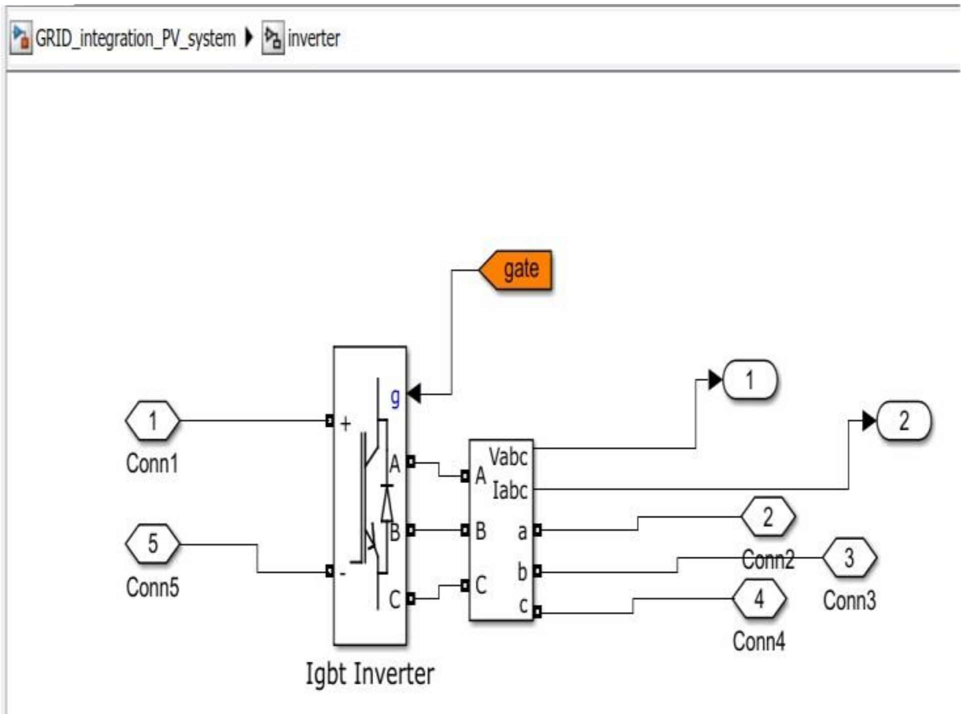

Fig 4.4 Inverter Subsystems

Fig 4.4 illustrates the inverter subsystem, where a three-level inverter is employed. The gating signals for the inverter are generated by a control strategy based on Proportional-Integral-Derivative (PID) control. The DC voltage, tuned by the PV module, is supplied to the inverter. The inverter itself converts the DC voltage into three-phase alternating current (AC), which is then supplied to the loads.

Fig 4.5 Load GRID Subsystem

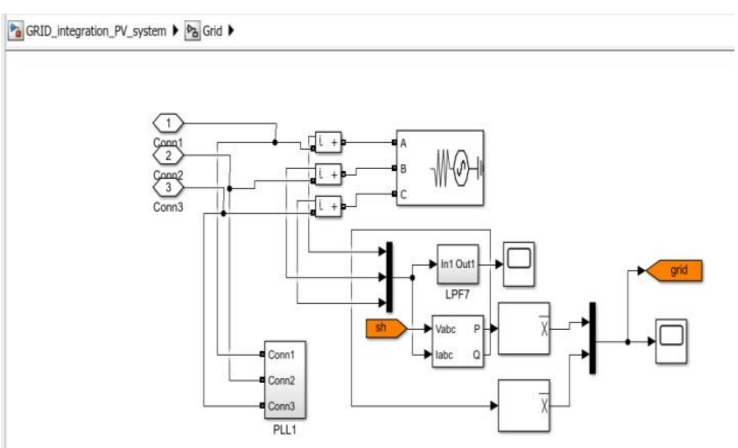

Fig 4.5 Load GRID Subsystem

Fig 4.5 depicts the GRID system, which functions as an infinite power source. The grid is synchronized with the output of the inverter's three-phase output, enabling both sources to provide the necessary power to fulfill the load requirement

CHAPTER 5

RESULTS AND DISCUSSIONS

Our system has seen significant efficiency gains by combining MPPT (Maximum Power Point Tracking), a PID controller, and a three-level inverter with hysteresis current management technology. This ensures dynamic stability during grid connection. The experimental outcomes substantiate the effective functioning of the entire control system design, showcasing its viability for grid-connected PV systems in remote locations and promoting the adoption of renewable energy sources. The integration of the MPPT technique further amplifies the system's capability in optimizing power extraction from the PV array.

5.1 RESULTS AND DISCUSSION FOR GRID INTERACTIVE SOLAR INVERTER.

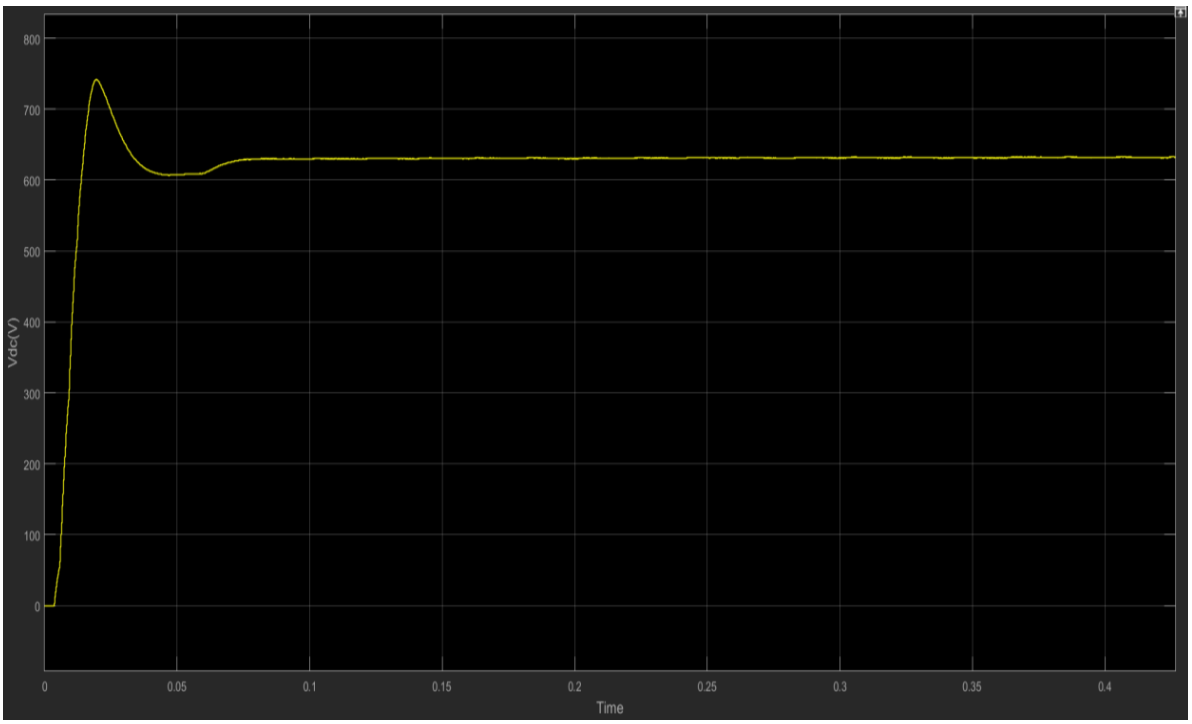

Fig 5.1 Tuned V_{DC}

The PV panel's tuned DC voltage (V_{DC}) output is shown in Fig 5.1, and this voltage is then delivered to the inverter for conversion into three-phase AC. In this instance, the V_{DC} has been explicitly set to 800V, and the PV panel is producing an overall amount power of 8kw

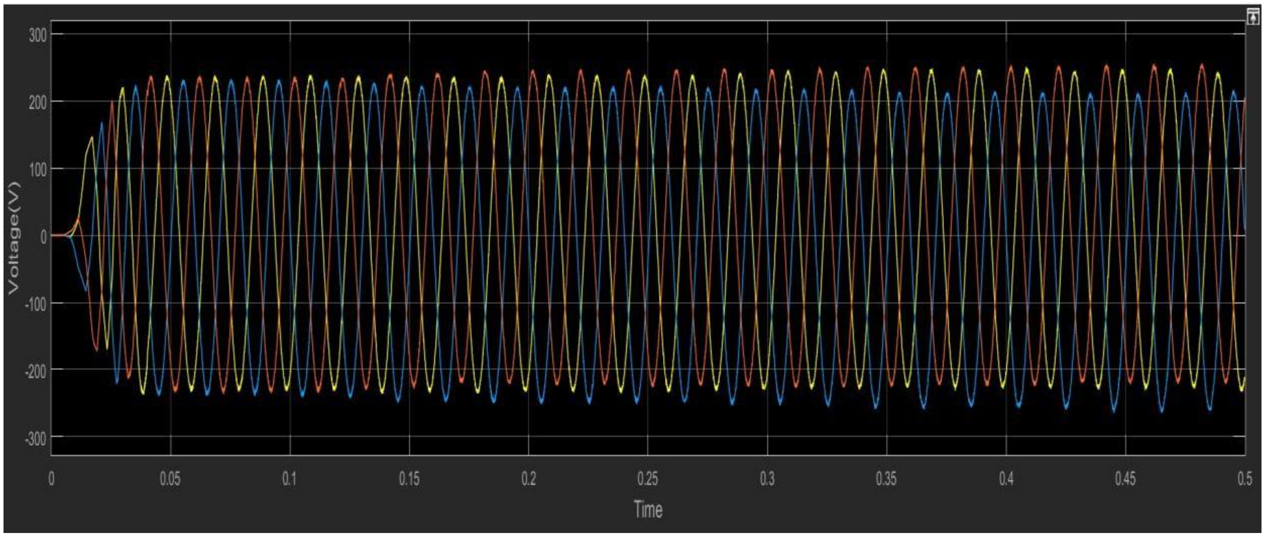

Fig 5.2 Three Phase Inverter Voltage

Fig 5.2 depicts 3-phase A.C. voltage with magnitude around 350volts.

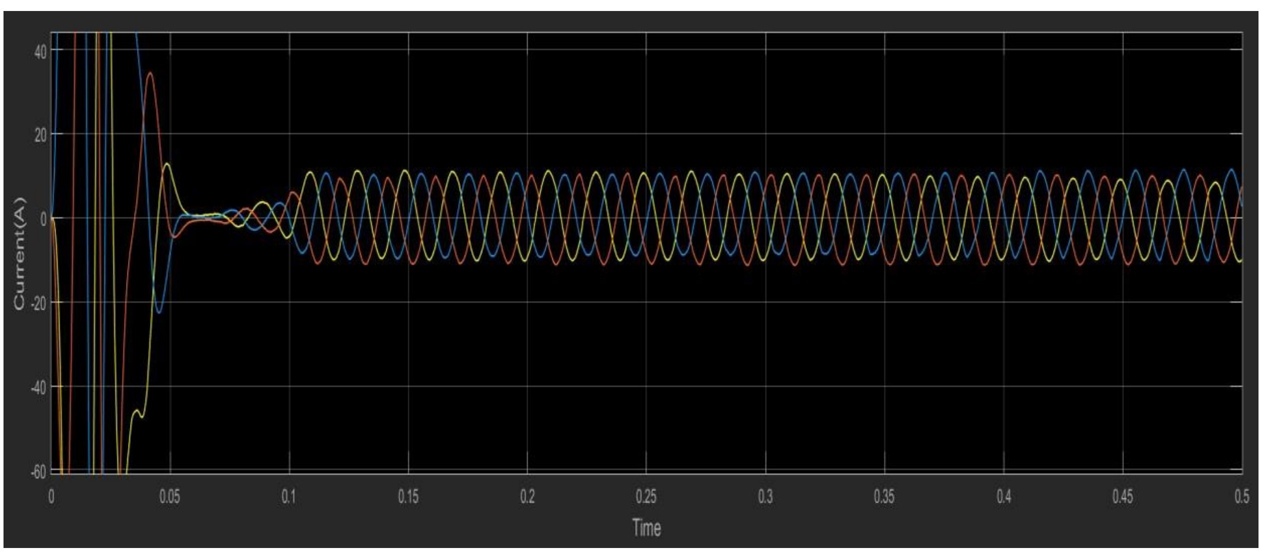

Fig 5.3 Three Phase Inverter Current

Fig 5.3 displays the output current of the inverter, representing the three- phase AC current. The magnitude of this current is approximately 30 amps

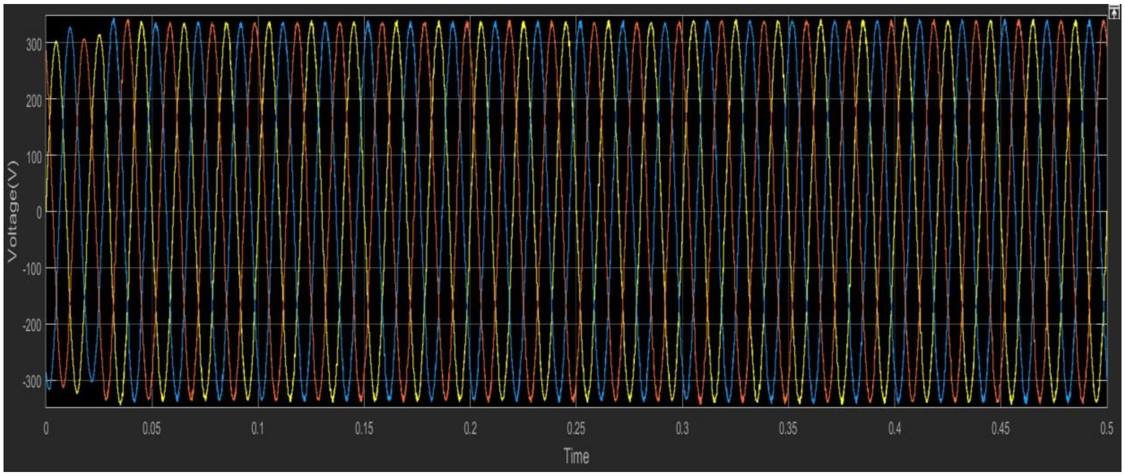

Fig 5.4 Three Phase Load Voltages

Fig 5.4 depicts the output voltage on the load side, specifically the three-phase AC voltage. The magnitude of this voltage is approximately 350 volts, which is supplied to the connected loads.

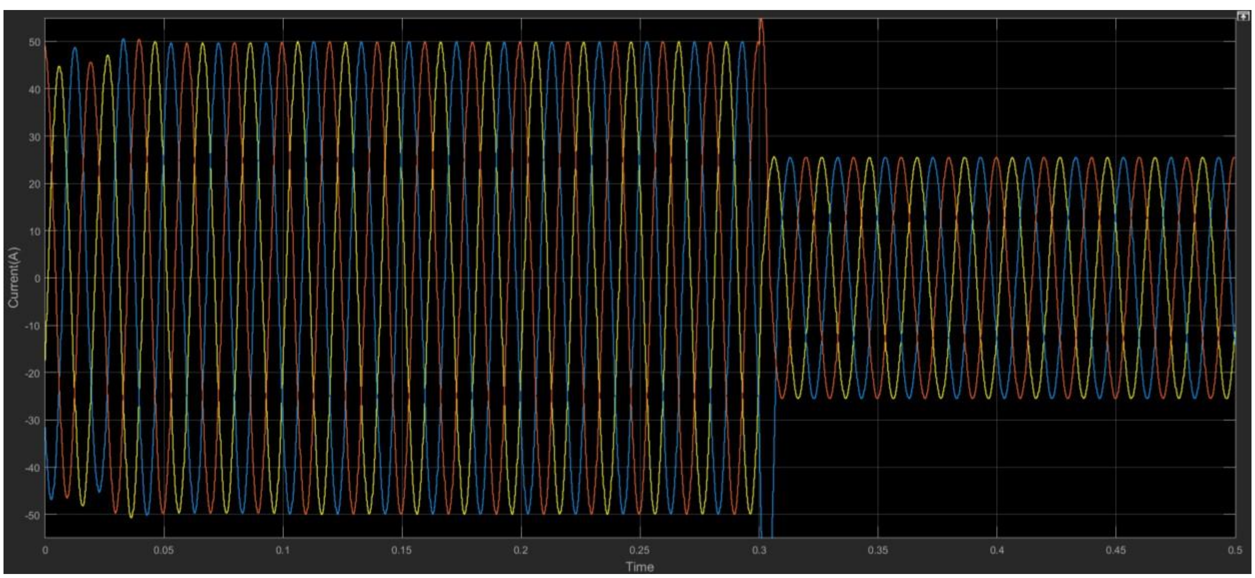

Fig 5.5 Three Phase Load Current

Fig 5.5 represents the three-phase load current. The load current is seen to diminish after 0.3 seconds. The Changes in current occurs due to the dynamic change in the load requirements.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

This project provides a comprehensive overview of a grid-connected photovoltaic (PV) system's components and outlines its operation. The maximum power point tracking (MPPT) algorithm using the perturb and observe (P&O) algorithm was utilized to enhance the power extraction from the PV Array while ensuring high efficiency and rapid dynamic response. The installation of a three-phase inverter proved successful. enabling the production of usable sinusoidal alternate current that complied with grid power quality requirements. The voltage source inverter (VSI)'s use of the sinusoidal pulse width modulation (SPWM) approach successfully decreased the filtering needs The grid-connected photovoltaic system's good control performance and dynamic behavior were demonstrated by the simulation results produced using the MATLAB Simulink environment. The advantages of photovoltaic systems are their portability, environmental friendliness, and simplicity of installation. However, in order to guarantee the generation of high-quality electric power, certain parameters must be met before these systems may be connected to the grid. This project's objective was to build a three-phase PV system that was wired into the grid and used a DC-DC boost converter with MPPT to get the most power possible from the solar panels. Any PV-based system's inverter, a crucial component, makes it easier to regulate the flow of power between the DC source, loads, and the grid. In order to inject the AC power into the grid, the DC power was first converted into AC power using a voltage source inverter (VSI). To increase efficiency, lower costs, increase reliability, and extend the lifespan of an inverter, it is critical to concentrate on design innovation in inverter topology. In addition, improving inverter quality requires innovation in manufacturing and testing practices. In order to enhance inverter performance, reduce downtime, and do away with the requirement for pricey sensors, additional research is also necessary to develop sophisticated and reliable control approaches.

6.2 FUTURE SCOPE

Renewable energy sources could benefit from the development of diverse maximum power control algorithms. By creating artificial neural network algorithms, the performance of the maximum power point tracking (MPPT)'s solar energy conversion function can be improved. The operational point (highest power point) of the system can be maintained by intelligent components like microprocessors and Programmable Logic Controllers (PLCs) for maximum effectiveness. Fuzzy control techniques can be used to deal with insolation level uncertainty. To change a variable's transformation ratio automatically, a feedback channel can be used, such as a position control servo. Simulations can be conducted to evaluate the performance of a photovoltaic (PV) system with a three-phase inverter and current control. Regarding a Grid Connected PV system with Smart Grid capabilities, it is crucial to design a control system that can effectively regulate the power output of the inverter. This control system should be capable of integrating the inverter with other available renewable energy sources

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