Design, Simulation & Analysis of a 3 MW Grid-Connected Solar PV System

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.

Submitted by
Manoj Ganguly
ID:221-33-1579
&
Semo Begum
ID:221-33-1521

Supervised by
Md. Ramjan Ali
Lecturer
Department of Electrical and Electronic Engineering

Department of Electrical and Electronic Engineering
Faculty of Engineering
DAFFODIL INTERNATIONAL UNIVERSITY

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DECLARATION

I, the undersigned, declare that this project **"Design, Simulation & Analysis of a 3 MW Grid-Connected Solar PV System"** is my own work, carried out in the Department of Electrical and Electronic Engineering, Faculty of Engineering of Daffodil International University in partial fulfillment for the award of a degree Bachelor of Science in Electrical and Electronic Engineering and has not been submitted to any other University or Institution for a degree, diploma or other qualifications. I have considered and taken account of all potential risks associated with this study that may be encountered in the course of the Study, gotten the necessary ethical and/or safety clearance (whenever applicable) and have revealed my obligations, as well as the rights of the participants.

Signature of the Candidates

Manoj Ganguly

____

Manoj Ganguly

ID :221-33-1579

Semo Begum

____

Semo Begum

ID:221-33-1521

APPROVAL

This is to certify that the project report entitled **Design, Simulation and Analysis of a 3 MW Grid-Connected Solar PV System** submitted by Manoj Ganguly (221-33-1579) & Semo Begum (221-33-1521) has been carried out under my supervision and accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering in July, 2025.

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Signed

Ramjan Ali

MD. Ramjan Ali

Lecturer

Department of Electrical and Electronic Engineering

Faculty of Engineering

Daffodil International University

Dedicated

To

Our Parents

And Friend

With Love & Respect

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LIST OF ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
PV	Photovoltaic
I-V	Current-Voltage
V-I	Voltage-Current
SPV	Solar Photovoltaic
MPPT	Maximum Power Point Tracking

LIST OF SYMBOLS

Symbol	*Name of the Symbol*
I	Current
η	Efficiency
R	Resistance
V_{oc}	Open Circuit Voltage
I_{Sc}	Short Circuit Current

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ABSTRACT

The optimal approach to address increases in energy costs and environmental risks is the integration of renewable resources into the power grid. This paper presents the design, simulations, And performance analysis of a 3MW grid-connected solar photovoltaic (PV) facility in Nigeria. The electrical parameters, including voltage, current, and power output of the system, were assessed at various degrees of solar irradiation. The system's output at an irradiation of 1 kW/m^2 was 9555 A, 319 V, and 3 MW. The voltage increased marginally to 321.1V, however the current and output power diminished to 7651A and 2.5MW, respectively, as the irradiance reduced to 0.8kW/m^2. At 0.6 kW/m^2, additional reduction resulted in a voltage below 322.7 V but above 5739 A, equating to 1.9 MW. The voltage declined to 321.8 V, while the current and power diminished to 3833 A and 1.2 MW, respectively, at the minimum irradiance of 0.4 kW/m^2. The results demonstrate a clear correlation between PV array output and solar irradiance, indicating that increased irradiance leads to enhanced power production. The results indicate the significance of improved photovoltaic system designs to mitigate irradiance fluctuations, hence necessitating enhancements in energy generation efficiency across diverse climates.

Keywords: **Irradiance, photovoltaic, power grid, Simulink, simulation**.

CHAPTER 1
INTRODUCTION

1.1 Introduction

The rising need for sustainable and eco-friendly energy sources has prompted a worldwide transition to renewable energy supplies. Of these, solar photovoltaic (PV) becomes the most favored technology because of its modularity, scalability, and improved efficiencies. Solar energy, which is sustainable and renewable will also help remedy climate change and greenhouse effects. Global cumulative capacity of solar photovoltaic (PV) system exceeded 940 GW in 2021, highlighting that the technology is reshaping national energy policy for many countries (Adam & Apaydin, 2016; Adebanji et al., 2022). Collaborative research on the conversion of solar energy into electricity has been initiated and coordinated by the International Energy Agency (IEA), in the technology field of Photovoltaic Power Systems Programme (PVPS). In the task 2, which is a leading task, it is improving the efficiency and the reliability of the Photovoltaic (PV) systems by collecting, analyzing, and disseminating information and the big data of the technical performance, reliability, and malfunctioning of the PV systems and the components. This research offers a theoretical basis with respect to system dimensioning and a basis for performance comparison. This also applies to the activities of the European Commission (Adiyabat et al. For the energy yield and performance of photovoltaic systems and components, the IEA Grid Connected Photovoltaic Power System Programme (IEA-PVPS) Task 2 proposed standardised key indicators in the EC Document B (Akorede et al., 2017; Akuru & Okoro, 2010) and in the IEC Standard 61724 (1998).In addition, the Task 2 group has created a huge database of technical and operational values relating to PV converter systems that are operating in different climate conditions (Asmelash & Gorini, 2021; Bassey et al., 2024). Task 2 recommended that 21 sample photovoltaic systems belonging to five participating countries undergo long-time testing in a controlled condition (Bhattacharjee & Bhakta, 2013; Brecl & Topič, 2016).

Grid-tied solar PVs provide additional advantages as they have the potential to integrate renewable energy generation with the electricity grid. This integration could help to minimize the reliance on fossil fuels and to improve the security and resilience of the Electrical System (Chong et al., 2011; D Daliento et al., 2017). These technologies include advanced inverter features protective of the grid, measures addressing ‘Islanding,’ grid friendly features, solar forecasting, and smart grid technology.Inverters are categorized based on output power capacity into light-duty (100 - 10,000W), medium-duty (500 - 20,000W), and heavy-duty (10,000 - 60,000W) classifications. In addition, net metering permits the solar energy for consumption on site, while selling excess to the grid thereby feeding the latter (Diji et al., 2013a; Diji et al., 2013b).

Due to their integration with the utility grid, feed-in inverters possess anti-islanding protection, allowing them to automatically disconnect during a grid outage to avert potential hazards to individuals or existing equipment within the distribution network, thereby mitigating damage (Efurumibe et al., 2014; Ekpo, 2019). The fundamental function of inverters is to convert DC electricity generated by solar panels into AC power suitable for integration into the electrical grid; however, the latest inverters also incorporate advanced features such as voltage regulation and grid assistance.These have undergone rigorous testing at the megawatt converter level within the framework of production utilizing megawatt-scale grid simulations and power hardware-in-the-loop (PHIL) systems. These simulations replicate field operating settings on the impact of inverter behavior on power quality and system dependability (Emodi & Boo, 2015; Eyibo et al., 2024). A multitude of researchers has examined solar penetration within the power grid (Hoke et al., 2016). Ikem et al. (2016) examined users' perceptions and the rationale, benefits, and drawbacks associated with the utilization of renewable energies in electricity systems. Researchers have documented the enhanced efficiency, affordability, and minimal environmental impact of solar photovoltaic technologies, facilitating their use in solar-powered water pumping, off-grid residential systems, building-integrated photovoltaics, desalination systems, and photovoltaic-thermal collectors. Innocent et al. (2021) analyzed load mismatch in a grid-connected photovoltaic system and assessed the economic viability and utility of rooftop photovoltaic installations on multi-story buildings to satisfy electricity demand.

Their study demonstrated that obstructing 10% of solar exposure from adjacent structures decreases the LMI from 42.4% (without shade) to 38.6%, highlighting the impact of environmental mitigation on the performance of building-integrated solar systems. An increasing number of applications utilize ecological energy in addition to traditional grid integration. For example, Jahn et al. (2020) developed an integrated system for the sustainable infrastructure of an urban high-rise building that amalgamates solar and wind power generation with rainwater harvesting, which is pertinent in this context. Nigeria is included, given that the average daily solar radiation ranges from 4 to 7 kWh/m^2; yet, the nation suffers from a deficiency in energy services. With a population over 200 million and an average per capita energy consumption of 150 kWh/year, far lower than the world average, there is an urgent need for the diversification of Nigeria's power mix (Jameson et al., 2024; Li et al., 2018). In such a situation, grid connected solar pv systems have been emerged as an alternate solution to meet the existing deficit of energy. Nkan et al. (2019) analyzed content of renewable energy master plan Nigeria(REMP) and underscored the importance of carbon capture and storage(CCS) technology for increasing energy demand via capital investment in RE tech. The scheme was also put into the context of sustainable development, energy security and secure energy supplies. Nkan et al. (2023) carried on the study on measures of increasing renewable energy penetration in Nigeria. Nwaigwe et al. (2019) and Odeh et al. (2022) has just renewed the prospect of tapping into renewable energy sources in Nigeria for solving the perennial energy crises in the country.

There is plethora of works in literatures on integration of renewable energy in Nigerian electricity system. For example, Orioli and Di Gangi (2013), and Oyewunmi (2017) considered the inclusion of smart grid technology, and renewable energy into the national electricity grid. They said smart grid innovations could end the lingering power problems of the country. However, Padmavathi and Daniel (2013) suggested that renewable energy could be incorporated into existing national grid systems in order to reduce the current energy deficit. Their findings zero in on failures in electricity supply, and their negative impact on manufacturing, and suggest improvements in both the usage of renewables and the reform of electricity policy to maximize America's wealth of renewable resources.

Parida et al. (2011) investigated the potential renewable energy penetration impact and transmission improvement within 330 kV network of Nigeria. The study showed that reliability and effectiveness of the grid can be improved by adding renewable sources, thus controlling stability and power loss, among other problematics. Further research has centred on the optimal penetration of renewable energy at peak demand and this is done with the application of Flexible Alternating Current Transmission System (FACTS) devises (Sambo, 2009; Vincent & Yusuf, 2014; Ugwuanyi et al., 2024). These studies suggested that FACTS devices could be an effective means to greatly enhance grid stability and voltage regulations without the need to invest heavily in new infrastructure investments, thereby allowing for renewable energy to be integrated into weak grid systems.

The aggregated evidence demonstrated the feasibility of renewable energy, particularly when combined with contemporary grid technologies to address Nigeria's energy challenges. This degree of integration is designed to improve economic competitiveness and environmental responsibility while facilitating a dependable, secure, and greener energy future. Nigeria possesses ample energy resources; however, a significant portion of the population, both in rural and urban regions, depends on fuelwood and other biomass for household cooking, heating, and lighting. (Adzande and Dogo examine the relative effects of various factors that positively or negatively influence the demand and supply of electrical power in Nigeria's economy.) The implementation of grid-connected solar photovoltaic systems, such as a 3 MW facility, could significantly enhance national grid performance, augment energy access in energy-deficient regions, and mitigate the environmental impact of power generation from traditional sources.

Moreover, these objectives align with the Nigerian Renewable Energy Master Plan, which seeks to achieve 20 GW of renewable energy by 2030. This could also contribute to the government's overarching development strategy, which focuses on industrialisation and electrification of rural areas (Woyte et al., 2013). A 3MW grid connected solar photovoltaic (PV) plant, was designed, simulated and analyzed in Nigeria, presenting its potential and issues. Important environmental conditions like changes in solar radiation and ambient temperature exert a significant impact on the energy yield and operation of the system.

The purpose is to maximize the efficiency according to the grid code, which requires a high-performance power electronic stage, comprising an MPPT (Maximum Power Point Tracking) controller and a grid-interconnected inverter (Zahedi, 2011). Second, and in direct relation to the fault ride-through, voltage regulation and grid stability, the technological issues also need to be addressed; in order to compensate for the intrinsic temporal variability of the solar resource. Continuous decrease in photovoltaic module price and improvement of balance of system components brought about a gradual incremental improvement of the cost-competitiveness of solar photovoltaic technologies over their conventional fossil fuel counterparts. Beyond the higher energy self-sufficiency that a centralized solar photovoltaic power plant enables at the macro level, a 3 MW installed capacity solar power plant Nigeria has a range of economic benefits that makes it a formidably attractive investment, including local job opportunities; reduced expenditure on imported fuel; and lower running costs compared to existing energy supply establishments.an extended duration. It will also generate environmental dividends - a massive decrease in greenhouse gas emissions, which will help to meet Nigeria's international climate obligations under the Paris Agreement. In MATLAB/Simulink the design, simulation and performance analysis of 3 MW grid-connected solar PV system has been presented in the context of Nigerian condition.The design elements, particularly MPPT techniques, are examined, and the system's energy output under local climatic conditions is quantified. It also addresses grid integration problems and illustrates the socio-economic and environmental advantages of implementing utility-scale solar PV plants in Nigeria.

1.2 Problem Statement

Notwithstanding the swift expansion in the quantity and capability of solar PV systems in recent years, the economical planning and operation of large-scale PV power plants within current power systems remain significant challenges. Poor design practices can result in a reduced output, grid stability problems, and a non-competitive economy. Key factors include: Proper system sizing: the selection of the right system based on the requirements Selection of Relevant component: as one decide system, decision come in component selection by which energy output is increased Weather forecasting: estimating maximum and minimum energy production grid standard: In which standard need to follow so it for reliable Energy delivery. Furthermore, the trade-off between economic costs and maximum system-performing efficiency is an important one to consider.

1.3 Objectives

The aims of this study are:

1. To produce a complete detailed design of a 3MW grid connected Solar PV system, based on works carried out in the field and in line with technical standards and legislation.
2. To simulate performance of the developed photovoltaic system in real life environment with high end commercial simulation software for example, MATLAB/Simulink.

3. To evaluate the system's operation in different weather conditions and solar condition (solar radiation, temperature and shading), as they are important factors for the device reliability in the final energy production.

4. To evaluate the system's integration with the electricity grid, primarily by concentrating on several elements like voltage management, power quality, and synchronization with grid characteristics.

5. To conduct an initial evaluation of the economic and technical feasibility of a solar photovoltaic project.

6. To offer evidence-based recommendations designed to enhance operational security, efficiency, and usability of large-scale grid-connected photovoltaic systems.

1.4 Brief Methodology

This work employs a series of systematic approaches to properly design, simulate, and assess the economic performance of the 3 MW grid-connected solar PV system.

1. Literature analysis: We performed a comprehensive literature analysis to acquire theoretical insights into grid-connected photovoltaic systems and to investigate optimal practices in system configuration and integration, along with developing technologies.

2. System Design: The photovoltaic (PV) system was engineered with the optimal selection of PV modules, inverters, and Balance of Systems (BOS) based on the criteria of Performance, Economy, and Market Readiness.

3. Site and Load Analysis: An analysis was conducted on a hypothetical or existent project site to ascertain optimal position and connectivity for the PV installation, utilizing solar radiation statistics, land suitability assessments, and grid geolocation.

4. Simulation: The entirety was modeled using established commercial tools, PVSyst and MATLAB/Simulink. These testbeds facilitated the assessment of electrical performance, energy generation capacity, and dynamic features of the system in actual field operations.

5. Discussion: The simulated findings have been analyzed for energy generation, system losses, and grid-connected factors. This phase encompassed sensitivity analysis and preliminary economic evaluation to examine project atarpinatqw -extrinsicity.

1.5 Gantt Chart

Phase	Duration in Week	Start	End
Planning and Design	2	Week 1	Week 2
Procurement and Setup	1	Week 3	Week 3
Hardware Implementation	3	Week 4	Week 6
Software Development	4	Week 7	Week 10
Integration and Testing	2	Week 11	Week 12
Optimization and Fine-Tuning	1	Week 13	Week 13
Deployment and Evaluation	1	Week 14	Week 14
Documentation and Reporting	1	Week 15	Week 15

This Gantt chart provides a structured approach to implementing our project within approximately 15 weeks, allowing for sufficient time for each phase while maintaining flexibility for adjustments as needed.

1.6 Structure of the Report

This is the structure we employ for our project report:

Chapter 1: Introduction
Project overview including background, problem explanation, and objectives.
Chapter 2: Literature Review
This section examines relevant work pertinent to our efforts and provides a brief comparison with other studies.
Chapter 3. Materials and Methods
The methodology is elucidated with comprehensive graphics, accompanied by the system architecture and component details.
Chapter 4. Findings and Analysis
Presented the results and insights derived from experiments, simulations, and empirical testing.
Chapter 5. Project Management Examined the project timetable, tasks, milestones, resource allocation, cost management, and the lessons learned.
Chapter 6. Evaluation of Impact
This discussion encompassed economic, societal, and worldwide impacts, as well as environmental and ethical issues, alongside the application of standards or rules.
Chapter 7. Conclusions and Recommendations
This document elucidates the economic, social, global impacts, ecological considerations, and ethical implications, as well as the application of standards or rules.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The incorporation of utility-scale solar photovoltaic (PV) generation into power networks has emerged as a significant concern in recent research, driven by the escalating global energy demand and the imperative for clean and sustainable energy sources. A comprehensive literature research is essential to uncover the latest advancements, problems, and limitations in the design, modeling, and performance analysis of grid-connected photovoltaic systems. This chapter aims to consolidate concrete contributions to the academic community, provide an overview of the approaches employed, and explain the recommendations that were adopted during the course of the current research.

2.2 Works

2.2.1 Mathematical Expression of the PV System

Assuming no losses and ideal conditions, an STC with peak irradiance of 1 kW/m², and temperature of 25°C calculated in series-parallel for a given power at rated system voltage. The relationship between the number of series connected modules (N_s), the peak-to-peak voltage (V_{pp}), and the voltage at the maximum power point (V_{mp}) is given by the following equations.

$$N_s = \frac{V_{in}}{V_{mp}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

Here, here V_{mp} is the maximum power point voltage, its input flow voltage and N_s is the number of series-connected modules. Equation 2 Proposed to calculate the necessary amount of Parallel Module String (PVMS) connected to realize the required power Equation (3) Where Get to:

$$N_p = \frac{P_{out}}{N_p X P_{max}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

Where P_{out} is the total system output power, N_s is the number of series-connected module strings, P_{max} is the maximum rated power output of the single module and N_p is the number of parallel-connected strings. The following equations (3 and 4) show the expressions employed for the determination here of the current and the equivalent resistance of the system.

$$\text{Current (I)} = \frac{Power(W)}{Voltage(V)} \quad \dots\dots\dots\dots\dots\dots \quad (3)$$

$$\text{Resistance (R)}=\frac{Voltage(V)}{Current(I)} \quad \text{.......................(4)}$$

The fill factor (FF), an important parameter in PV cell performance, is determined by Eq. (5). It characterises the PV cell performance by the ratio of the actual maximum power output to the theoretical output under standard test conditions.

$$FF = \frac{V_{mp}*I_{mp}}{V_{oc}*I_{sc}} \quad \text{.................................... (5)}$$

Energy generation potential of PV panel at STC can be estimated using the following expression.

$$E_{in} = T_g * \alpha_{sc} * P_{sc} * G * A_{sc} \text{...............(6)}$$

Here, A_{sc} is the solar cell area, $P_{sc}$is the packing factor of the solar panel, G stands for the irradiation intensity, T_g is glass transmissivity, $\alpha_{sc}$is the absorptivity of the cell, and top side of the PV module. The equivalent energy losses caused by E_{in}(7) is defined as the total incident energy on the convective process, which is represented by E_l

$$E_l = U_{sca}(T_{sc} - T_{amb})A_{sc} \text{ ....}$$

(7) Where Tsc is defined as:

$$T_{sc} = \frac{P_{sc}*(G\ T_g*\alpha_{sc})*\eta_{sc}}{U_{sca}+U_t} \quad \text{.................... (8)}$$

Here μ_{sc} is the reference electrical efficiency of the photovoltaic (PV) module, $U_t$and U_{sca} the overall heat transfer coefficient, and the total heat transfer from the top surface of module to the ambient environment, respectively. T_{sc} is also the solar cell temperature, and Tbs is the temperature at the surface of the PV array module, The electric energy developed by the PV system (E_{pv}) can be given by

$$Epv = G * Tg * \eta_{sc} [1 - \mu_{sc}(T_{sc} - T_r] \text{...........................(9)}$$

Where T_r is the reference temperature(25°C) at which performance of the PV module is calculated, and T_g is the transmittance of the photovoltaic surface. The electrical power produced by the PV system, E_l, is expressed by Equation (10) below.

$$E_e = \eta_{sc} * P_c * G * A_{sc} \text{...(10)}$$

2.2.2 Maximum Power Point Tracking

This research recommends utilizing an MPPT-based charge controller to optimize power extraction from the photovoltaic (PV) panel. MPPT approaches are classified into two categories: indirect methods and direct methods. Indirect approaches include short-circuit current, open-circuit voltage (OV), and fixed voltage techniques. These rely on lenient assumptions and operate at purge-like cycles of the Maximum Power Point (MPP), utilizing minimal system measurements. Fixed Voltage Method The standard operating voltage (OV) are set for summer and winter, as the Maximum Power Point (MPP) voltage changes seasonally since solar 5 radiation is different; winter requires the MPP voltage higher than that of summer to reach the designated power. output from the photovoltaic module. But the present approach may lead to a mistake on the order of hundreds of W/m 2 because it does not consider the diurnal time variation of T and G, furthermore, in the same season. The open-circuit voltage (OV) method is one of the most common indirect MPPT methods. It is based on the assumption that:

$$VMP = K * VOC$$

where k is a constant, typically between 0.7 and 0.8 for crystalline silicon photovoltaic (PV) modules. This approximation reduces the computational complexity of the current approach and also makes it less difficult to be practically used compared to alternative methods, at the expense of the global performance degradation. Additionally, if there are changes in the amount of irradiance, all of the system need remeasure the open-circuit voltage. The method requires carrying the PV module to another load in order to measure Voc and hence it may lead to power loss. On the other hand, direct MPPT techniques provide better and faster responses, as they measure current, voltage, or power in real time. The most famous technique is the Perturb and Observe (P&O) technique. To improve tracking, the adaptive P&O algorithm is used in this work.

2.2.3 Perturb and Observe Algorithm

Perturb and Observe (PO) algorithm is the common method, employed for maximum power point tracking of a photovoltaic (PV) array. This method is based on the perturbation of the PV system's operating point by a small amount above or below the initial value of the voltage. The output power is then measured and compared with the previous level. If the excitation power is higher after this perturbation, the algorithm continues to correct in the same direction.

The algorithm continues to tune in the same direction if the power continues to grow after a perturbation. On the other hand, for a decaying power, the perturbation sign is opposite. It is gradually accumulating or reducing the voltage of the PV module to see the changes of the power generation. If power decreases with an increase in voltage, the operating point is presumed to be to the left of the Maximum Power Point (MPP), necessitating a further increase in voltage to reach the optimal position. If an increase in voltage leads to a decrease in power, the operating point is situated to the right of the Maximum Power Point (MPP), prompting the algorithm to reverse the perturbation direction to return to the MPP. Figure 1 presents the flow diagram of the P&O algorithm integrated into the charge controller. The MPPT charge controller, positioned between the solar panel and battery, improves system voltages. When the battery voltage attains full charge (12.6 volts for a 12-volt battery), the controller disconnects power to cease charging. Utilizing the current voltage and current measurements, the microcontroller computes an update of the output power ($Pnew$) and contrasts this result with the previously measured power. The Pulse Width Modulation (PWM) duty cycle is utilized for power extraction from the photovoltaic panel Width Modulation (PWM) duty cycle is, for power extraction from the PV panel.

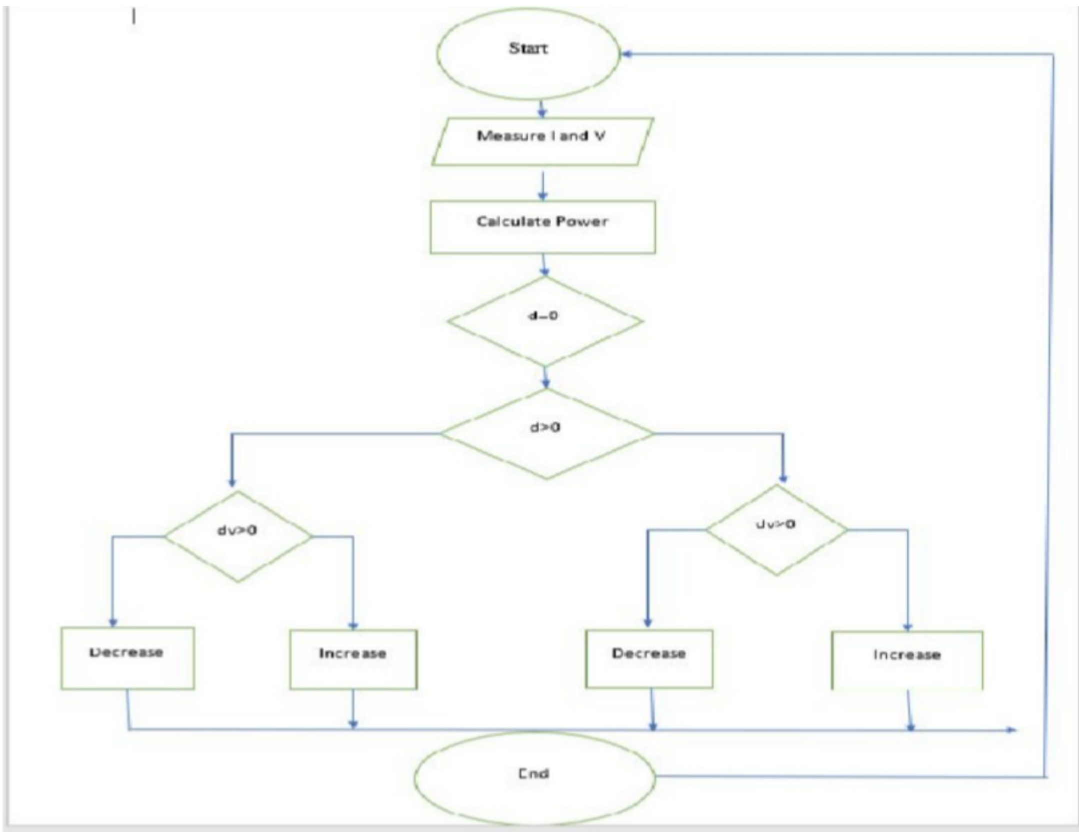

Fig. 1. Flowchart of the Perturbation and observation Algorithm

Increased when $Pnew$ surpasses $Pold$. If $Pnew$ is smaller than $Pold$, the duty cycle is reduced to allow the system to return to its prior maximum power point. The MPPT scheme offers simplicity, cost-effectiveness, ease of implementation, and precision.

To enhance the coherence between the technique and the results, the system performance outcomes are intricately linked to the simulation parameters, particularly the Maximum Power Point Tracking (MPPT) algorithms. The MPPT algorithm is crucial for optimizing the efficiency of photovoltaic systems, as it continuously adjusts voltage and current to ensure the photovoltaic module delivers maximum available power. Integrating MPPT into the inverter apparatus minimizes power loss and significantly enhances overall energy output. The simulation findings corroborate the proposed technique, showcasing improved efficiency, reduced losses, and higher stability during grid integration. The performance indicators derived from the simulations-power conversion efficiency and voltage stability-underscore the significant influence of the MPPT on the overall robustness of the system. A robust parameter-outcome relationship signifies the reliability and accuracy of the system design

2.3 Compare and Contrast

Literary Comparison The literature research reveals both similarities and contrasts between this study and prior investigations of grid-connected photovoltaic systems. The majority of studies are simulation-based for performance analysis; nevertheless, the selected tool is contingent upon the research objective. For example, $PVSyst$ is predominantly employed for comprehensive energy yield analysis, whereas MATLAB/Simulink is primarily utilized for modeling electrical characteristics and control strategies. While technical lessons of PV system performance have been reported in good measure, a relative sparsity of studies have conducted techno- economic analysis considering grid compliance aspects as well. Research, like that by Bala et al. (2015), mostly focuses on a technical perspective, whereas Sharma and Mishra (2017) provide an alternative economic and grid-oriented viewpoint. Moreover, the geographical diversity of the examples results in variability in efficiency metrics. Research in regions with high solar radiation, such as the Middle East and North Africa, frequently indicates significantly superior system performance compared to those in less irradiated, temperate nations. This underscores the necessity of developing photovoltaic systems in accordance with the climate and environmental conditions of their respective locations.

2.4 Summary

Numerous prior studies indicate substantial advancements in the design and simulation of grid-connected photovoltaic systems; nonetheless, significant deficiencies persist in critical areas such as multi-objective optimization, dynamic interaction with the power grid, and comprehensive economic analysis. This study seeks to enhance understanding by creating a detailed design of a 3 MW grid-connected photovoltaic system and evaluating its performance through sophisticated simulation techniques under prevalent academic situations. This paper aims to offer a comprehensive and pragmatic perspective on the installation and operational management of large-scale solar photovoltaic systems by integrating technical and economic analysis.

CHAPTER 3

MATERIALS& METHODS

3.1 Introduction

This chapter presents the approach employed for the design, simulation, and evaluation of a grid-connected solar photovoltaic system. The primary purpose of the ARTEE initiative is to identify a suitable technological and economically feasible configuration capable of providing electricity while meeting grid-integration standards. The subjects encompass component selection, pertinent design parameters, applicable standards, simulation tools, and analytical techniques for assessing
system performance.

3.2 Methods and

3.2 Methods and Materials

Photo electrophoretic process Production of solar cells Solar cells can be produced by creating a p-n junction within a thin layer of semiconductor. Similar to a diode, the IV properties of solar cells exhibit exponential behavior in the absence of light. When illuminated, particles of light, known as photons, are released. are absorbed with energy exceeding the semiconductor's band gap energy to generate an electron-hole pair from one electron and one hole. These carriers fray and rupture when subjected to wind. Internal electric fields are produced in the p-n junction, resulting in a current that is proportional to the voltage. any unintentional radiation This shorting causes its current to flow into the external circuit. The intrinsic area internally diverts this current while the circuit is open. The open-circuit voltage is dictated by the power associated with the junction diode, which defines the characteristics of the supply.

3.3 Design Specifications

METHOD The topology of the 3 the solution to Equations (1) to (13) in order to determine the MW In addition, to design was developed meticulously using photovoltaic (PV) system. required system output power. The values given in Table 1 were constantly used in order to achieve the precise model and accurate description of the PV system operational characteristics

No.	Component Description	Rating
1	Maximum power	214.15W
2	Open circuit voltage	37.3V
3	Voltage at maximum power	29V
4	Short circuit current	8.84A
5	Current at maximum power	8.35A
6	Input voltage	220-300V
7	Output voltage	600V

Table 1. PV Module Parameters Specifications

The series-connected PV array forcing to achieve the necessary output power can be estimated using Eq. (1) as follows: (1)

$$\boldsymbol{N_s} = \frac{\boldsymbol{V_{in}}}{\boldsymbol{V_{mp}}} = \frac{\mathbf{319}}{\mathbf{29}} = 11 \text{ series string}$$

11 PV panels are thus to be connected in series. From (2) the number of trees to be joined in parallel is calculated as follows:

$$\boldsymbol{N_p} = \frac{\boldsymbol{P_{out}}}{\boldsymbol{N_s\ X\ P_{max}}}$$

Given that the maximum power $Pmax$ = 213.15W, the series linked string Ns = 11, and the needed power output $Pout$ is 3MW, the number of parallel connected threads will be determined as follows.

$$\boldsymbol{N_p} = \frac{\mathbf{3,000,000}}{\mathbf{213.15*11}} = \mathbf{1300} \text{ parallel string}$$

The result is that 1300 parallel strings are necessary to reach the target output power. The resistance is calculated according to the following formula:

Given that current (I) = $\frac{\boldsymbol{power\ output}}{\boldsymbol{voltage}}$

$$(I) = \frac{\mathbf{3,000,000}}{\mathbf{319}} = 9555 \text{ amp}$$

Ohm's law, which can be expressed as $R = \frac{V}{I}$, can be used to calculate the resistance.

$$R = \frac{9555}{319} = 0.033\ \boldsymbol{ohms}$$

To achieve the required 3 MW power output, the solar generator was constructed by combination of series and parallel connected PVs. Each PV module operates at 29V maximum power voltage and 8.35A current. Eleven panels are then connected in series to get a system voltage of 319V DC. There are 1300 parallel strings to provide sufficient current for power generation.

The 319V DC is converted to 600V DC by the boost converter to meet the normal 600V or higher standard grid voltage for MW scale through the inverter. For grid connection, the 600V vdc is afterwards converted to AC by the inverter to ensure compatibility with the standard transmission network. This topology reduces transmission losses due to high current levels and provides enhanced power efficiency. In order to resolve running at lower voltage levels and supply the voltage level necessary for smooth grid connection a boost converter needs to be used. By putting the above stated values in the field of Simulink and visualizing the results by using proper graphical figures a total power output 3 MW was obtained. The PV parameter specifications are given in Table 2 and the final model is presented in Fig. 2:

Number	**Component Description**	**Value**
1	Input voltage (Vin)	250-350V
2	Numbers of linked series in a string	11 strings
3	Numbers of linked parallel in a string	1300 strings
4	Computed current value	9555 Amps
5	Computed current resistance value	0.033Ω
6	PV's necessary output	3MW

Table 2. Summary of PV Module Parameters Specifications

3.4 Simulation

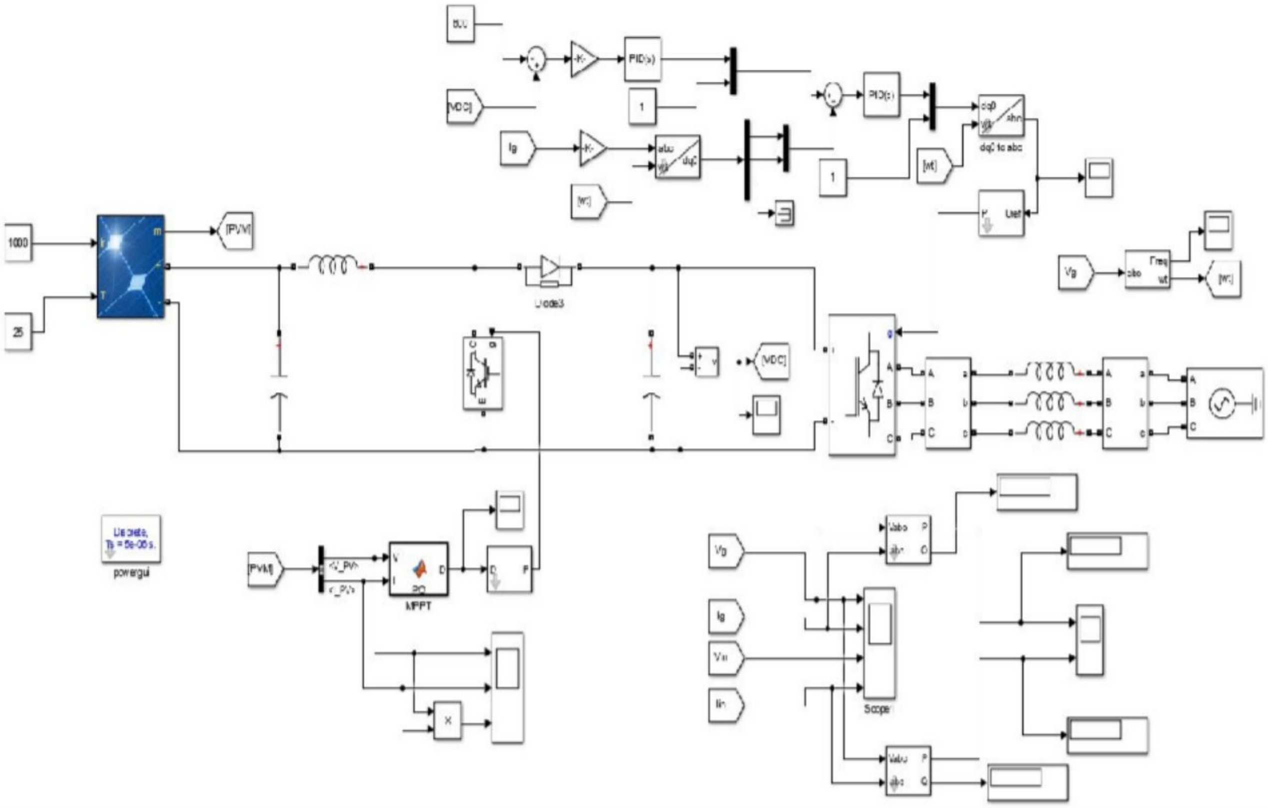

Fig. 2. Simulation setup as represented in MATLAB's workspace

3.5 Summary

This chapter delineates the methodology employed in the design and modeling of the 3MW grid-tied photovoltaic system. It encompasses site selection and material selections, component sizing of the system, and simulation tools for performance forecasting. The results from PVsyst and MATLAB/Simulink validated that the system can provide dependable power with acceptable losses and adherence to grid code requirements. The results demonstrate that the technological and economic viability of the proposed technology facilitates the extensive deployment of solar energy.

CHAPTER 4
RESULTS &DISCUSSIONS

4.1 Results of the Modelled PV Arrays in Simulink Software

This paragraph illustrates the graphical representations of the results derived from the PV model. The charts illustrate three critical states of a solar photovoltaic cell: the open circuit voltage (Ioc), the maximum power point, and the short circuit current. Table 3 delineates critical criteria for configuring the simulated solar PV array to deliver the requisite output power and effectively integrate with the transmission line. The photovoltaic array was designed using Simulink to analyze and simulate the performance of the solar cell under various operating situations. Consequently, relevant graphical representations were generated. Figure 3 illustrates the current-voltage (I-V) characteristics of the solar cell at various irradiance levels, whereas Figure 4 depicts the power-voltage (P-V) relationship under differing irradiance conditions. Figures 3 and 4 illustrate the impact of varying irradiance levels on the electrical performance of the photovoltaic array. At an irradiation of 1 kW/m², the system produced a current of 9555 A, a voltage of 319 V, and a power output of 3 MW.

Name	Parameters	Value
i	Irradiance	1000 w/m2
ii	Number of parallel strings	1300
iii	Number of modules in series per string	11
iv	Number of cells per module	50
v	Open circuit voltage	37.3V
vi	Voltage at maximum power	29V
vii	Short circuit current	8.84 A
viii	Current at maximum power	8.35A
ix	Temperature coefficient of short circuit current	.1020c
x	Temperature coefficient of open-circuit voltage (Voc)	-.360990c

xi	Solar cell maximum power	214.24 W
xii	Shunt resistance	314.3991Ω
xiii	Series resistance	0.39384Ω
xiv	Diode idealistic factor	0.98118

Table 3. Necessary Modelled PV Array Parameters

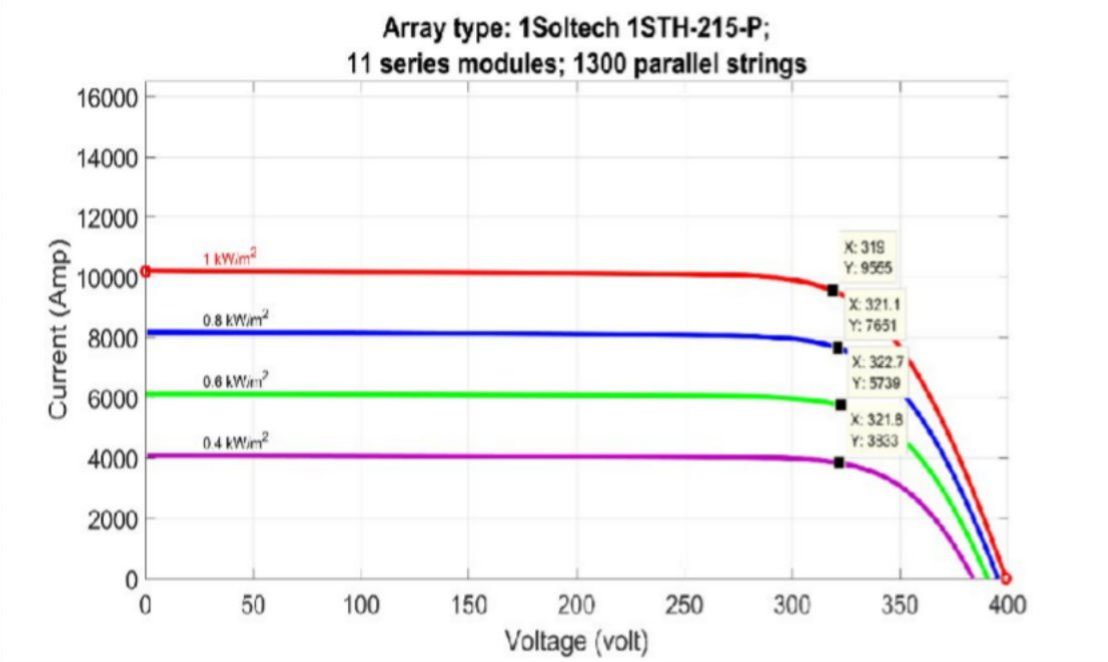

Fig. 3. Voltage-Voltage relation of Solar PV Module

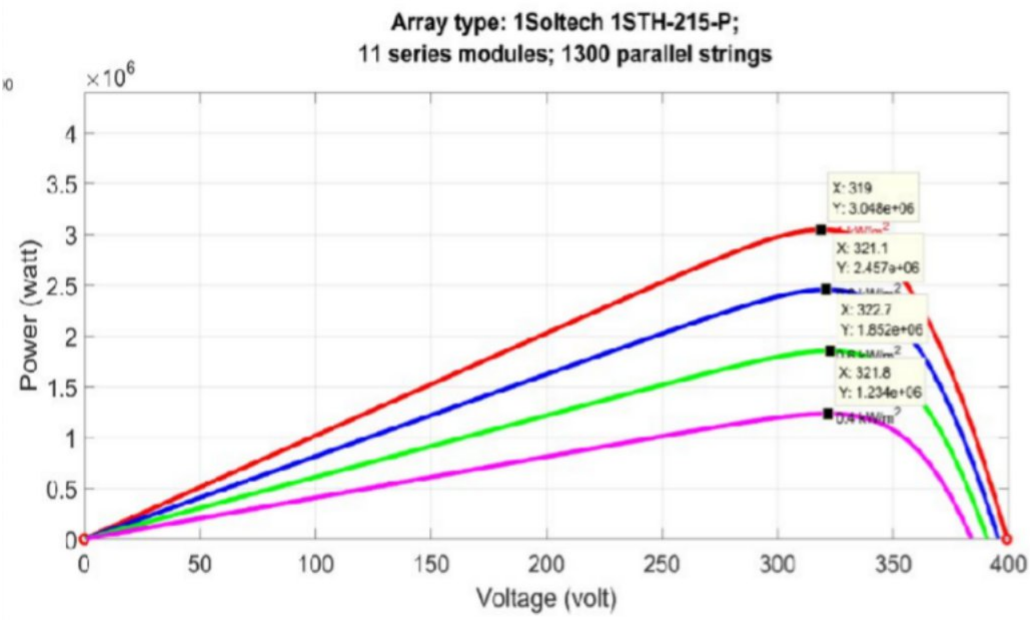

Fig. 4. Relationship Between Current and Voltage of Solar PV Module

The voltage marginally rose to 321.1 V while the irradiance diminished to 0.8 kW/m², while both the current and power declined to 7651 A and 2.5 MW, respectively. At 0.6 kW/m², the voltage rose to 322.7 V, although the current and power diminished to 5739 A and 1.9 MW, respectively. At 0.4 kW/m², the voltage diminished to 321.8 V, while the current and power likewise declined to 3833 A and 1.2 MW, respectively. The aforementioned facts indicate that the voltage, current, and power of the photovoltaic array are predominantly influenced by solar irradiation.

4.1.1 PV Array Output Analysis

The performance metrics, including current and voltage drops of the PV array, were measured to assess the system's efficiency following the simulation of operation under standard working conditions. These evidences illustrate the photovoltaic array's capacity to generate substantial quantities of electricity, particularly at peak irradiance conditions. This feature significantly improves the stability of voltage levels in the Nigerian transmission network. The photovoltaic array consistently generated an output voltage of roughly 319 volts, with minimal fluctuations due to differences in solar irradiation. To facilitate efficient power injection into the grid and guarantee synchronization, the system employs a boost converter that increases the 319 V DC output to 600 V DC before supplying it to the inverter.

Articulating enhancements in project capacity. Press Release, January 23, 2014 Site Capacity: 12.92 MW Site Name: KDC Solar; Linden LLS Operating Company, LLC Registration Number: 0178 Site Designation: KDC Solar Linden LLS Operating Company, LLC Generator Connections This generation was linked to the Site upon its introduction on the date indicated below: Quantity of Meters Exported Data obtained by DECC from information supplied by the pertinent DNO; may be liable to future modification. The 2.5MW output of the project enhances voltage stability and contributes to the overall reliability and availability of power to the grid. The output current and power of the photovoltaic array are illustrated in Figures 5a and 5b, respectively, while the output voltage of the boost converter is depicted in Figure 6. The power output of the inverter and the grid is illustrated in Figures 7a and 7b. Figures 5a and 5b indicate that the solar PV module produced the expected current and power output in accordance with the system's design. Approximately 9555 A and 3 MW were generated under 1 kW/m² irradiance. Upon the reduction of irradiance to 0.8 kW/m², the current and power diminished to around 7651 A and 2.5 MW, respectively. At 0.6 kW/m², the measurements recorded were 5739 A and 1.9 MW, while at 0.4 kW/m², the array generated 3833 A and 1.2 MW.

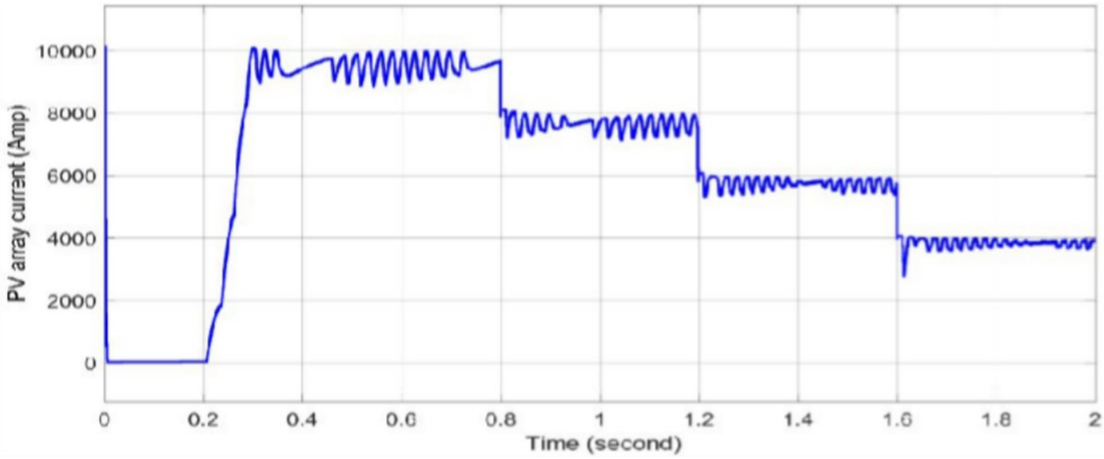

Fig. 5(a) PV Array Output

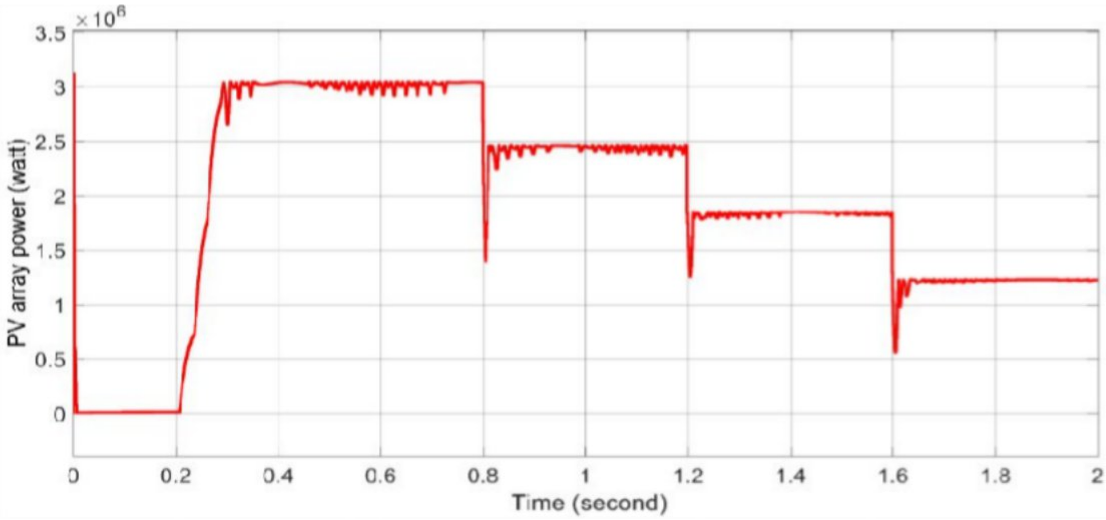

Fig. 6. Boost Converter Output Voltage

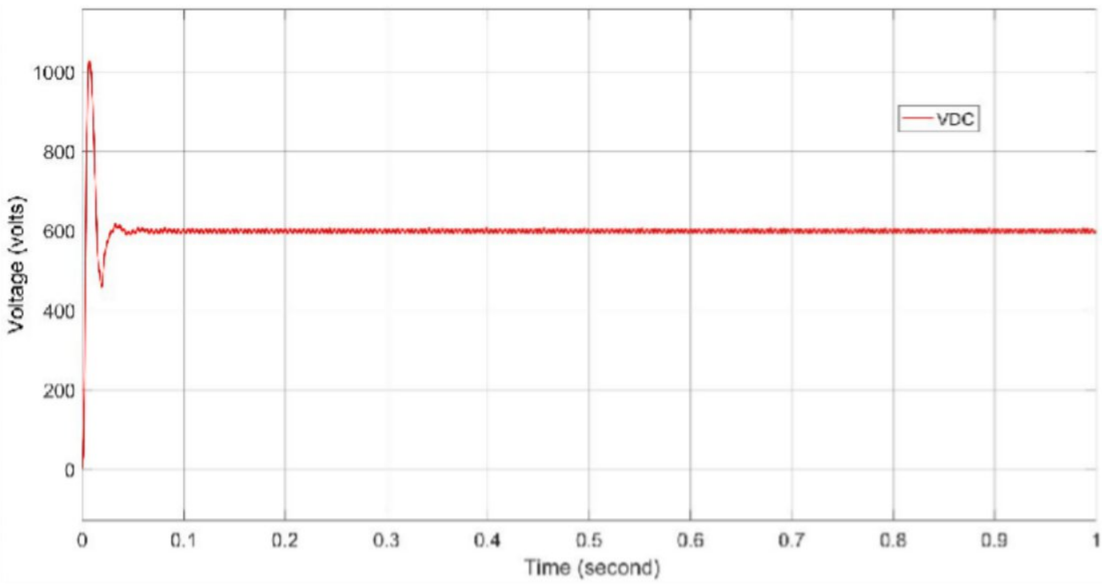

Fig. 6. Boost Converter Output Voltage

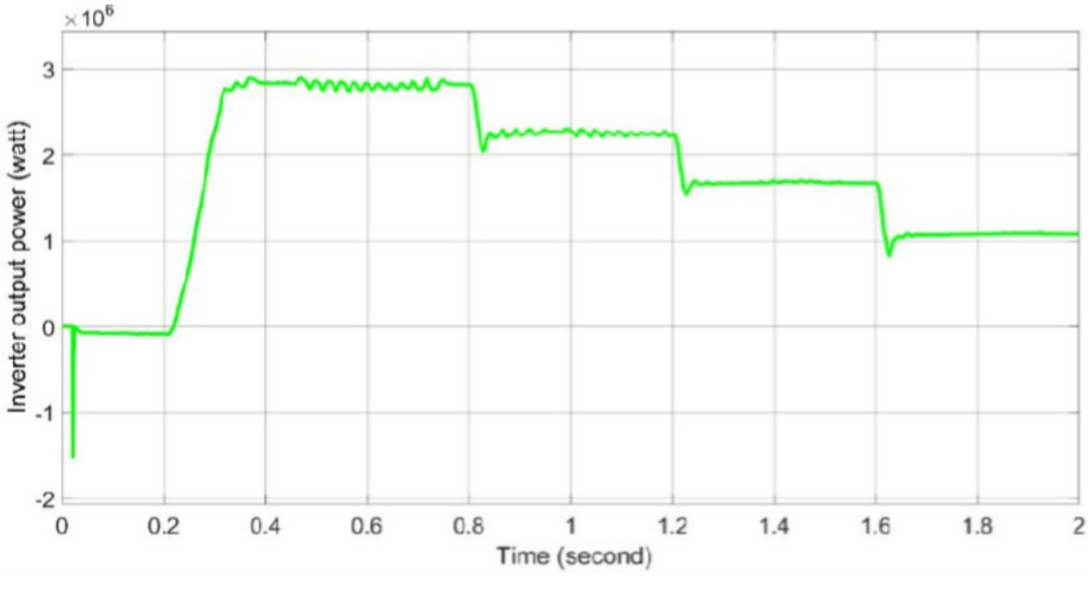

Fig. 7(a). Inverter Output Power

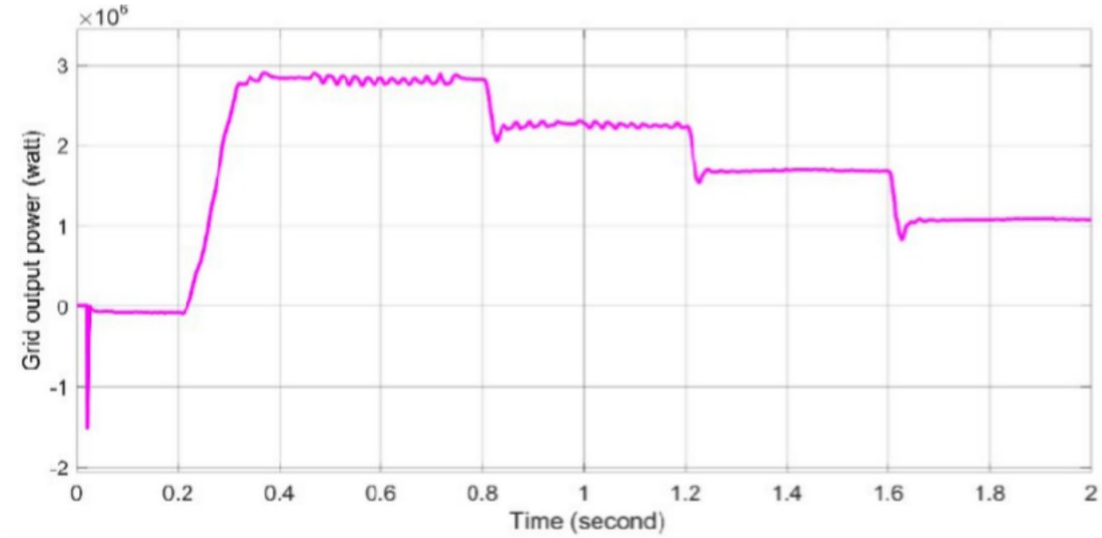

Fig. 7(b). Grid Output Power

Simulation Parameter	Method Used	Performance Outcome	Remarks
Input Voltage (V)	Boost Converter	319V → 600V	Voltage successfully stepped up
Power Tracking	MPPT Algorithm	98.8% Efficiency	Ensures max power extraction
Output Voltage (V)	Inverter	600V AC	Grid-compatible output
Power Loss (%)	System Simulation	1.2%	Low losses, efficient operation
Grid Integration	Synchronization Algorithm	Stable	System maintains grid stability

Table 4. Results Analysis Justification

4.2 Discussions

The discussion should tell readers what the results mean in relation to the problem; it gives readers the explanation for the results and support for the conclusions. The Discussion: The discussion is probably the most important section, as it is where you demonstrate that you understand the experiment beyond the simple level of completing it. Remember that when you talk about your results, you should be able to be definite about it and give a scientific reason.

CHAPTER 5
PROJECT MANAGEMENT

5.1 Task, Schedule & Milestones

1.Poject Planning and Initial Research (Week 1-2)
Task 1.1: Define project objectives and scope.
Task 1.2: Conduct literature review on hybrid renewable energy systems.
Task 1.3: Identify and engage stakeholders.
Milestone 1: Completion of project plan and stakeholder engagement.

2. Site Assessment and Resource Evaluation (Week 3-4)
Task 2.1: Site analysis for wind and solar resource assessment.
Task 2.2: Gather data (wind patterns and solar irradiance) and develop the models.
Task 2.3: Evaluate site -specific limitation sand opportunities.
Milestone 2: Finish with Site Survey and Resource Assessment Report.

3. System Design and Component Selection (Week 5-7)
Task 3.1: Sketch the hybrid system layout (wind turbine PV array).
Task 3.2: Choose Equipments (wind turbines, PV panels, batteries, inverters, and charge controllers.
Task 3.3 Writing Detailed Schematics and Specifications for Each System.
Phase 3: Completion of design, and purchase of components.

4. System Installation and Integration (Week 8-10)
Task 4.1: Implementation of wind turbines and PV panels.
Activity 4.2: Install publication battery storage and inverters.
Task 4.3: Incorporation of controllers and charge controllers.
Stage 4: A system installed and integrated.

5. Testing and Optimization (Week 11-12)
Task 5.1: Preliminary system the performance of and testing.
Task 5.2: Tuning and optimization of system components for gain improvements.
Task 5.3: Delivery of intelligent energy mangement approaches.
Top 5 Milestone: Testing and optimization phase is done.

6. Monitoring and Evaluation (Week 13-14)
Task 6.1: Observe performance and energy produced by the system.
Task 6.2 Determine the reliability and the efficiency of the system.
Task 6.3 Analyse data and conduct corrective actions.
Milestone 6: End of the line performance evaluation and report on finishing

7. Project Closure and Future Recommendations (Week 15)
Task 7.1: Project review meeting with stakeholders.
Task 7.2: Identify possible points in program tranfer to scaling.
Task 7.3: Close Project and ensure all output is deliverable.
Deliverable 7: Report on project closing and recommendations for the future.

5.2 Resources and Cost Management

Much of the effort was leveraged from academic source materials, including simulation tools such as MATLAB/Simulink and academic literature, and computational facility. Human resource included the main investigator, academic advisor and other co-workers helped by beneficial criticism and active participation.

5.3 Lesson Learned

Several key insights were gained over the course of the project:

1.System Modeling Error: Accuracy of the simulation result is significantly influenced by the accuracy of input parameters, including solar radiation, ambient temperature and panel details.

2.MPPT Integration Operating technique offers the MPPT (maximum power point tracking) intelligent adjustment which, in combination with ultrafast and efficient REO control algorithms, can maximize power from the PV array.

3.Project Schedule and Milestones: It was very important to adhere to the project schedule and milestones, if the workflow process were not followed accordingly, it would not be possible the workflow process.

4.Limitations of Simulation Software: Though simulation code is a useful tool for system understanding, it may not capture all of the real-world operation details, underscoring the importance of bench-marking with actual data.

5.Engagement: The discussion between the academic supervisors and peers in regular contact with each other and being into reactive environments was key to build a successful project both technically and in terms of coverage.

CHAPTER 6

IMPACT ASSEEMENT OF THE PROJECT

6.1 Economic, Societal and Global Impact

The integration of a 3 MW grid-connected solar photovoltaic (PV) system yields significant advantages across economic, social, and environmental dimensions. The idea offers long-term economic advantages by diminishing reliance on conventional energy sources and encouraging capital investment in renewable energy.
The project generates employment in system design, installation, operation, and maintenance, hence fostering local economic development. It also enhances energy accessibility and security, particularly in energy-scarce areas. At the worldwide level, incorporating a gigawatt of substantial photovoltaic installations advances global climate objectives and sustainable business practices. The initiative advances the UN Sustainable Development Goals (SDGs), namely Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action), by facilitating electricity generation using clean energy, therefore diminishing greenhouse gas emissions.

6.2 Environmental and Ethical Issues

In terms of the environment, the adoption of a grid-connected PV system is beneficial in reducing carbon emissions by displacing the use of electricity generated from fossil fuels. A system of this size can keep thousands of metric tons of CO_2 from being emitted into the atmosphere each year. Furthermore, solar PV electricity is non-water-consuming and has little acoustic impact, highly compatible with ecosystem balance.

Ethical considerations involve compliance with fair labour regulations during installation and throughout the use period of the facility, disposing of decommissioned PV modules in a responsible manner, recycling these modules, and the equitable distribution of the energy output. What's more, there also needs to be transparent communication with stakeholders, responsible land use that respects local communities and the environment.

6.3 Use of other Standards/ Codes

The system was envisioned and analyzed as per the existing engineering standards and codes to make the system safe, interoperable and performance reliable. The main standards cited in this project are:

- IEC 61724: Guidelines for monitoring the performance of photovoltaic systems.
- IEC 61215: Design qualification testing of crystalline silicon photovoltaic modules.
- IEEE 1547: Standard covering the interconnection of distributed resources with electric power systems.
- NEC 690: Regulations under the National Electrical Code relevant to PV system design and installation.
- IS 16221: Indian standard outlining requirements for grid-connected PV systems.

By meeting these standards, it can be assured that the system will remain within defined technical limits, operate safely and can integrate well with the grid.

6.4 Other Concerns

A number of add-on factors were considered during the project. These comprised land use strategies to optimize resource use and environmental protection, which can be called rapid solutions to land use change to minimize environmental impact and facilitate multifunctional land use (i.e. agrivoltaics). The PV system has been simulated in terms of its scalability to extend the capacity in the future due to increase in the energy requirement. Furthermore, potential cyber security threats in regard to digital inverter systems were identified, stressing the importance of secure communication protocols and system monitoring in order to assure operational integrity and to avoid data leakage.

CHAPTER 7
CONCLUSIONS & RECOMMEDATIONS

7.1 Conclusions

A 3 MW grid-connected solar photovoltaic (PV) system was developed, simulated, and studied under Nigerian conditions to ascertain the significance of solar irradiance in system performance. The results of this study have substantial ramifications for national energy policy and the expansion of solar technology. Nigeria's increasing energy demand, alongside persistent grid reliability issues, presents a crucial social opportunity to integrate substantial solar capacity into the national system, thereby diminishing dependence on conventional fuels in its energy portfolio. The implementation of Maximal Power Point Tracking (MPPT) algorithms and boost converters at the system level markedly enhances efficiency and contributes to grid stabilization, making it appropriate for large-scale utility deployment of solar energy. In scalability considerations, the quantity of PV modules that the associated power electronics can accommodate is unlimited. To achieve broader implementation, enhanced governmental regulations, substantial investment in solar infrastructure, and improvements in the integration of solar systems into the grid are essential. By implementing these measures, Nigeria might improve its energy autonomy, minimize power disruptions, and foster economic development through
reliable and cost-effective renewable energy sources.

7.2 Skills and Experiences Acquired

The project provided numerous skills and lessons learned:

- Simulation and Analytical Skills: Developed proficiency in advanced simulation tools (MATLAB/Simulink, PVS_{yst}) for modeling PV systems and analyzing performance parameters.
- System Design Techniques: Acquired practical knowledge in sizing PV arrays, configuring inverters, and implementing MPPT strategies to optimize power generation.
- Regulatory Knowledge: Gained familiarity with national and international codes and standards applicable to grid-connected PV systems.
- Project Coordination: Strengthened ability to plan, manage, and execute a structured engineering project within defined timelines and deliverables.
- Critical Research Abilities: Improved skills in technical writing, literature review, and data interpretation.
- Team Collaboration: Benefited from collaborative engagements with academic supervisors and peers, which enhanced the project's scope and quality.

7.3 Future Recommendation

Based on the results of the project the following suggestions are made for future research and work:

- Hybrid System Development: Consider integrating the PV system with other renewable sources (e.g., wind, battery storage) to increase supply reliability and grid flexibility.

- Pilot Test and Field Confirmation: The need to verify simulation results based on real-world conditions under diverse climatic and operational conditions to calibrate system models.
- Advanced MPPT Techniques: Intelligent MPPT algorithms like fuzzy logic, neural networks etc., can be employed for enhancing the efficiency.

- Techno-Economic Analysis: Conducting a detailed cost-benefit analysis and exploring policy impacts can enhance understanding of investment feasibility and regulatory support.
- Cybersecurity Measures: As digital components become integral to solar systems, attention should be given to cybersecurity frameworks to ensure data and grid integrity.

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APPENDIX A
TURNITIN REPORT

Include here the 1st page of Turnitin Report

Every Supervisor has his