MODELING AND SIMULATION OF 4.8 KW GRID CONNECTED SOLAR PV BASED WATER PUMPING SYSTEM FOR SUSTAINABLE AGRICULTURAL IRRIGATION

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

I hereby declare that this project "**Modeling and Simulation of 4.8 kW Grid Connected Solar PV Based Water Pumping System for Sustainable Agricultural Irrigation**" represents my own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

Signature of the candidates

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APPROVAL

The project entitled **"Modeling and Simulation of 4.8 kW Grid Connected Solar PV Based Water Pumping System for Sustainable Agricultural Irrigation"** submitted by **Shuvo Halder (192-33-5215)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **January, 2024.**

Signed

23.12.23

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Dedicated

To

My Parent

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LIST OF ABBREVIATIONS

PV	Photovoltaic
VSC	Voltage Source Converter
MPPT	Maximum Power Point Tracking
PLL	Phase-Locked Loop
AC	Alternating Current
DC	Direct Current
P&O	Perturb and Observe
IGBT	Insulated Gate Bipolar Transistors
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
PWM	Pulse Width Modulation
MPP	Maximum Power Point
PI	Proportional and Integral
RL	Resistor and Inductor
RPM	Revolutions Per Minute
GDP	Gross Domestic Product
UL	Underwriters Laboratories
IEEE	Institute of Electrical and Electronics Engineers
NEC	National Electrical Code
VFD	Variable Frequency Drive
dq0	Direct Quadrature Zero

LIST OF SYMBOLS

Vdc	DC voltage source
W/m^2	Watts per square meter
V	Voltage
A	Ampere
P	Power
C	Celsius
$V_{boostOut}$	Boost converter output voltage
$V_{boostIn}$	Boost converter input voltage
D	Duty cycle
L_{boost}	Inductor
C_{boost}	Capacitor
f_{sw}	Switching frequency
ΔI_r	Ripple current
$\Delta V_{BoostOut}$	Voltage ripple
R_{load}	Load resistance
i_C	Capacitor carries the ripple current
i_{pv}	PV array current
i_{dc}	DC link current
i_{Cmax}	Maximum capacitor carries the ripple current
Δv_{pv}	Ripple content in PV voltage
K_p	Proportional gain
K_i	Integral gain
Ts	Switching period of the inverter
τ_i	Time constant
µ	Micro
F	Farad
ΔD	Step size of duty cycle
I_r	Irradiance
V_{pv}	PV voltage
P_{pv}	PV power
D_{ref}	Reference duty cycle
$V_{inverter}$	Inverter phase to line voltage
$I_{inverter}$	Inverter phase to line current

$P_{inverter}$	Inverter power
V_{im}	Induction motor voltage
I_{im}	Induction motor current
IN_s	Induction motor speed
T_e	Induction motor torque
kW	Kilowatt
kVA	Kilovolt-ampere
H	Henry
rpm	Revolutions per minute
Nm	Newton-meter
$kg.\,m^2$	Kilogram-meter-square
Ω	Ohm
V_o	Open circuit voltage
I_o	Short circuit current
V_m	MPPT voltage
I_m	MPPT current
P_{mpp}	Power at MPP
V_{mpp}	MPP voltage
I_{mpp}	MPP current
N_s	Number of series connected module
N_p	Number of parallel connected module
P_n	Induction motor nominal power
V_{l-l}	Induction motor voltage
P_p	Induction motor pole pairs
L_m	Mutual inductance
T_m	Motor torque constant
I_j	Inertia
R_s	Stator resistance
L_s	Stator inductance
R_r	Rotor resistance
R_l	Rotor inductance
wt	Angular velocity

ACKNOWLEDGEMENT

First and foremost, I am grateful to the Almighty for His blessings, which enabled me to complete this work to the best of my ability.

I would like to express my deepest respect to my supervisor, **Ms. Tasmia Baten, Assistant Professor** of the **Department of EEE, Daffodil International University**. She gave me the opportunity to work on a meaningful idea and took care of every aspect of its development. I would also like to take this opportunity to thank her for her dedicated support, motivation, and guidance throughout this project. This project would not have been possible without her helpful advice and assistance. I am also grateful to her for giving me the opportunity to work on this project.

ABSTRACT

The study presents the modeling and simulation of 4.8 kW grid connected solar PV based water pumping system for sustainable agricultural irrigation. With a focus on reducing reliance on fossil fuels and mitigating greenhouse gas emissions, the proposed system integrates renewable energy solutions into agricultural practices. The core components, including the PV array, boost converter, and three-level voltage source converter (VSC), are carefully developed to optimize energy transfer and power generation. A maximum power point tracking (MPPT) algorithm is employed to extract the maximum power from the PV array, while smart control mechanisms ensure efficient power utilization and seamless grid integration. The simulated performance analysis under varying solar irradiance and temperature conditions demonstrates the system's robustness and effectiveness. The research aims to promote the adoption of renewable energy-based solutions in agriculture, fostering sustainable practices and contributing to a greener future for farming.

Keywords: Renewable energy, Solar PV array, Solar irradiance, MPPT, Induction motor, Agricultural irrigation, VSC, PLL, Boost converter, Net metering, Control strategy.

CHAPTER 1
INTRODUCTION

1.1 Introduction

With the world's population steadily increasing and the effects of climate change becoming more apparent, agricultural irrigation, being a vital component of food production, demands significant amounts of electricity, traditionally sourced from fossil fuels, which not only contributes to greenhouse gas emissions but also poses economic challenges due to fluctuating fuel prices. As a result, integrating renewable energy solutions, such as solar power, into agricultural irrigation systems has emerged as a promising approach to achieve sustainable and environmentally friendly practices.[1]

A grid connected solar PV based water pumping system for sustainable agricultural irrigation. This system utilizes solar energy through a photovoltaic (PV) array and efficiently converts it into usable electrical power for both grid and induction motor-driven water pump. By utilizing solar power for grid and irrigation, the proposed system aims to reduce reliance on conventional energy sources, mitigate greenhouse gas emissions, and foster sustainable agricultural practices.

The importance of a grid connected solar PV based water pumping system for sustainable agricultural irrigation is that it addresses a critical challenge facing the agricultural sector today. By providing a sustainable and efficient solution for water pumping, this system can help to improve food security and reduce the environmental impact of irrigation.

1.2 Problem Statement and Proposed Solution

Agricultural irrigation, a crucial component of food production, relies predominantly on electricity sourced from fossil fuels. This traditional energy source not only contributes to greenhouse gas emissions but also poses economic challenges due to volatile fuel prices. The increasing global population and the escalating impacts of climate change necessitate a shift towards sustainable and environmentally friendly agricultural practices. The conventional reliance on fossil fuels for powering agricultural irrigation systems presents a twofold challenge environmental sustainability and economic stability. To address this challenge, there is a pressing need to develop and implement renewable energy-based solutions that reduce greenhouse gas emissions, promote sustainable agriculture, and provide economic benefits to farmers. [2]

To address the challenge of unsustainable fossil fuel reliance in agricultural irrigation, this research proposes an integrated solution comprising a solar photovoltaic (PV) array grid-connected with an induction motor-driven water pumping system. The system harnesses solar energy efficiently through the PV array and employs a maximum power point tracking (MPPT) algorithm to optimize energy extraction. A boost converter enhances voltage output from the PV array, facilitating efficient energy transfer. A three-level voltage source converter (VSC) then transforms solar-generated power into high-quality three-phase AC power suitable for grid connection. Simultaneously, the system powers an induction motor-driven water pump to meet irrigation needs. This holistic approach not only reduces dependence on conventional energy sources but also mitigates greenhouse gas emissions, promoting sustainable agricultural practices while enhancing economic stability for farmers.

1.3 Objectives

The objectives are of this project:

- To integrate solar energy adoption in agriculture for sustainability and reduced emissions.
- To optimize system design for efficient power generation and transfer to grid as well as for the load.
- To implement MPPT for maximizing PV array power output.
- To validate system performance through simulations under varying solar conditions.
- To stable operation of an induction motor at low power generation.
- To develop smart controls for effective power use, grid connection, and potential surplus energy injection into the grid for net metering or feed-in tariff schemes.

1.4 Methodology

The research project on a solar-powered irrigation system begins with the design and configuration of a solar photovoltaic (PV) array. An MPPT algorithm is implemented to continuously track and extract the maximum available power from the PV array under changing solar irradiance conditions. A boost converter is used to elevate the DC voltage output from the PV array, ensuring efficient energy transfer to subsequent components. The three-level voltage source converter (VSC) is employed to convert DC power from the boost converter into high-quality three-phase AC power suitable for grid connection as well as for the induction motor-driven water pump. The induction motor-driven water pump is utilized to meet the irrigation demands of agricultural fields, powered by the AC output of the VSC. It is also able to operate when the solar PV generate zero power, by taking power from the grid. Advanced control mechanisms are implemented to manage power flow within the system, optimizing energy utilization for both grid integration and water pumping. The entire system, including components and control strategies, is simulated using MATLAB/Simulink software. Simulations are conducted to analyze system performance under varying solar irradiance and temperature conditions. Detailed performance analysis is carried out based on simulation results, assessing the system's robustness and effectiveness in providing sustainable energy solutions for agricultural irrigation.

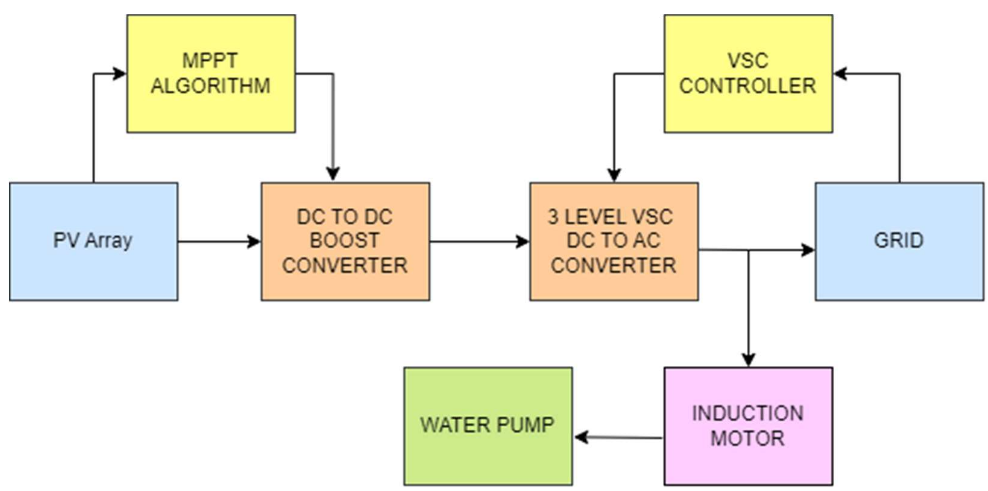

Figure 1. 1 Overall System Block Diagram

1.5 Gantt Chart

Gantt Chart of my project activities are shown below.

Figure 1. 2 Gantt Chart

1.6 Structure of the Report

The report is structured into chapters, each serving a distinct purpose. Chapter 2, the Literature Review, establishes the foundational knowledge by reviewing existing research, drawing comparisons and contrasts, and summarizing key findings. Chapter 3, System Design & Procedure, delves into the heart of the project, detailing system components, explaining the methodology, discussing design specifications, and presenting system analysis. Chapter 4, Results and Discussions, showcases the project outcomes and provides a comprehensive analysis. Chapter 5, Project Management, focuses on efficient organization, covering tasks, schedules, resource allocation, and lessons learned. Chapter 6, Impact Assessment of the Project, evaluates the project's broader implications, including economic, societal, and environmental impacts. Chapter 7, Conclusions and Recommendations, concludes the report by summarizing key findings and offering insights for future work. This sequential structure ensures clarity and guides the reader through the project's development and findings.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

It offers a comprehensive overview of the existing body of knowledge related to renewable energy integration in agricultural irrigation, with a specific focus on solar photovoltaic (PV) systems. It begins by tracing the historical evolution of renewable energy in agriculture, highlighting the transition from traditional wind and water-driven systems to the contemporary use of solar PV technology. The review explores the diverse applications of solar PV systems in agriculture, emphasizing their potential to reduce operational costs and environmental impact. It acknowledges the challenges faced in real-world applications, including system efficiency and intermittency issues, and discusses the importance of Maximum Power Point Tracking (MPPT) techniques for optimizing PV arrays. Additionally, it delves into grid integration mechanisms, such as net metering, and examines the role of induction motor-driven water pumping systems in agricultural irrigation. This comprehensive literature review sets the stage for the research by identifying gaps in knowledge and highlighting the significance of the proposed solar PV array grid-connected system for sustainable agriculture.

2.2 Related Research

The research problem addressed in this paper is the need for sustainable and environmentally friendly energy solutions for agricultural irrigation. Traditional agricultural irrigation systems rely heavily on electricity sourced from fossil fuels, which not only contribute to greenhouse gas emissions but also present economic challenges due to fluctuating fuel prices. As the global population continues to increase, the demand for food production and agricultural irrigation grows. Hence, finding alternative energy sources that reduce reliance on fossil fuels and mitigate environmental impacts is crucial.

Similar designs and research in this field have explored various aspects of renewable energy integration and sustainable agricultural practices:

Grid-Connected PV Systems: Previous research has extensively examined grid-connected solar PV systems, which are used in residential, commercial, and agricultural settings. These systems often incorporate MPPT algorithms to optimize power generation. [3]

MPPT Algorithms: Multiple MPPT algorithms, such as Perturb and Observe (P&O), Incremental Conductance, and Fuzzy Logic Control, have been employed to enhance the efficiency of solar PV systems under varying environmental conditions. [4]

DC-DC Converters: The use of DC-DC converters, including boost converters, to optimize the voltage output from solar PV arrays is a common practice in solar energy systems. [5]

Grid Integration and Net Metering: The integration of renewable energy into the grid and the adoption of net metering schemes have been widely studied to promote the use of solar energy and contribute to grid stability. [6]

Induction Motor-Driven Water Pumping Systems: Agricultural irrigation often relies on induction motor-driven water pumping systems, and research efforts have explored the feasibility of powering these systems with renewable energy sources like solar. [7]

2.3 Compare and Contrast

Existing agricultural irrigation systems primarily rely on conventional fossil fuel-powered methods, often using diesel or gasoline generators to drive water pumps. These systems are characterized by high operating costs due to fuel expenses and maintenance requirements. Furthermore, they contribute significantly to greenhouse gas emissions, exacerbating environmental concerns. Additionally, the vulnerability to fluctuating fuel prices poses economic challenges for farmers. As such, there is a critical need to transition from these unsustainable practices to more environmentally friendly alternatives.

Some agricultural irrigation systems have already adopted solar technology, which represents a significant step towards sustainability. These systems typically connect to the grid and utilize solar panels to power water pumps. While more sustainable than fossil fuel-based systems, they may still face inefficiencies in power conversion and grid integration. Control and optimization mechanisms in these systems may not be as advanced as they could be. Therefore, there is room for improvement in terms of maximizing power generation and grid integration efficiency.

In areas where grid connection is not feasible, stand-alone solar water pumping systems offer a solution. These systems employ solar panels and batteries to operate water pumps, making them highly efficient in terms of solar energy utilization. However, they may have limitations in terms of water storage capacity and battery life, and research efforts should aim to improve these aspects.

In contrast, manual irrigation methods, such as bucket irrigation or manual well pumps, are still prevalent in some regions. These methods are labor-intensive, inefficient, and may not provide a consistent water supply, limiting agricultural productivity. Consequently, there is a pressing need to transition from these manual methods to automated, energy-efficient systems to enhance productivity and sustainability.

Addressing these research gaps is essential for advancing sustainable agricultural irrigation. Research efforts should focus on improving the efficiency of energy transfer from solar panels to water pumps, minimizing energy losses during conversion. Advanced control algorithms, including Maximum Power Point Tracking (MPPT) techniques and smart grid integration, can further optimize energy utilization and enhance system performance. Additionally, developing advanced energy storage solutions, such as high-capacity batteries, will ensure a continuous water supply, particularly in off-grid scenarios.

Cost reduction remains a crucial aspect of making renewable energy-based irrigation systems more accessible to a broader range of farmers. Innovations in component design, manufacturing processes, and economies of scale can contribute to cost-effectiveness. Furthermore, conducting comprehensive environmental impact assessments will help quantify the ecological benefits of renewable energy-based irrigation systems compared to conventional methods.

Moreover, research should focus on scalable solutions that can be adapted to various farm sizes and geographical locations, promoting accessibility and widespread adoption. Education and awareness initiatives should inform farmers about the benefits of renewable energy-based irrigation systems, and government incentives and subsidies can encourage their adoption. Finally, the development of remote monitoring and predictive maintenance systems is essential to ensure the long-term reliability and performance of these eco-friendly technologies.

In conclusion, while renewable energy-based irrigation systems offer promising solutions for sustainable agriculture, addressing research gaps in efficiency, reliability, cost-effectiveness, and environmental impact is crucial for their widespread adoption. By tackling these challenges, we can contribute to a greener and more sustainable future for farming, reducing dependence on fossil fuels and mitigating the environmental impact of agricultural practices.

2.4 Summary

This chapter provides an introduction and overview of renewable energy integration in agricultural irrigation, with a focus on solar photovoltaic (PV) systems. It traces the historical evolution of renewable energy in agriculture, emphasizing the transition to solar PV technology, explores various applications and challenges of PV systems in agriculture, including system efficiency and grid integration, and highlights the importance of Maximum Power Point Tracking (MPPT) techniques. The chapter discusses related research, such as grid-connected PV systems, MPPT algorithms, DC-DC converters, grid integration, and solar-powered water pumping. It compares conventional fossil fuel-based irrigation systems with solar technology adoption and the potential for automated, energy-efficient systems. The chapter concludes by stressing the need to address research gaps in efficiency, cost-effectiveness, and environmental impact for the widespread adoption of renewable energy-based irrigation, reducing reliance on fossil fuels and enhancing sustainability in agriculture.

CHAPTER 3
SYSTEM DESIGN

3.1 Introduction

In this Chapter the complex design and components of the proposed solar photovoltaic (PV) array grid connected with an induction motor-driven water pumping system described in details. This chapter aims to address the urgent need for sustainable agricultural irrigation while reducing reliance on fossil fuels and curbing greenhouse gas emissions. We begin by elucidating the key components and their specifications within the system, shedding light on their roles and functionalities. The components discussed encompass the Solar PV Array, the DC Link Capacitor, the Boost Converter, the Three-Level Voltage Source Converter, and the Induction Motor. Each of these components plays a pivotal role in ensuring the system's efficiency and reliability. Furthermore, we delve into the methodology behind the system's operation and performance analysis, highlighting the implementation of a Maximum Power Point Tracking (MPPT) algorithm, boost converter design, and control strategies for the three-level VSC. The chapter also emphasizes design specifications, standards, and constraints for each component, ensuring compliance with industry norms. To facilitate a comprehensive understanding, the design analysis section provides insights into the rationale behind component selection and optimization, particularly focusing on the DC link capacitor. Finally, the simulation setup is detailed, elucidating the coordinated functioning of the MPPT algorithm, boost converter, three-level VSC, and induction motor, all working in tandem to maximize power extraction and grid integration while ensuring efficient water pumping. This chapter, in its entirety, provides a comprehensive foundation for the subsequent chapters, highlighting the intricacies and synergies within the solar PV system and its applications in sustainable agricultural irrigation.

3.2 System Design and Components

The proposed grid connected solar PV based water pumping system is developed to address the pressing need for sustainable agricultural irrigation while minimizing the reliance on fossil fuels and reducing greenhouse gas emissions. This section outlines the key components and their specifications within the system, providing an overview of their roles and functionalities.

3.2.1 Solar PV Array

A Solar PV (Photovoltaic) Array is a collection of interconnected solar panels or solar modules that work together to capture sunlight and convert it into electricity using the photovoltaic effect. Each individual solar panel within the array contains numerous solar cells made of semiconductor materials, typically silicon, that generate direct current (DC) electricity when exposed to sunlight.

Here's how a Solar PV Array typically works:

Sunlight hits the solar panels: When sunlight falls on the solar panels, the photons (particles of light) in the sunlight interact with the semiconductor material in the solar cells.

Generation of electrical current: This interaction between photons and the semiconductor material creates an electric current in the form of DC electricity. The more sunlight the panels receive, the more electricity they generate.

Inverter conversion: The DC electricity generated by the solar panels is then sent to an inverter, which converts it into alternating current (AC) electricity. Most of the appliances and electrical systems in homes and businesses use AC electricity.

Distribution and use: The AC electricity is then distributed within the building or sent to the electrical grid, depending on the system's configuration and whether it's connected to the grid. It can power lights, appliances, and other electrical devices.

Solar PV arrays can vary in size and capacity, ranging from small residential installations on rooftops to large utility-scale solar farms with thousands of solar panels. The size of the array and the number of panels are typically determined by the energy needs and available space of the user or the requirements of the energy project.

Solar PV arrays are a clean and renewable energy source, and they play a significant role in reducing greenhouse gas emissions and dependence on fossil fuels for electricity generation. They are commonly used for both residential and commercial applications, as well as in remote areas where access to a traditional electrical grid is limited.

3.2.2 DC Link Capacitor

A DC link capacitor, also known as a DC bus capacitor or DC capacitor, is a fundamental electrical component found in power electronics and motor drive systems. Its primary function is to store and smooth direct current (DC) voltage, ensuring the stability and proper operation of these systems. DC link capacitors store electrical energy in an electric field, helping to stabilize the voltage on the DC bus by absorbing or supplying energy as needed. They play a vital role in reducing voltage fluctuations, transferring energy between system components, filtering high-frequency noise, and improving overall system efficiency. DC link capacitors come in various sizes and capacitance ratings, tailored to the specific requirements of the system they serve. Selecting the right capacitor is crucial to prevent voltage instability, system malfunction, or equipment damage.

3.2.3 Boost Converter

A Boost Converter, also known as a step-up converter, is an essential component in solar PV (photovoltaic) systems. This electronic circuit serves the crucial role of increasing the voltage level of the DC electricity generated by solar panels. Solar panels produce DC voltage that can vary depending on environmental conditions, and to efficiently charge batteries or power electrical loads that require higher voltages, a Boost Converter steps up the voltage to the necessary level. Additionally, Boost Converters are integral to solar charge controllers, implementing Maximum Power Point Tracking (MPPT) algorithms to optimize solar panel performance by adjusting voltage and current to ensure panels operate at their maximum power point. They are also used for battery charging in off-grid or grid-tied solar systems with energy storage and facilitate the injection of solar power into the grid in grid-tied setups. In essence, Boost Converters play a vital role in enhancing the efficiency and effectiveness of solar PV systems, ensuring the conversion and utilization of solar energy are maximized.

3.2.4 Three-Level Voltage Source Converter

A Three-Level Voltage Source Converter (VSC) is a specialized power electronic device widely utilized in high-voltage applications within electrical power systems. Its primary function is to transform direct current (DC) power into alternating current (AC) power while offering control over the voltage magnitude and frequency. It earns its name "three-level" due to its capability to generate three distinct voltage levels in its output waveform, typically represented as +Vdc, 0, and -Vdc, with Vdc representing the magnitude of the DC voltage source.

The operation of a Three-Level VSC follows a specific sequence. It begins with a DC voltage source, which could be derived from a grid-connected rectifier or an independent DC source like a battery or a capacitor. The converter is equipped with switching devices like insulated gate bipolar transistors (IGBTs) or metal-oxide-semiconductor field-effect transistors (MOSFETs). These switching devices are responsible for modulating the DC voltage into a series of pulses.

To achieve this modulation, a Pulse Width Modulation (PWM) control strategy is employed. By varying the duration (width) of each pulse, the converter effectively synthesizes an AC waveform with adjustable voltage levels and frequencies. What sets a Three-Level VSC apart is the incorporation of a third intermediate voltage level (0), in addition to the conventional +Vdc and -Vdc levels. This inclusion reduces the harmonic distortion in the output voltage waveform, resulting in a cleaner and more sinusoidal AC output.

The advantages of Three-Level VSCs are notable. Firstly, they significantly reduce harmonic distortions in the output voltage due to the three-level operation. This feature is especially valuable in applications that demand a high-quality AC power supply. Secondly, Three-Level VSCs typically operate at lower switching frequencies compared to their two-level counterparts, which translates to reduced switching losses and enhanced overall efficiency. Lastly, the inclusion of the intermediate voltage level allows for finer control over the output voltage, making these converters suitable for applications requiring precise voltage regulation.

In practice, Three-Level VSCs find extensive use in high-power scenarios, such as industrial motor drives and grid-connected renewable energy systems like wind and solar farms. Their ability to provide high-quality AC power with reduced harmonic content and improved efficiency makes them a preferred choice for applications where precise control and clean power generation are essential.

3.2.5 Induction Motor

An induction motor is an electric motor renowned for its reliability and simplicity, widely employed across diverse applications. Its operation relies on electromagnetic induction principles: a stator with three-phase windings generates a rotating magnetic field when supplied with alternating current. Inside the stator, a rotor, typically constructed with copper or aluminum, interacts with this magnetic field, inducing an electromotive force in its windings. This induction generates a current, creating a secondary magnetic field in the rotor, causing it to turn. However, the rotor never quite catches up with the speed of the rotating magnetic field, resulting in a lag called slip, which enables the motor to produce mechanical work. Induction motors are prized for their ruggedness, low maintenance, efficiency, and self-starting capabilities, making them essential components in various applications, from household appliances to industrial machinery.

3.3 Methodology

The research paper involves a comprehensive theoretical analysis and simulation of the system's operation and performance. The key steps and theoretical analysis methods include the implementation of a Maximum Power Point Tracking (MPPT) algorithm to continuously adjust the boost converter's duty cycle for maximum power extraction from the PV array. A perturb and observe (P&O) MPPT technique is utilized, involving perturbing the PV voltage and comparing it to the previous voltage to track the maximum power point (MPP). Theoretical analysis includes determining appropriate P&O algorithm parameters and their impact on the MPPT efficiency.

Regarding the boost converter design, theoretical analysis encompasses calculating the boost converter's output voltage, inductor value, and capacitor value. Equations are utilized to determine the output voltage based on the input voltage and duty cycle, ensuring it remains stable at 500 V. Proper inductor and capacitor values are calculated to optimize boost converter performance.

For Three-Level VSC control, theoretical analysis includes the design of voltage and current control loops. Proportional and integral gains for the PI controllers are determined based on system parameters and requirements. The voltage control loop maintains a stable DC bus voltage, while the current control loop regulates power injection into the grid.

Grid synchronization is crucial for smooth integration with the grid and power quality maintenance. A phase-locked loop (PLL) is employed to synchronize the system's voltage and frequency with the grid. The PLL continuously tracks grid voltage and frequency, ensuring proper synchronization during system operation.

3.4 Design Specifications, Standards and Constraints

3.4.1 Solar PV Array

Table 3. 1 Solar PV Array Design Specifications

SOLAR PV ARRAY DESIGN	
Specification of Solar PV Module	
Open circuit voltage, V_o	64.2 V
Short circuit current, I_o	5.96 A
MPPT voltage, V_m	54.7 V
MPPT current, I_m	5.58 A
Design of PV Array	
Power at MPP, P_{mpp}	4.8 kW
MPP voltage, V_{mpp}	218.8 V
MPP current, I_{mpp}	22.32 A
Number of series connected module, N_s	4
Number of parallel connected module, N_p	4

The PV array is comprised of series and parallel connections of individual PV modules to achieve the desired power output. The specifications of the PV modules used in the array include an open circuit voltage of 64.2 V and a short circuit current of 5.96 A. The Maximum Power Point Tracking (MPPT) voltage and current are recorded as 54.7 V and 5.58 A, respectively. The power rating of the entire PV array at Maximum Power Point (MPP) is 4.8 kW, with an MPP voltage of 218.8 V and an MPP current of 22.32 A. To achieve this power rating, the PV modules are arranged in series and parallel configurations.

The series connection of five PV modules increases the overall voltage output, reaching the required MPP voltage of 218.8 V. This arrangement optimizes energy harvesting, ensuring that the PV array operates at its maximum efficiency. Additionally, the parallel connection of four sets and four series-connected PV modules further enhances the total current output, enabling the PV array to meet the desired MPP current of 22.32 A. The combination of series and parallel connections allows the PV array to generate the required 4.8 kW of power efficiently.

The PV array with maximum power capacity of 4.8 kW at standard atmospheric condition 1000 W/m^2 and 25°C.

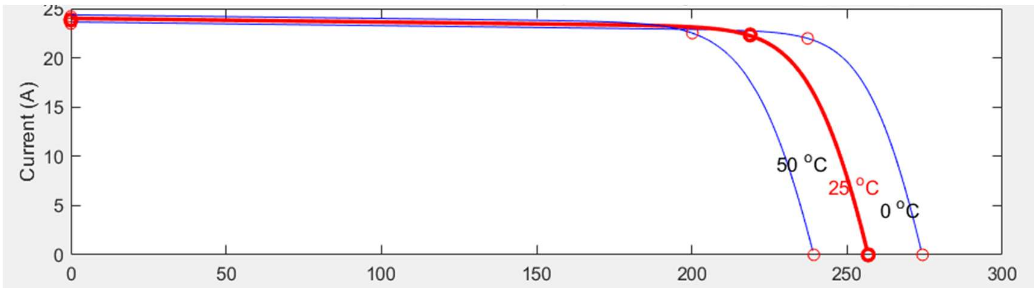

Figure 3. 1 PV Current Versus Voltage Characteristic for Different Levels of Irradiation

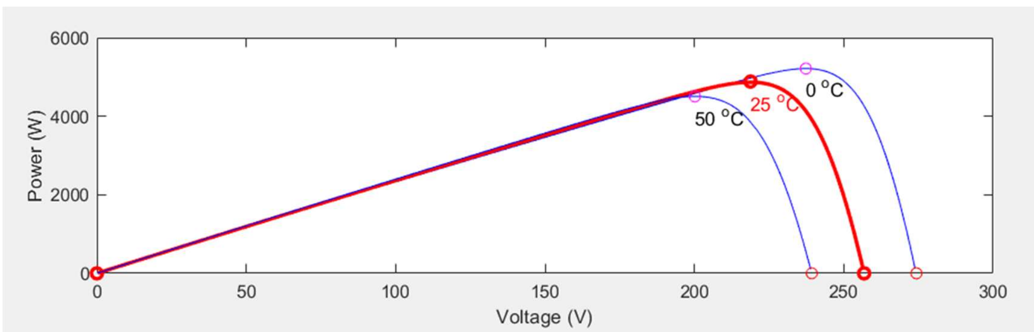

Figure 3. 2 PV Power Versus Voltage Characteristic for Different Levels of Irradiation

The MPPT algorithm is employed to extract the maximum power from the solar photovoltaic (PV) array. The algorithm continuously adjusts the duty cycle of the boost converter to maintain the PV array operating point at its maximum power point, even under varying solar irradiance and temperature conditions.

The MPPT controller continuously tracks the maximum power point (MPP) of the PV array. The perturb and observe (P&O) MPPT technique is used because of its simple structure, easy implementation, and high reliability. The P&O algorithm works by repeatedly perturbing the PV voltage, either increasing or decreasing it, and then comparing the perturbed voltage with the previous voltage. If the perturbed voltage results in a higher power output, the algorithm increments the voltage. If the perturbed voltage results in a lower power output, the algorithm decrements the voltage. This process continues until the MPP is reached, at which point the algorithm will no longer change the voltage. [8]

The operation of P&O MPPT technique's implementation algorithm is given in figure 3.3.

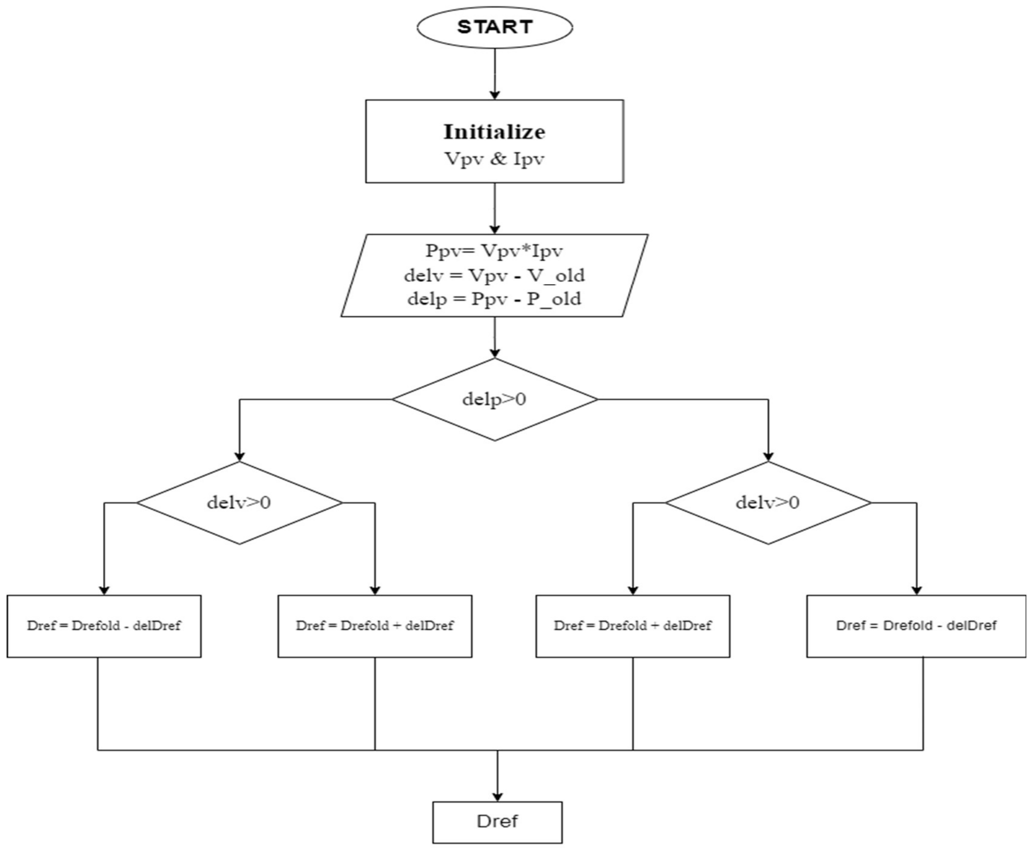

Figure 3. 3 P & O MPPT Algorithm

3.4.2 Boost Converter

The design of a boost converter to facilitate the integration of a solar photovoltaic (PV) array with a three-level voltage source converter (VSC). The boost converter serves as a vital interface, stepping up the PV array's output voltage to meet the requirements of the three-level VSC. The system is using maximum power point tracking (MPPT) algorithm to get the maximum power output. By optimizing the boost converter design, the paper aims to enhance the efficiency and reliability of renewable energy integration, contributing to sustainable energy solutions for grid-connected systems.

Boost converter output voltage, inductor and capacitor are calculated using the following equations, [9].

$$V_{boostOut} = \frac{V_{boostIn}}{1-D} \quad (1)$$

$$L_{boost} \geq \frac{V_{boostIn \times D}}{f_{sw} \times \Delta I_r} \quad (2)$$

$$C_{boost} \geq \frac{V_{boostOut \times D}}{2 \times f_{sw} \times \Delta V_{BoostOut} \times R_{load}} \quad (3)$$

Where in these equations, $V_{boostOut}$ is the output voltage, $V_{boostIn}$ is input voltage, D is the duty cycle value, f is the converter frequency, ΔI_r is the current ripple, C_{boost} is the capacitor capacitance, $\Delta V_{BoostOut}$ is the output voltage ripple and R_{load} is the load resistance given by $\frac{V_{boostOut}}{R_{load}}$.

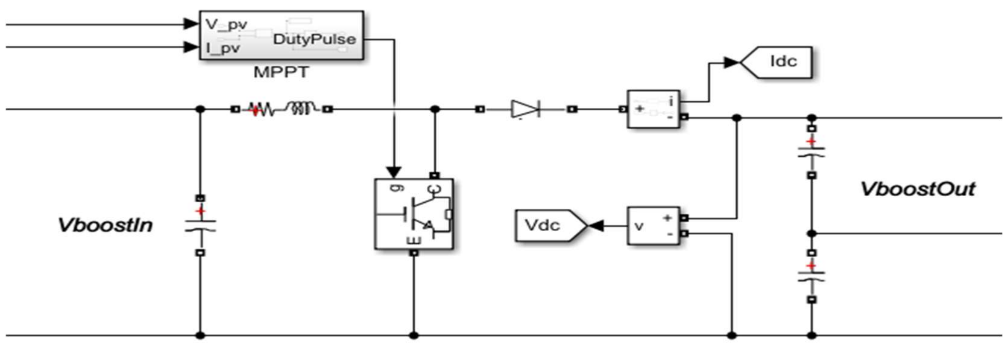

Figure 3. 4 DC to DC Boost Converter Design

3.4.3 DC Link Capacitor

The DC link capacitor in a photovoltaic (PV) system is a crucial component positioned between the PV array and the boost converter. Its primary function is to smooth out and stabilize the variable voltage and current generated by the PV array. As solar output fluctuates due to changing environmental conditions, the capacitor stores excess energy during high power production and releases it during low output, ensuring a consistent input for the boost converter. Additionally, the capacitor reduces voltage ripples and current fluctuations, improving system efficiency, transient response, and voltage regulation. Selecting an appropriately sized capacitor is essential for optimal performance and reliability of the PV system. The capacitor carries the ripple current,

$$i_C = i_{pv} - i_{dc} \quad (4)$$

where i_{pv} is PV array current at MPP and i_{dc} is the DC link current.

The required capacitor, [10]

$$C = \frac{i_{Cmax}}{f_{sw} \times \Delta v_{pv}} \quad (5)$$

Where C = Minimum capacitance required, f_{sw} is switching frequency, Δv_{pv} is the ripple content in PV voltage (considered as 4% of the open circuit voltage).

3.4.4 Three-Level Voltage Source Converter

The three-level VSC is connected between the boost converter output and the grid side, acting as an interface for power transfer and control. The VSC ensures seamless integration with the grid and provides bidirectional power flow. The control approach involves three main aspects. Those are voltage control of the VSC, current control of the VSC and Grid Synchronization.

Voltage Control

A voltage control loop is employed to maintain a stable DC bus voltage for the VSC. A PI controller is used to compare the reference DC bus voltage with the actual measured value, and the controller adjusts the modulation index of the VSC to regulate the voltage at the desired level. PI controller gains were selected using this formula, [11]

$$K_p = \frac{3C}{20Ts} \tag{6}$$

$$K_i = \frac{Kp}{20Ts} \tag{7}$$

Where the proportional and integral gains of the PI controller are represented by K_p and K_i, the boost converter capacitor value is denoted by C, and the switch period of the inverter switching is represented by Ts. DC voltage regulator is shown in figure 3.5.

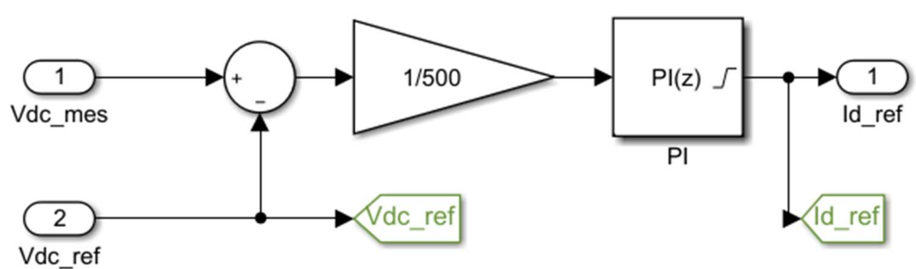

Figure 3. 5 DC Input Voltage Regulator

Current Control

A current control loop is implemented to regulate the current injected by the VSC into the grid. This control ensures that the system operates in synchronization with the grid and allows the VSC to supply or absorb reactive power as needed. A PI controller compares the reference grid current with the actual grid current, and the controller adjusts the VSC modulation index to minimize the current error. PI controller gains were selected using this formula, [11]

$$K_p = \frac{2L}{5Ts} \tag{8}$$

$$K_i = \frac{K_p}{\tau_i} \tag{9}$$

Where the proportional and integral gains of the PI controller are represented by K_p and K_i. The inductance of the RL filter is L, the switching period of the inverter is Ts, the time constant is the product of the inductance and the resistance, and the resistance of the filter is equal to 1 Ω. This current controlling system, controls the current in the dq0 reference frame. The Current controller is depicted in figure 3.6.

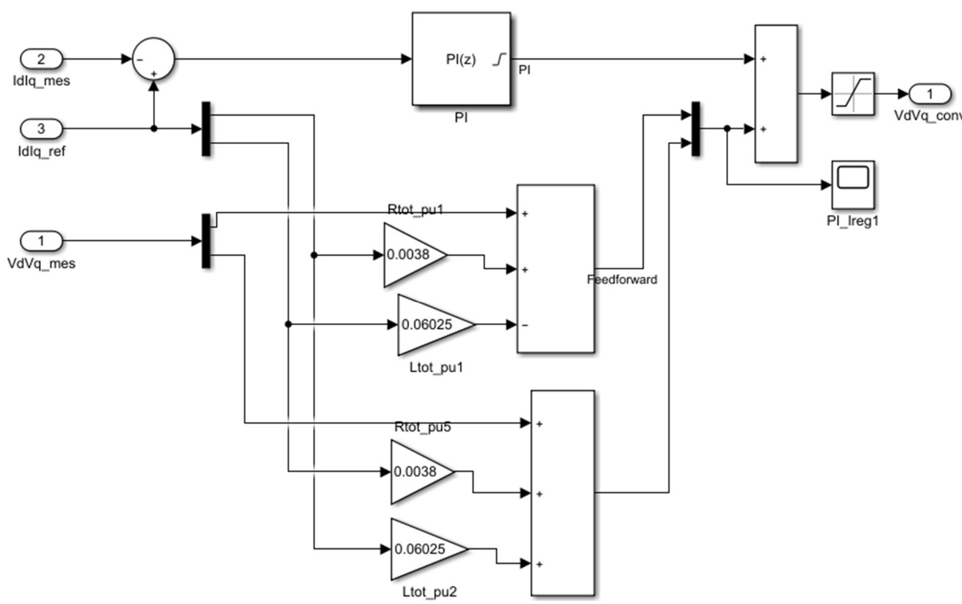

Figure 3. 6 Current Controller

Grid Synchronization

To ensure smooth integration with the grid and to maintain power quality, the system employs a phase-locked loop (PLL) to synchronize the system's voltage and frequency with the grid. The PLL continuously tracks the grid voltage and frequency, allowing the VSC to maintain proper synchronization during operation. The designed PLL and dq0 transformer blocks are shown in the figure 3.7.

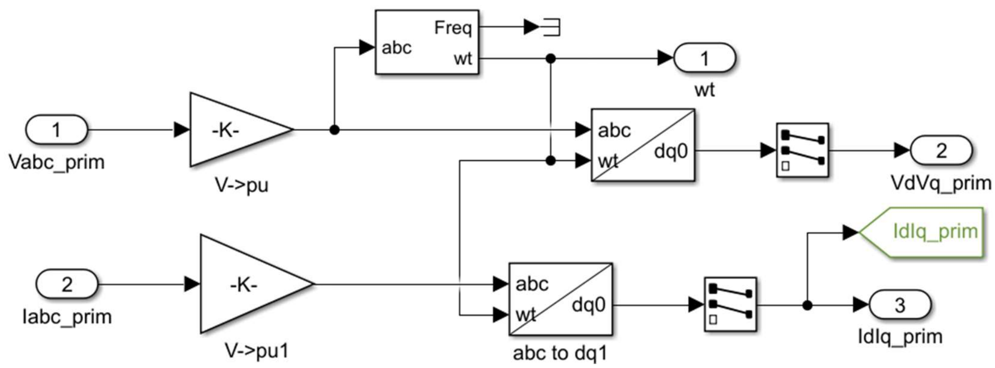

Figure 3. 7 Phase Locked Loop and dq0 Transformation

3.4.5 Induction Motor

The Induction Motor-Driven Water Pump is an essential component responsible for water pumping in agricultural irrigation. It features a 2-pole induction motor with a power rating of 2.24 kVA, running at 1500 RPM. The motor is mechanically linked to a water pump to facilitate efficient water flow and operates at a constant torque level of 14 Nm while maintaining a speed of 1450 RPM for optimal performance. The IM was designed using the below data from table 3.2.

Table 3. 2 Induction Motor Specifications

INDUCTION MOTOR SPECIFICATIONS	
Nominal power, P_n	2.24 kVA
Voltage, V_{l-l}	450 V
Speed, N_s	1500 rpm
Pole pairs, P_p	2
Mutual inductance, L_m	0.693
Motor torque constant, T_m	14 Nm
Inertia, I_j	$0.089\ kg.m^2$
Stator resistance, R_s	$0.435\ \Omega$
Stator inductance, L_s	4×10^{-3}
Rotor resistance, R_r	$0.816\ \Omega$
Rotor inductance, R_l	2×10^{-3} H

3.5 Design Analysis

I conduct a design study of the DC link capacitor in a photovoltaic (PV) system, focusing on how its selection and optimization contribute to achieving the desired output and addressing both technical aspects and business needs. The core objective of this analysis is to shed light on the factors and considerations that led to the choice of an 80 µF DC link capacitor, highlighting the resultant benefits and outcomes.

Optimizing a PV system involves the meticulous selection of components and configurations to ensure the system's efficient performance and adherence to specific standards or requirements. In the context of our project, optimization is the key to achieving the best possible solution in terms of power output, system stability, and cost-effectiveness while staying within defined constraints. This optimization process aims to maximize desired factors and minimize undesired ones, ultimately leading to a well-performing system with good results. Below table 3.3 shows the tested data.

Table 3. 3 Performance of DC Link Capacitor

PERFORMANCE OF DC LINK CAPACITOR			
Time (Seconds)	**Capacitor (F)**	**Min - Max Voltage (V) at ΔD = 1×10^{-5}**	**Min - Max Voltage (V) at ΔD = 1×10^{-6}**
0.2 - 0.3	10×10^{-6}	211.6 - 225.4	211.6 - 225.4
	20×10^{-6}	214.5 - 222.9	214.5 - 222.9
	30×10^{-6}	215.4 - 222.2	215.4 - 222.2
	50×10^{-6}	214.2 - 222.9	216.0 - 221.8
	80×10^{-6}	212.9 - 224.3	216.1 - 221.7
	100×10^{-6}	211.4 -225.4	216.1 - 221.8
	150×10^{-6}	208.8 - 227.9	215.8 - 222.1

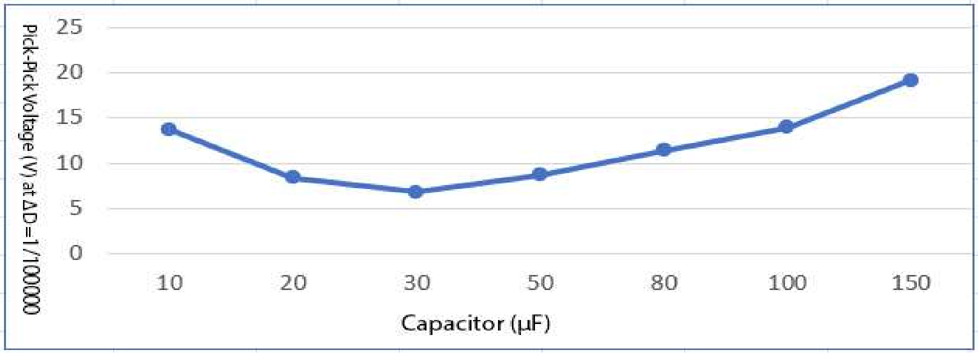

Figure 3. 8 Voltage ripple for $\Delta D = 1 \times 10^{-5}$ at different capacitor

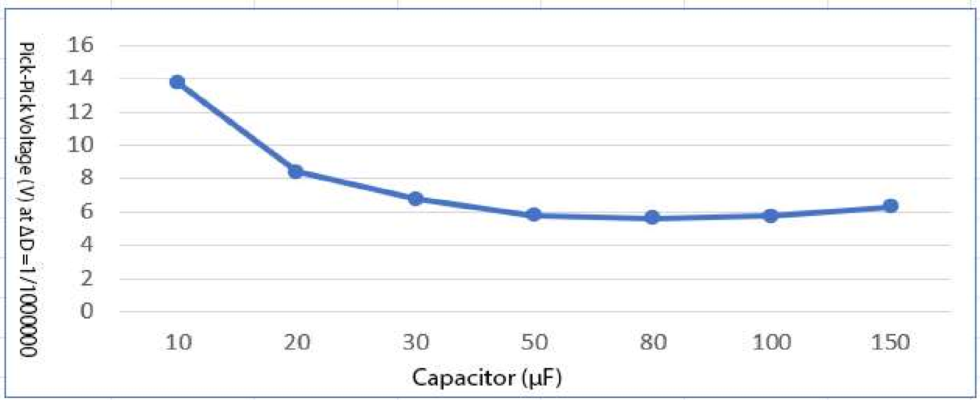

Figure 3. 9 Voltage ripple for $\Delta D = 1 \times 10^{-6}$ at different capacitor

In here, ΔD is the step size of duty cycle. Upon thorough analysis, it has become evident that utilizing an 80 µF DC capacitor link leads to the attainment of optimal power output. Furthermore, our observations reveal that employing an 80 µF capacitor significantly reduces system ripple, ensuring its smooth operation.

Through a comprehensive analysis of technical aspects and business needs, it became evident that utilizing an 80 µF DC link capacitor is the optimal choice for our PV system. This capacitor size was selected to:

- Achieve the desired power output by stabilizing voltage and current, ensuring the system operates at peak efficiency.
- Reduce system ripple, thus guaranteeing smooth and reliable operation.
- Maintain cost-effectiveness by avoiding over-specification of components while meeting performance requirements.

- Enhance the system's reliability by improving transient response and minimizing potential sources of failure.

3.6 Simulation Setup

The overall design and control strategy for the solar PV system incorporates the MPPT (Maximum Power Point Tracking) algorithm, a boost converter, and a three-level Voltage Source Converter (VSC) in a coordinated manner. The primary goal of the MPPT algorithm is to continuously adjust the boost converter to extract the maximum power from the solar PV array. The boost converter plays a vital role in efficiently stepping up the varying output voltage from the solar PV array to a maximum output voltage.

Three-level VSC, which takes charge of regulating the power injection into the grid. The system is also regulating DC input voltage of the three-level voltage source keeping a constant value of 500 V. The VSC incorporates sophisticated voltage and current control loops to ensure that power is efficiently injected into the grid while adhering to grid requirements and maintaining synchronization with the grid's voltage and frequency.

Additionally, an induction motor is connected to the grid side. The motor operates at a constant torque level to get required speed which is 1450 RPM and enhance efficiency during power transmission.

By combining the MPPT algorithm, boost converter, and three-level VSC in this coordinated manner, the solar PV system can achieve maximum power extraction from the PV array and seamless integration of renewable energy into the grid, contributing to a more efficient and sustainable power generation system. Also ensuring a constant power supply to the designed Induction Motor for water pumping.

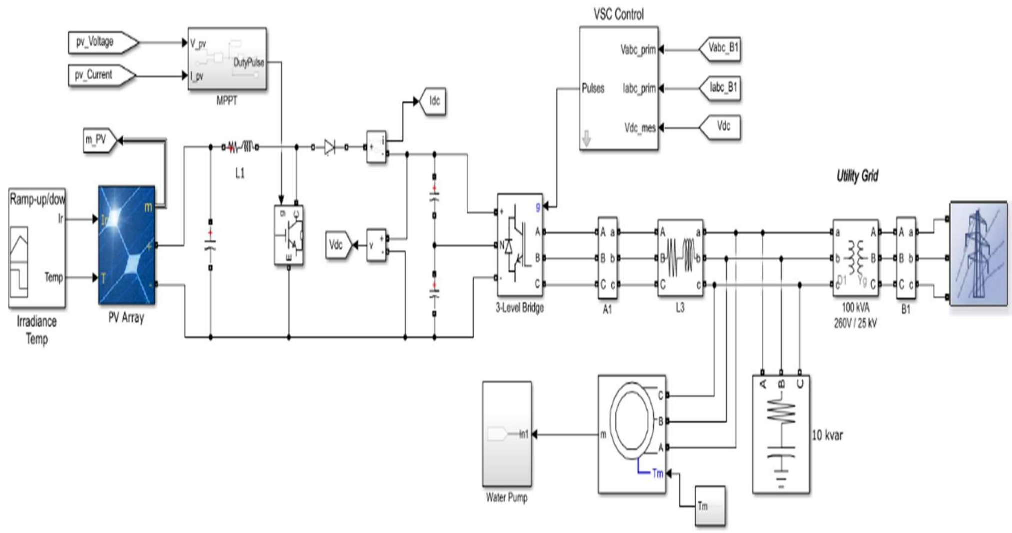

Figure 3. 10 Grid connected solar PV based water pumping system

3.7 Summary

In this chapter introduces solar PV system for agricultural irrigation, emphasizing sustainability and reduced fossil fuel reliance. It highlights components like the Solar PV Array, DC Link Capacitor, Boost Converter, Three-Level Voltage Source Converter, and Induction Motor, explaining their functions. The methodology section discusses MPPT, boost converter design, and three-level VSC control strategies. Design specifications, standards, and constraints for each component are detailed, along with formulas for component sizing. The chapter analyzes the role of an 80 µF DC link capacitor in stabilizing the system, and it outlines the coordinated operation of MPPT, boost converter, three-level VSC, and induction motor for efficient power extraction, grid integration, and water pumping in the simulation setup, laying the foundation for in-depth system evaluation.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results

The proposed modeling and simulation of 4.8 kW grid connected solar PV based water pumping system for sustainable agricultural irrigation is modeled and its performance is simulated in MATLAB/Simulink under various steady state, starting and other dynamic conditions. Simulated results demonstrate the worthiness of proposed system as shown in Figs. 4.1 – 4.10.

4.1.1 Developed Signal

The solar input signal is designed to simulate five stages of solar radiation and temperature conditions.

In stage 1 (0-0.6 seconds), the irradiance is set to 1000 W/m^2, while the temperature remains constant at 25°C. This stage emulates a high solar radiation scenario under standard operating temperature conditions. In stage 2 (0.6-1.1 seconds), the irradiance drops to 0 W/m^2, while the temperature remains constant at 25°C. This stage is designed to assess the system's performance under reduced solar exposure while keeping temperature effects constant. In stage 3 (1.2-1.7 seconds), the irradiance starts increasing to 1000 W/m^2, while the temperature remains constant at 25°C. This stage evaluates the system's response to a second period of peak solar radiation. In stage 4 (2-2.1 seconds), the temperature is increased to 50°C, while maintaining the irradiance at 1000 W/m^2. This stage is designed to test the system's performance under high temperature conditions. In stage 5 (2.1-3 seconds), the final stage sustains a constant temperature of 50°C and irradiance of 1000 W/m^2. This stage is used to assess the system's long-term performance under steady-state conditions.

In summary, the solar input signal is designed to simulate a variety of solar radiation and temperature conditions that a solar system may experience in the real world. This allows to test and evaluate the system's performance under a variety of conditions.

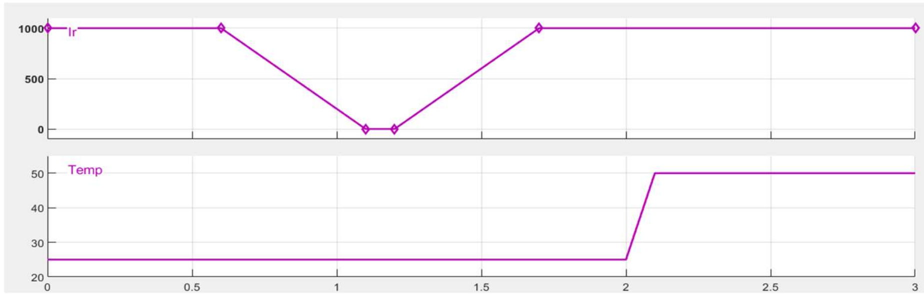

Figure 4. 1 Solar Input Irradiance and Temperature

4.1.2 Starting and Steady State Performance

Solar PV Array Performance

Figure 4.2 exhibits solar PV at an irradiance, I_r in W/m^2, PV voltage, V_{pv}, PV current, I_{pv}, PV power, P_{pv} and duty cycle, D_{ref}. From the figure we can observe that after 0.145 seconds PV output power at its maximum stage. These indicates demonstrate a well performance of the MPPT.

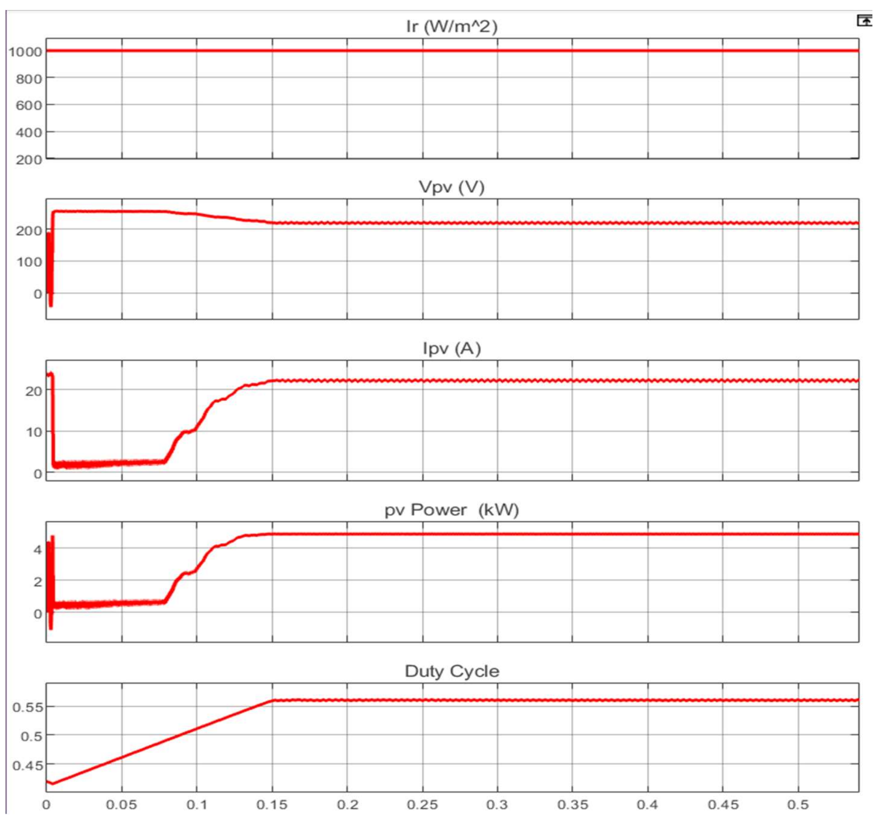

Figure 4. 2 Starting and Steady State Performance of the PV array

Boost Converter Performance

In figure 4.3 boost converter output voltage, V_{boost} is shown, we can observe that after 0.04 seconds boost converter output voltage is almost stable around 500 V as we designed for the system.

Three-Level VSC Performance

In figure 4.3 inverted power from Three-Level VSC, phase to line voltage $V_{inverter}$, phase to line current $I_{inverter}$ and power $P_{inverter}$, is also shown, here we can observe that from 0.18 seconds three-level VSC provides a stable power supply to the grid as well as to the induction motor for water pumping.

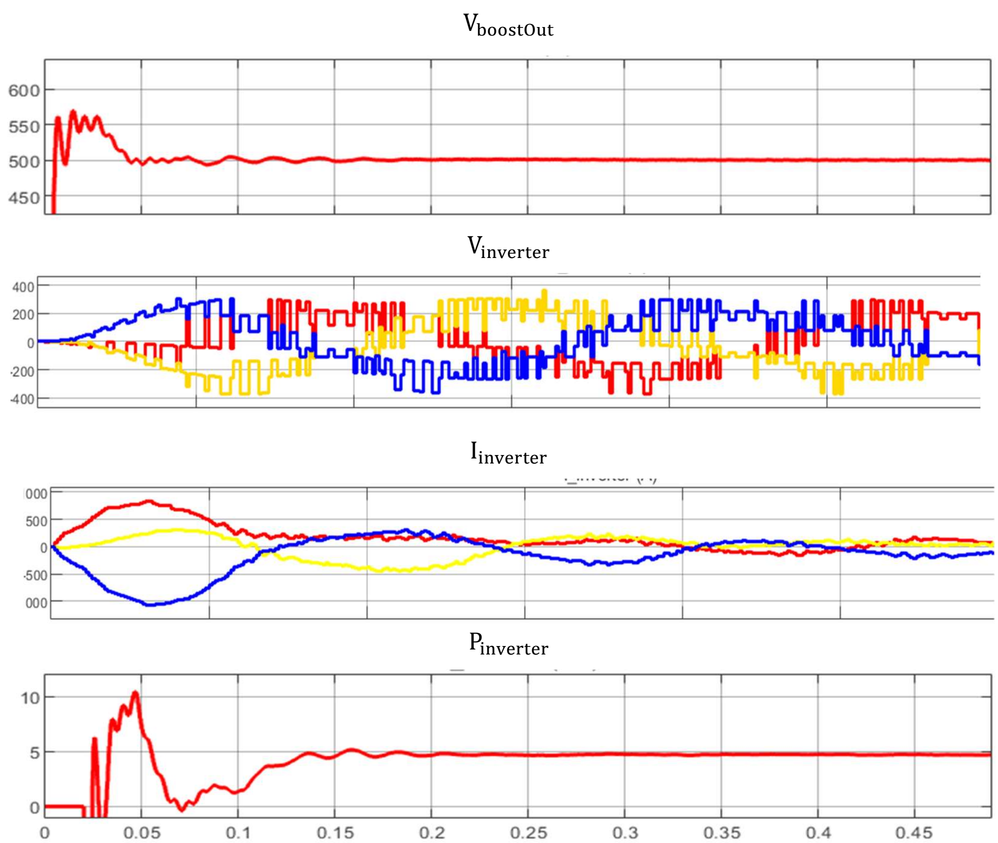

Figure 4. 3 Starting and Steady State Performance of Boost Converter and VSC

Induction Motor Performance

Figure 4.4 exhibits Induction Motor voltage, V_{im}, Induction Motor current, I_{im}, speed of IM, IN_s in rpm, electromagnetic torque of IM, T_e and we can observe that after 0.35 seconds induction motors torque become stable which is 14 Nm and speed reach to 1450 RPM.

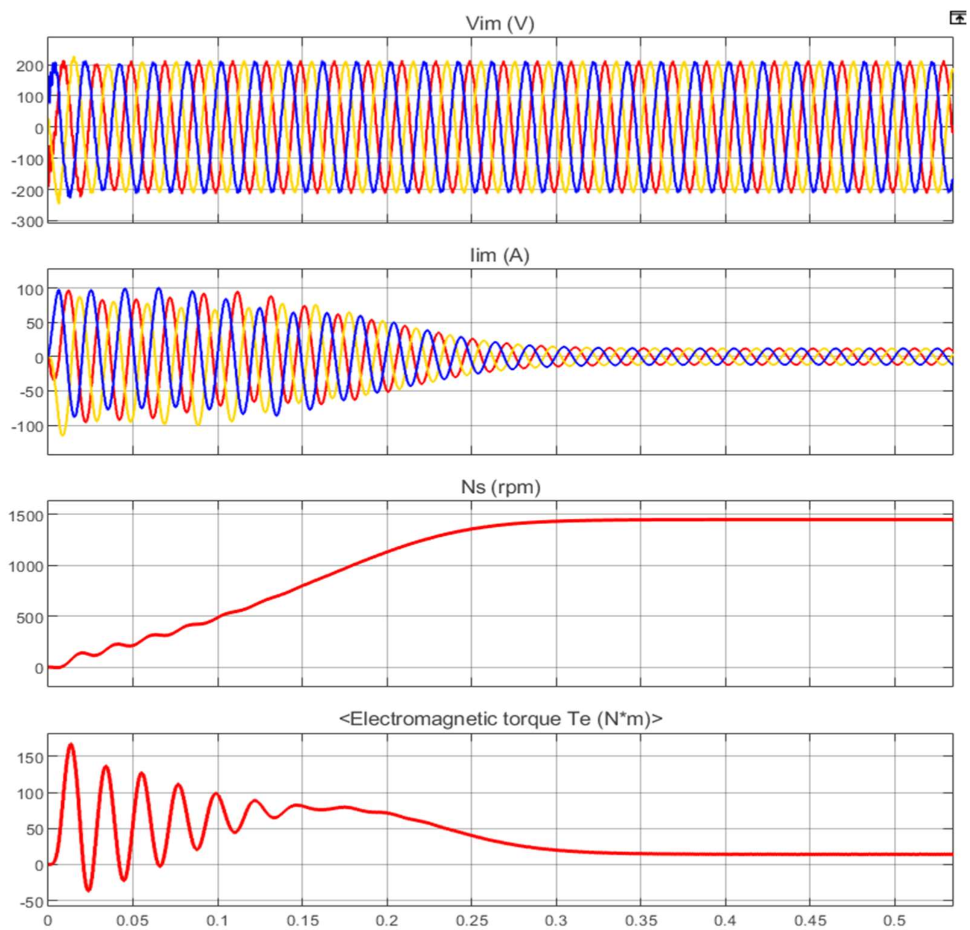

Figure 4. 4 Starting and Steady State Performance of Induction Motor

4.1.3 Dynamic Performance

In here figure 4.5, we observed that the irradiance decreases to 0 W/m^2 and again increased to 1000 W/m^2. The PV array power is optimized successfully under the considered dynamics.

During this dynamic period the voltage of the boost converter output which is also input of the VSC is maintaining 500 V. Shown in figure 4.6.

In figure 4.6, VSC is providing the optimized power to the grid as well as to the induction motor maintaining the same bus voltage.

In figure 4.7, we can observe that in dynamic condition induction motors speed, torque, stator current remaining same. When the solar PV array produces low power, the induction motor draws the necessary power from the grid for pumping water.

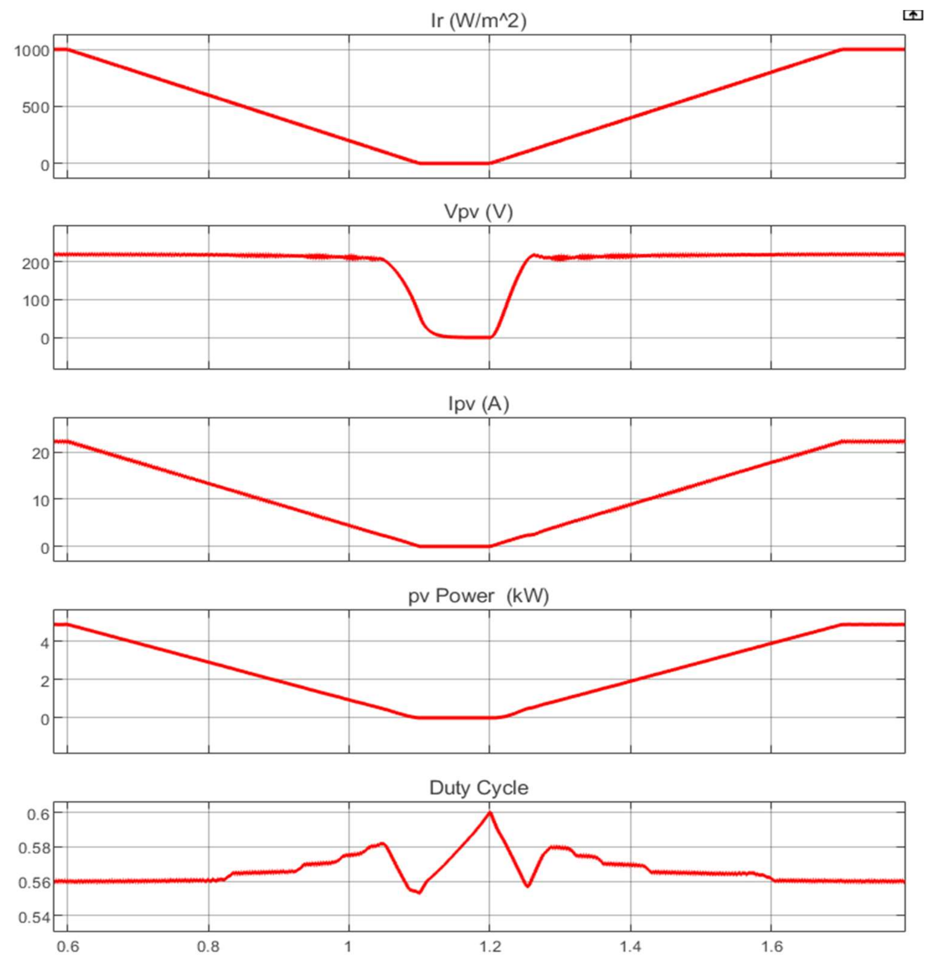

Figure 4. 5 Dynamic Performance of the PV array

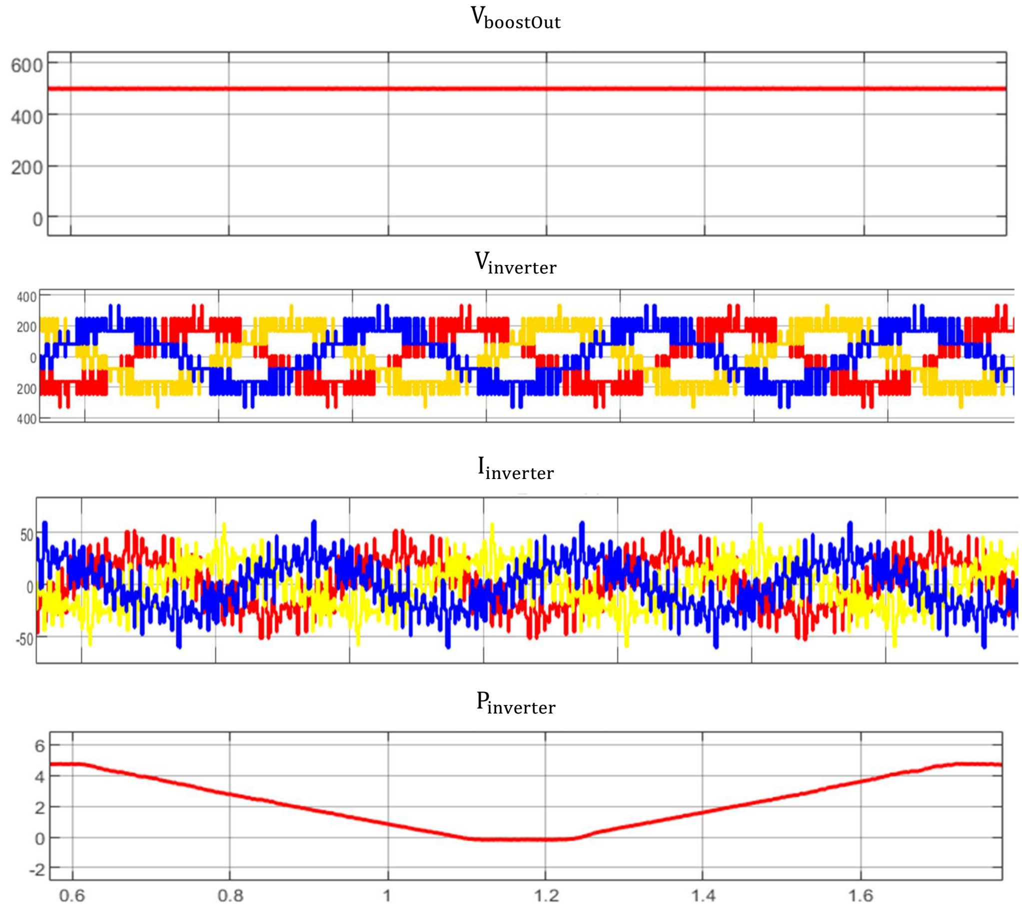

Figure 4. 6 Dynamic Performance of the Boost Converter and Three-Level VSC

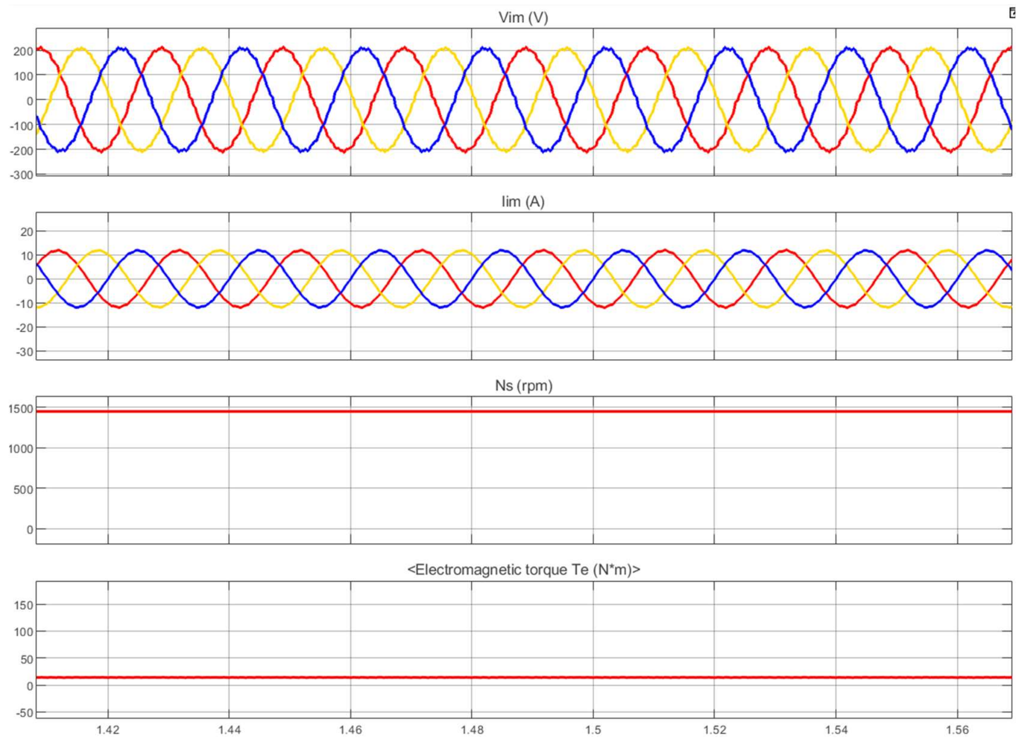

Figure 4. 7 Dynamic Performance of Induction Motor

4.1.4 Overall Performance

Below figure 4.8 shows the 3 seconds of simulation result of PV array performance. Figure 4.9 shows the 3 seconds of simulation result of boost converter and three-level VSC performance. Figure 4.10 shows the 3 seconds of simulation result of induction motor voltage, current, speed in RPM and torque. Those represent the overall performance of the proposed system.

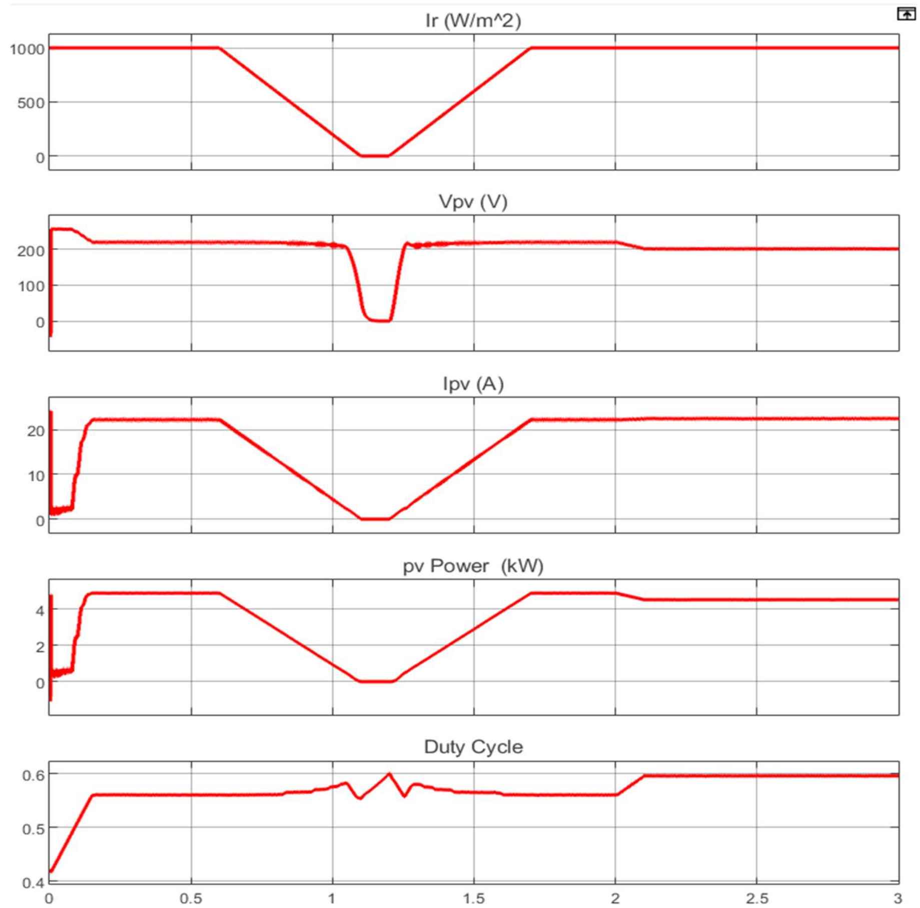

Figure 4. 8 Overall Performance of the PV array

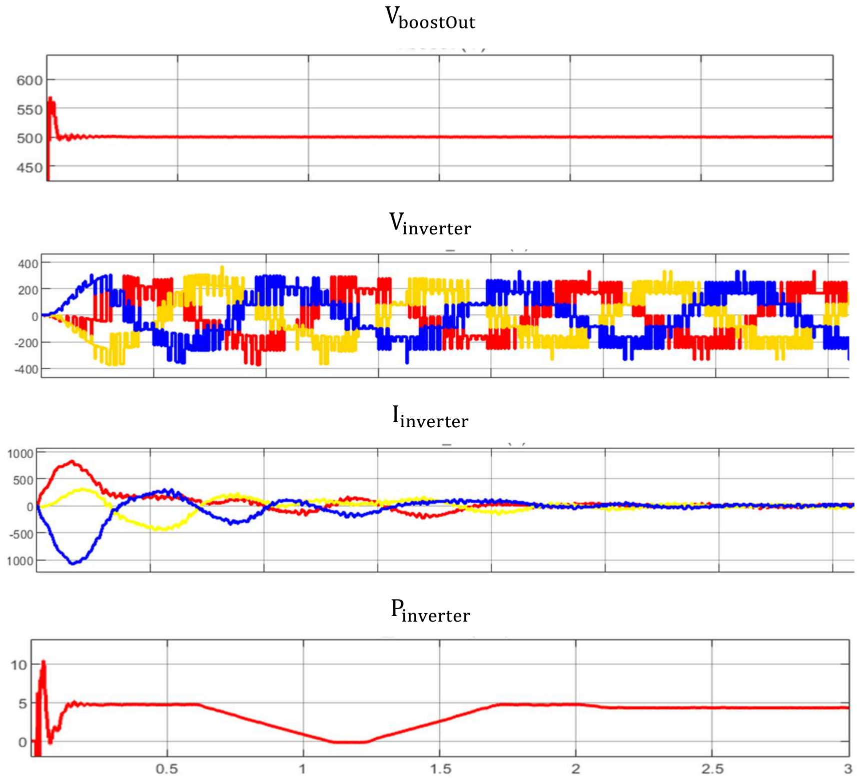

Figure 4. 9 Overall Performance of the Boost Converter and Three-Level VSC

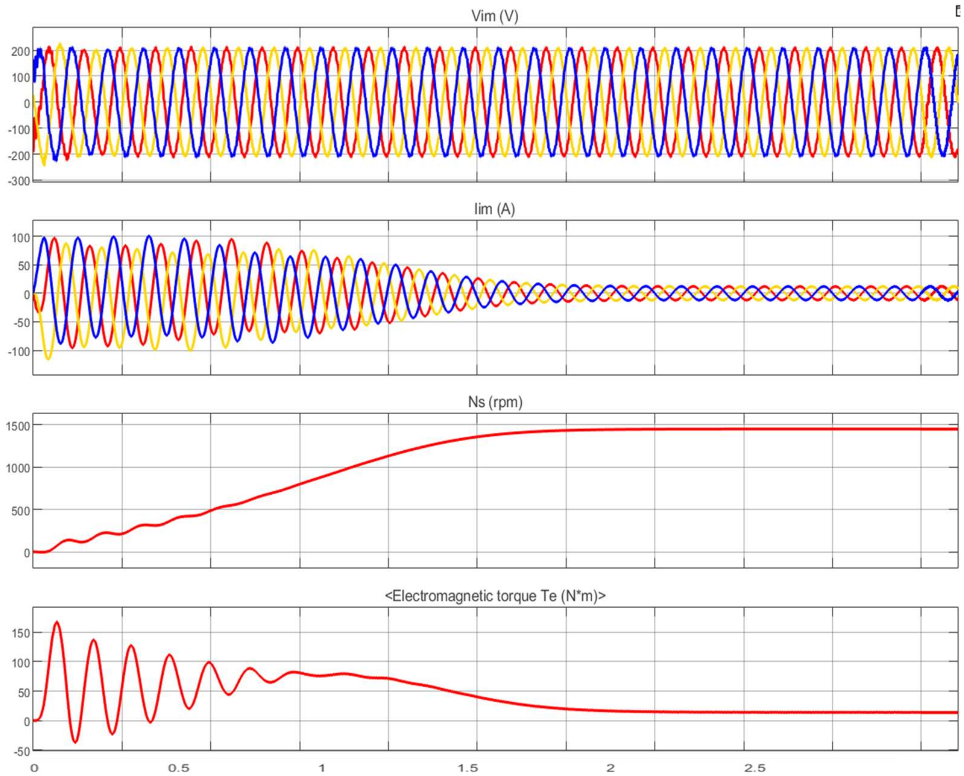

Figure 4. 10 Overall Performance of Induction Motor

4.2 Discussions

The analysis of the simulation results reveals a promising outlook for the proposed grid connected solar PV based water pumping system designed for sustainable agricultural irrigation. The system demonstrates impressive adaptability to varying solar radiation and temperature conditions, effectively harnessing solar energy while maintaining a stable power supply and motor operation. The reliability of the Maximum Power Point Tracking (MPPT) algorithm, in conjunction with the consistent performance of the boost converter and Three-Level Voltage Source Converter, underscores the system's potential to significantly reduce reliance on fossil fuels in agricultural irrigation. From the study, we can observe that when irradiance is at 1000 W/m^2 and the temperature is at 25°C, the solar PV array can generate approximately 4.86 kW of power. This power output is sufficient to operate the induction motor under its rated conditions, with any surplus energy being able to be transferred to the grid. we can also observe that when the irradiance drops to 0, and the solar PV system generates almost no energy, the system relies on the grid to power the induction motor. This is a crucial aspect to consider, as it highlights the need for a reliable backup power source to ensure continuous operation during periods of insufficient solar energy production. However, it's important to acknowledge the limitations of this study, primarily its idealized nature. In real-world applications, factors such as component wear and tear, maintenance requirements, and variations in environmental conditions can impact the system's performance. Therefore, while these results are promising, further experimentation and field testing are essential to validate the system's feasibility in practical agricultural settings and to address any challenges that may arise during real-world deployment.

CHAPTER 5
PROJECT MANAGEMENT

5.1 Task, Schedule and Milestones

The project's activities are structured over a span of several months, each with specific tasks aimed at achieving the project's objectives.

January - March 2023, During the first quarter of the year, the project kicks off with a thorough literature review. This activity involves an in-depth exploration of existing research, publications, and relevant studies in the field of solar PV arrays, induction motor-driven water pumping systems, and their grid integration. The literature review will serve as the foundation for understanding the current state of the art and identifying gaps and opportunities in the chosen area of research.

April - May 2023, in the subsequent two months, the focus shifts to data collection. This phase involves gathering essential data and information related to the components, parameters, and conditions relevant to the grid connected solar PV based water pumping system. Data collection is a critical step in ensuring the accuracy and reliability of the project's experimentation and analysis.
June 2023, June marks the beginning of the experimental phase. This stage involves the practical implementation and testing of the grid connected solar PV based water pumping system. The experiments will be conducted under varying conditions to evaluate the system's performance and efficiency.

July 2023, the next major activity is result analysis. This phase focuses on processing and interpreting the data collected during the experimentation. The goal is to draw meaningful insights, assess the system's behavior under different scenarios, and identify any trends or patterns in the results.

August 2023, the emphasis shifts to writing. This is when the research findings, analysis, and conclusions are synthesized into a comprehensive research paper. The writing phase includes the drafting of the research paper, which will encompass the project's objectives, methodology, experimental results, and their implications.

September 2023, the project's final phase in September is submission. The research paper is polished, refined, and prepared for submission to relevant academic journals, conferences, or publications.

Throughout these activities, careful planning, attention to detail, and adherence to the project timeline are essential to ensure the successful completion of the grid connected solar PV based water pumping system for sustainable agricultural irrigation research project.

5.2 Resources and Cost Management

In a simulation-based project like the modeling 4.8 kW grid connected solar PV based water pumping system, efficient resource management and adherence to the budget plan play pivotal roles. This section outlines the strategies employed to effectively manage resources, including DC capacitor optimization, and maintain cost control throughout the project's lifecycle.

5.2.1 Resource Allocation

Resource allocation involved meticulous planning and distribution of personnel, equipment, materials, and time. To ensure optimal resource utilization, the following strategies were employed:

Resource Selection: Careful consideration was given to selecting the appropriate individuals for specific tasks based on their expertise and experience. This approach ensured that tasks were executed efficiently and effectively.

Equipment and Materials: Prioritizing the selection of high-quality equipment and materials helped minimize operational issues and reduce maintenance costs. Regular equipment maintenance schedules were established to extend the lifespan of critical components.

Time Management: A well-defined project schedule was developed, including milestones and deadlines. Project management software was utilized to monitor progress and identify potential delays early, allowing for timely corrective actions.

Practice and Development: Continuous practice and development programs were implemented to keep the team updated on the latest technologies and best practices in renewable energy and simulation techniques.

5.2.2 DC Capacitor Optimization

In addition to resource management, the optimization of the DC capacitor was a crucial aspect of the project. The DC link capacitor played a vital role in stabilizing variable voltage and current generated by the PV array. Careful selection and sizing of the DC capacitor helped to reduce voltage ripples and current fluctuations, improving system efficiency and transient response.

5.2.3 Net Metering

This project also considered net metering as an integral part of cost management. Net metering allowed the surplus solar electricity generated during periods of high solar irradiance to be fed back into the grid. This not only contributed to grid stability but also potentially enabled the system owner to receive financial incentives or credits for the excess energy supplied to the grid. Net metering was a key component of the project's cost-benefit analysis, as it factored into the overall economic viability of the system. [12]

Effective resource and cost management, along with DC capacitor optimization and the incorporation of net metering, were integral to the success of the simulation-based project involving the design and simulation of the grid connected solar PV based water pumping system. Through meticulous planning, allocation, monitoring, and control of resources, as well as strict adherence to the budgetary plan, the project achieved its objectives while minimizing financial risks and maximizing the benefits of renewable energy integration into the grid. Continuous evaluation and adjustment of resource allocation and cost control strategies contributed to the overall efficiency and sustainability of the project.

5.3 Lesson Learned

The execution of the grid connected solar PV based water pumping system research project provided valuable insights and lessons that can guide future endeavors in the field of renewable energy and simulation-based projects. Here are some key lessons learned:

- Comprehensive planning is essential, starting with a thorough literature review.
- Proper resource allocation, including personnel and equipment, is crucial for efficiency.
- Effective time management through a detailed project schedule is vital.
- Continuous learning and skill development are necessary due to evolving technologies.
- Optimizing specific components, such as the DC capacitor, can significantly impact system efficiency.
- Economic viability, including factors like net metering, must be considered for sustainability.
- Flexibility and adaptability are key to overcoming unexpected challenges.
- Comprehensive documentation of all project phases aids in knowledge transfer and future reference.
- A sustainability mindset is crucial, considering long-term environmental and societal impacts.

CHAPTER 6
IMPACT ASSESSMENT OF THE PROJECT

6.1 Economical, Societal and Global Impact

The development of the grid connected solar PV based water pumping system for sustainable agricultural irrigation has the potential to bring about significant economic, societal, and global impacts.

6.1.1 Economic Benefits

The development and implementation of the solar PV array grid connected with water pumping system hold significant economic promise. One of the primary advantages lies in cost savings for farmers. This system allows farmers to substantially reduce their energy costs, which are typically high when using traditional energy sources like diesel generators for irrigation. By shifting to solar power, farmers can lower their operating expenses, ultimately leading to increased profitability in agricultural activities.

6.1.2 Environmental Impact

The transition from fossil fuels to solar energy in agriculture carries substantial environmental benefits. This renewable energy solution helps mitigate carbon emissions and air pollution. This reduction in greenhouse gas emissions contributes to a cleaner and healthier environment, particularly in rural areas where air quality can suffer due to the use of diesel-powered machinery. By adopting sustainable energy practices, this system promotes both economic and environmental sustainability.

6.1.3 Energy Security and Job Creation

Solar power offers energy security to farmers. By reducing dependence on fluctuating fuel prices and ensuring a consistent energy supply, it enhances the resilience of agricultural operations. Moreover, the installation, maintenance, and operation of solar PV systems and water pumping equipment create employment opportunities, particularly in rural communities. This job creation spans across skilled technicians and laborers involved in installation and maintenance, providing an economic boost at the local level.

6.1.4 Agricultural Productivity

Reliable access to water for irrigation, facilitated by the solar-driven water pumping system, can significantly boost agricultural productivity. The deployment of renewable energy systems like this often triggers rural infrastructure development. This includes improved access to electricity and water resources, fostering the growth of rural communities with better educational, healthcare, and transportation facilities.

6.1.5 Contribution to GDP

The growth of the renewable energy sector, driven by systems like this one, contributes significantly to a nation's Gross Domestic Product (GDP). Investments in equipment, installation, and maintenance stimulate economic activity and encourage innovation within the renewable energy sector. This sectoral growth has positive ripple effects throughout the broader economy.

6.1.6 Enhanced Quality of Life

Access to a reliable and clean energy source, such as solar power, directly improves the quality of life for farmers and rural communities. It ensures a dependable energy supply for daily needs, enhances living standards, and provides better access to education and healthcare services.

6.1.7 Global Food Security and Technology Transfer

Sustainable agricultural practices powered by renewable energy are critical for global food security. Predictable crop yields and stable food production are vital for ensuring that people worldwide have consistent access to an adequate food supply. Furthermore, the successful implementation of this system can serve as a model for technology transfer to regions and countries facing similar agricultural and energy challenges. This transfer can promote the widespread adoption of renewable energy solutions, positively impacting global sustainability efforts.

Developed solar PV array grid connected with an induction motor-driven water pumping system offers a holistic solution with far-reaching impacts. It not only aligns with global sustainability goals but also addresses economic, environmental, and societal needs. By harnessing renewable energy for agriculture, this project contributes to a more sustainable and prosperous future for farming practices and rural communities worldwide.

6.2 Environmental and Ethical Issues

The design and implementation of a solar PV array grid connected with an induction motor-driven water pumping system for sustainable agricultural irrigation have significant environmental implications. From an environmental perspective, the system's primary objective is to promote sustainability and reduce the carbon footprint associated with conventional agricultural practices. By harnessing solar energy, the system mitigates greenhouse gas emissions typically generated by fossil fuel-based electricity generation. This reduction in emissions contributes to a cleaner and more environmentally friendly agricultural sector.

Moreover, the system's ability to integrate surplus energy into the grid through net metering or feed-in tariff schemes can lead to further environmental benefits. It encourages the generation of clean energy that benefits not only the agricultural sector but also the broader community. This contributes to overall grid stability and resilience while reducing the reliance on non-renewable energy sources.

Regarding ethical considerations, the responsible use of resources and the implementation of sustainable practices are paramount. Farmers and system operators must ensure that the system is maintained and operated efficiently to maximize its environmental benefits. Proper maintenance and monitoring of the solar PV array, induction motor, and associated components are essential to prevent any environmental harm caused by system malfunctions or inefficiencies.

Additionally, ethical responsibilities extend to ensuring the well-being of local ecosystems and communities. The installation of solar panels and infrastructure should be carried out in a manner that minimizes disruption to local environments and respects the rights and interests of neighboring communities.

6.3 Utilization of Existing Standards and Codes

When designing and implementing the proposed solar PV array grid-connected with an induction motor-driven water pumping system, it is essential to comply with all applicable standards and codes. This ensures the safety and reliability of the system, while also protecting the environment and the grid.

Some of the key standards and codes that apply to this project include:

- UL 1741: This standard outlines the safety requirements for inverters used in grid-connected photovoltaic systems. [12]
- IEEE 1547: This standard provides guidance on the interconnection of distributed energy resources, such as solar PV systems, with the electric grid. [13]
- NEC 690: This section of the National Electrical Code (NEC) provides specific requirements for the installation and operation of solar PV systems. [14]

6.4 Other Concerns

Using an Induction motor instead of a DC motor or other types of motors in your solar-powered water pumping system for agricultural irrigation offers several advantages.

Cost: Induction motors are typically less expensive than DC motors.

Durability: Induction motors are very robust and can withstand harsh operating conditions, making them ideal for agricultural use.

Efficiency: Induction motors are highly efficient, especially when used in conjunction with a variable frequency drive (VFD).

Availability: Induction motors are widely available and easy to repair.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This research project modeling and simulation of 4.8 kW grid connected solar PV based water pumping system for sustainable agricultural irrigation, successfully incorporating an induction motor for pumping. The system's components, including the PV array, boost converter, and three-level voltage source converter (VSC), were meticulously developed to optimize energy transfer and power generation. The maximum power point tracking (MPPT) algorithm effectively extracted the maximum power from the PV array, ensuring efficient energy utilization.

One notable feature of the system is its ability to maintain stable operation even under varying solar irradiance and temperature conditions. When the solar PV system produces low power due to adverse weather conditions or reduced sunlight, the induction motor seamlessly switches to drawing power from the grid. This ensures uninterrupted and reliable water pumping for agricultural irrigation.

The project's outcomes highlight the potential of renewable energy-based solutions, like grid-connected solar PV systems with backup from the grid, in agriculture. This approach fosters sustainable practices by reducing reliance on fossil fuels and contributes to a greener and more environmentally friendly future for farming. Additionally, the research has broader implications, extending beyond agricultural irrigation, and can be applied to various other fields where renewable energy integration with grid-connected systems is essential for sustainability and efficiency. This includes applications in residential and commercial settings, water supply systems, and more, where a reliable power supply is critical, and renewable energy sources can play a significant role in reducing carbon emissions and promoting sustainable energy practices.

7.2 New Skills and Experiences Learned

New skills and experiences I have learned doing this project are mentioned below.

- Profound understanding of integrating renewable energy, particularly solar PV arrays, into agricultural irrigation systems.

- Skill in designing and simulating complex systems, including PV arrays, boost converters, VSCs, and induction motors.
- Knowledge of Maximum Power Point Tracking (MPPT) algorithms and their role in optimizing solar power output.
- Familiarity with DC-DC boost converter design principles and component selection.
- Understanding of voltage source converter (VSC) control strategies for grid integration and bidirectional power flow.
- Knowledge of grid synchronization using Phase-Locked Loop (PLL) for power quality and grid compatibility.
- Ability to coordinate various control elements within a system for efficient power generation.
- Proficiency in dynamic system analysis under changing environmental conditions, including solar irradiance and temperature variations.
- Interdisciplinary approach, bridging knowledge from renewable energy, electrical engineering, control systems, and simulation techniques.
- Insight into the impact of renewable energy integration on sustainable agricultural practices and environmental sustainability.

7.3 Future Recommendations

The research presents the modeling and simulation of 4.8 kW grid connected solar PV based water pumping system for sustainable agricultural irrigation. The system aims to reduce reliance on fossil fuels and mitigate greenhouse gas emissions in agriculture by efficiently harnessing solar energy. It consists of a PV array, boost converter, and a three-level voltage source converter (VSC) to optimize energy transfer and grid integration. A maximum power point tracking (MPPT) algorithm extracts maximum power from the PV array, while smart control mechanisms ensure efficient power utilization. Simulated performance analysis under varying solar conditions demonstrates system robustness. Future recommendations include energy storage integration, advanced MPPT techniques, fault tolerance, remote monitoring, water management, hybrid energy systems, cost reduction, environmental impact assessment, scaling and adoption efforts, and policy support to enhance sustainability in agriculture.

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APPENDIX A: TURNITIN REPORT

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APPENDIX B
COMPLEX ENGINEERING PROBLEM SOLVING AND ENGINEERING ACTIVITIES

Complex Engineering Problems (P) Solving		
	Attributes	Statement from students
P1	Depth of knowledge required	Extensive understanding of grid connected solar PV systems, control system and power electronics are required.
P2	Range of conflicting requirements	Striking the right balance between maximizing power extraction from the PV array and determining the optimal value for the DC link capacitor presented significant challenges in this research.
P3	Depth of analysis required	In-depth analysis of system components, control strategies, and performance under various conditions is required.
P4	Familiarity of issues	Environmental Impact, Agricultural Productivity, GDP, Enhanced Quality of Life, Global Food Security and Technology Transfer.
P5	Extent of applicable codes	Compliance with key standards such as UL 1741 for inverter safety, IEEE 1547 for grid interconnection and NEC 690 for solar PV system installation is imperative to ensure safety, reliability and environmental adherence in the proposed system.
P6	Extent of stakeholder involvement and conflicting requirements	-
P7	Interdependence	The interdependence of PV array performance, boost converter efficiency, and grid integration strategies are carefully considered.

Engineering Activities (A)		
	Attributes	Statement from students
A1	Range of resources	Text Book, Laptop, Internet, Software.
A2	Level of interaction	Supervisor.
A3	Innovation	-
A4	Consequences of society and environment	This project can have positive consequences for society and the environment. It reduces greenhouse gas emissions associated with conventional energy sources, promotes sustainable farming practices, and contributes to a cleaner and more environmentally friendly agricultural sector.
A5	Familiarity	Familiarity with renewable energy technologies, grid integration, and agricultural irrigation practices is crucial for successfully executing in this project.

APPENDIX C
PROGRAM CODE

Used function code for MPPT.

```
function Dref = mppt(V,I)
Dinit = 0.42;
Dmax = 0.9;
Dmin = 0.1;
delDref = 0.00001;
persistent Vold Pold Drefold
if(isempty(Vold))
   Vold = 0;
   Pold = 0;
   Drefold = Dinit;
end
P = V*I;
delv = V - Vold;
delp = P - Pold;
if delp>0
   if delv>0
      Dref = Drefold - delDref;
   else
      Dref = Drefold + delDref;
   end
elseif delp<0
         if delv>0
            Dref = Drefold + delDref;
         else
            Dref = Drefold - delDref;
         end
      else
         Dref = Drefold;
end

if Dref>Dmax || Dref<Dmin
         Dref = Drefold;
end
      Drefold = Dref;
      Pold = P;
      Vold = V;
```

APPENDIX D
SIMULATION DIAGRAM

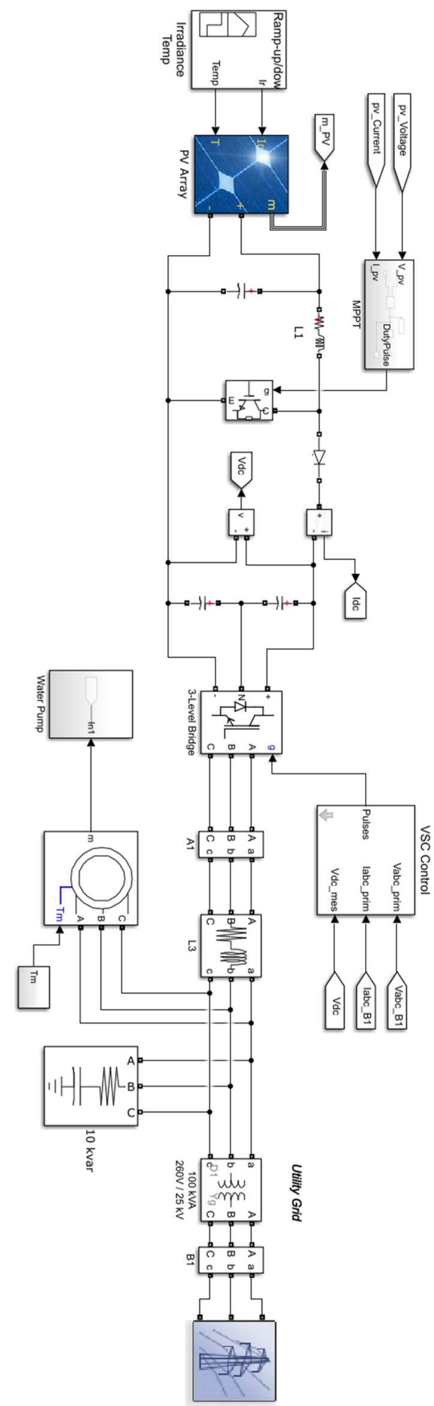

Figure 4. 11 Overall Simulation Diagram

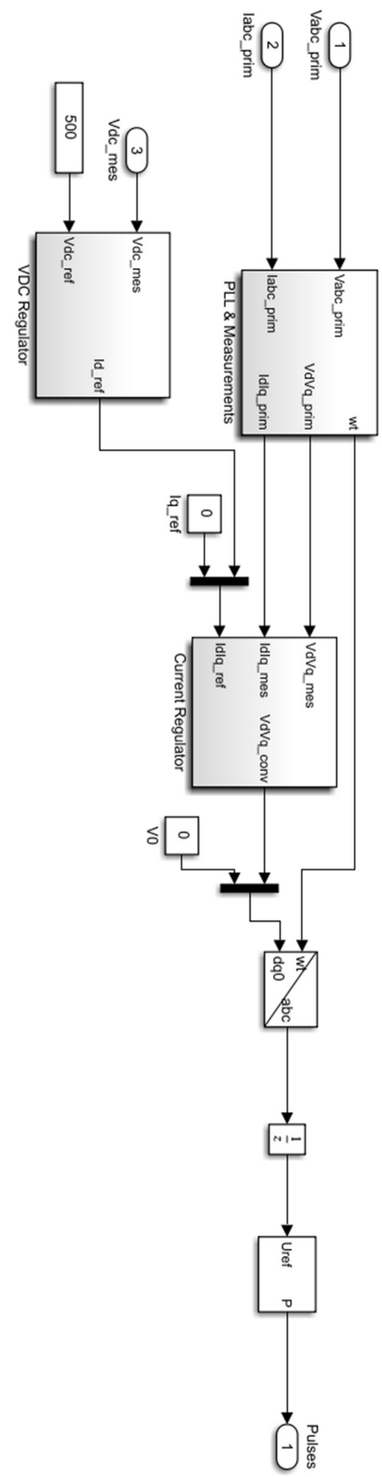

Figure 4. 12 VSC Main Controller