Perturbation and Observation based Controller Design of Solar Energy for Remote Telecommunication Base Transceiver Stations

Diriba Ayana Biru

A Thesis Submitted to the Department of Electrical Power and Control Engineering
School of Electrical Engineering and Computing

Office of Graduate Studies
Adama Science and Technology University

June, 2024
Adama, Ethiopia

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Advisor: - Ass.Prof. Endalew. A

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DECLARATION

I now assert that the thesis named "Perturbation and Observation based Controller Design of Solar Energy for Remote Telecommunication Base Transceiver Stations" is original to me and hasn't been submitted for a similar purpose to any university. This thesis properly acknowledges its references with appropriate citations.

Diriba Ayana ______________ __________

Name of Student Signature Date

RECOMMENDATION OF ADVISOR

I, the advisor of this thesis, hereby certify that I have closely advised the student while developing this thesis and read the draft thesis entitled “Perturbation and Observation Based Controller Design of Solar Energy for Remote Telecommunication Base Transceiver Stations” prepared under my guidance by Diriba Ayana. Therefore, I recommend the submission of the thesis to the department for further review and evaluation.

_____________________   ________________   ____________

Advisor   Signature   Date

APPROVAL PAGE

I hereby certify that the recommendation and suggestion given by the thesis review committee are appropriately incorporated into the final thesis entitled “Perturbation and Observation Based Controller Design of Solar Energy for Remote Telecommunication Base Transceiver Stations” by Diriba Ayana.

Dr. Endalew Ayelew ____________ __________

Advisor Signature Date

We, the signers, members of the Board of Reviewers of the thesis open defense by Diriba Ayana have read and assessed the thesis entitled “Perturbation and Observation based Controller Design of Solar Energy for Remote Telecommunication Base Transceiver Stations” and evaluated the candidate's comprehension of the research. Consequently, this certifies that the thesis is approved and we recommend the implementation of the thesis.

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Chairperson Signature Date

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Reviewer 1 Signature Date

Dr Beteley Teka ____________ June 28, 2024

Reviewer 2 Signature Date

The thesis's final copy must be submitted to the Office of Postgraduate Studies (OPGS) via the Department Graduate Council (DGC) and School Graduate Committee (SGC) for it to be approved and accepted in whole.

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Department Head Signature Date

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LIST OF ABBREVIATIONS

AC	Alternating current
BTS	Base Transceiver Station
CO2	Carbon Dioxide
DC	Direct current
DG	Diesel Generator
DOD	Depth of Discharge
GHG	Greenhouse gases
H	Hour
RER	Renewable Energy System
HOMER	Hybrid Optimization Model for Electric Renewables
HPS	Hybrid Power System
ICT	Information and Communication Technology
KG	Kilogram
KWH	Kilowatt-hour
LPS	Loss of Power Supply
MNO	Mobile Network Operator
MPPT	Maximum Power Point Tracking
NPC	Net Present Cost
OPEX	Operational Expenditure
O&M	Operational and Maintenance
OSC	Optimal System Configuration
PV	Photovoltaic
P&O	Perturbation and Observation
RES	Renewable energy system
SMPS	Switch mode power supply
SOC	State of Charge

ABSTRACT

The objective of this thesis is to design a Perturbation and Observation based controller for solar energy for telecommunication BTS. Telecom sites get power typically from the grid and at the incidence of power outages alternative power needs to be provided for sites. Solar energy with a battery bank is a great alternative for telecom sites to fulfill power calls. This thesis discusses a smooth battery bank charging and discharging system with solar power as the supply source to give uninterrupted electricity for remote area sites and also to replace the site with a grid while needed. The necessities for telecommunication power systems are related to their care, extended lifespan, and uninterruptible power. So, solar power system optimization for power feeding of telecommunication equipment has to satisfy the same desires. The focus of this thesis is standalone solar power system requirements, optimization, practical calculation, and sizing of its major parts. This kind of system has benefits such as fuel intake and CO2 release declining and logistic costs decreasing and increasing the socio-economic growth of a country. Given the foregoing, the primary goal of this thesis is to design P & O based MPPT algorithm with proper boost converter. From the previous works on this area, there was no boost converter designed and tested on Matlab Simulink. Telecom installations should be powered by energy systems that use efficient storage batteries, such as solar photovoltaic panels. Additionally, information about the telecom industry's expansion, telecom BTS designs, the benefits of photovoltaic systems, power supply specifications, and conventional power supply options were examined. This thesis can support the development of policy mechanisms to support optimal renewable energy-based telecom site power systems, as well as the evaluation of appropriate low-carbon tools. The MATLAB/Simulink is used to model the entire system.

Keywords: - Renewable energy, PV Solar, Diesel Generator, Storage Battery, Telecom sites.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Energy needs to be created and used effectively since it is vital to the development of a community and a country(Abdulkareem et al., 2014). Energy is said to be an essential necessity for the modern lifestyle. Interest in renewable energy sources (RES) has grown due to traditional electrical energy sources' rising costs and environmental concerns(Abed et al., 2014). Therefore, technologies for producing energy from all energy sources in an environmentally friendly way should be developed. Efficient energy resource conservation should be also accorded enough significance.

Diesel generator sets are used to provide the electrical power needed for the majority of communication towers situated in rural locations. High capital expenditures are linked to the expansion of the main grid into sparsely populated areas, particularly those situated in challenging terrain. As indicated in Table 1, using a diesel-based generator results in a number of environmental problems as well as significant O&M expenses (Sami & Mahmood, 2021a).

Table 1: Comparison of RES with Diesel Generator

Item	Renewable Energy source	Diesel Generator
Cost	Low op and M cost	High Op and M cost
Pollution	Operate silently and with zero emissions	Produce carbon emissions and noise
Dependency	Depends on natural and RES	Depends on oil and fuel supply
Maintenance	Low maintenance	Costly, fuel, and oil spillage.
Life	Longer useful life	Shorter life
Power supply	Depends on the availability of RES	No guaranteed uninterrupted generation

With more and more evidence of global weather change occurring, measures must be taken to lessen greenhouse gas emissions caused by human activity. The global transition to sustainable energy must be accelerated to reach net-zero emissions as much as possible.

An integral part of the ICT sector is telecom BTS. They are the actual configuration that enables wireless communication between cell phones, internet-connected devices, and other electronic gadgets. Customers can utilize additional mobile services, make and receive calls, and access the internet thanks to telecom towers' coverage of the cellular network. By enabling quicker data transfer, they can also aid in the world's connectedness and the Internet of Things' explosive growth. The design, installed equipment, number of antennas, power output, and surrounding environment are some of the aspects that determine how much energy a telecom tower need to operate (Mohamed Omar Abdulmula et al., 2019). The average monthly energy usage of a telecom tower is in the range of several hundred to several thousand kWh.

Usually, grid electricity is used to meet these electricity needs; if this isn't available, a diesel generator which emits a lot of carbon dioxide is used (Deevela et al., 2023). This creates a good opportunity for using renewable energy-based solutions to replace conventional power supply sources. In light of this, an effort has been made in this work to develop a power supply based on renewable energy to satisfy the demand for electricity from telecom towers by identifying and evaluating:

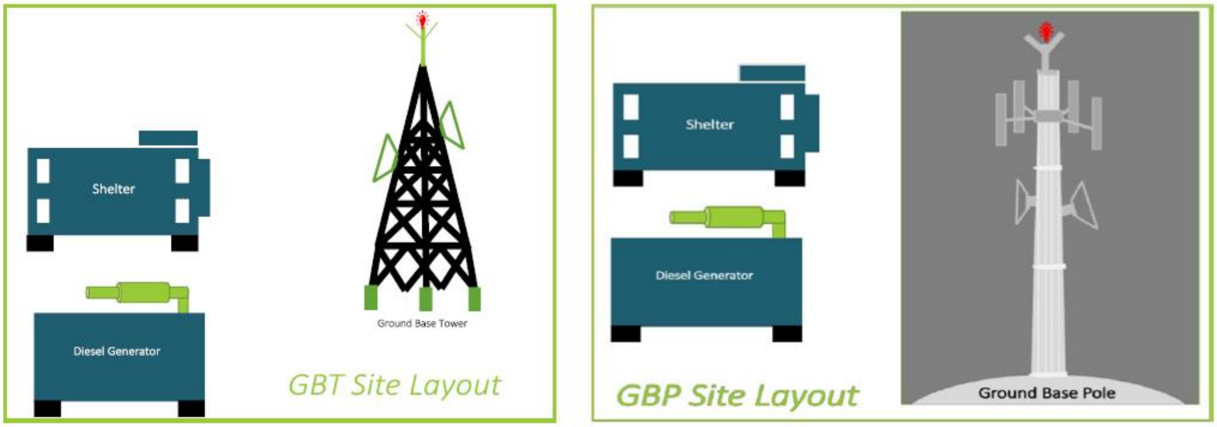
(a) Options for renewable energy-based power supply;
(b) Energy storage.
(c) Possible solar-based energy system and its advantages.

1.2 Electrical Supply System for Telecom BTS

To guarantee reliable and uninterrupted telecom services, there must be a ready and consistent supply of electricity. As was previously mentioned, the telecom industry's energy consumption is rising quickly in rural and urban areas, which is driving up energy demand and the corresponding carbon emissions. Grid electricity is frequently used to power telecom towers. All the same, fuel-powered generators like diesel generators (DGs) in particular are being used to meet demand because of the explosive growth of mobile phone services in isolated, rural areas without grid connection or in places with unstable grid supply. In addition to being carbon-intensive, electricity delivered by distributed generation systems (DGs) raises the operational costs associated with telecom towers. The primary motivation behind this is the potential to cut diesel use by shortening or stopping the DGs operational hours, which would lower carbon emissions and save operating costs. In emerging nations where the telecom industry is rapidly growing and renewable energy is plentiful, there is a great deal of opportunity for developing telecom tower power supply systems utilizing renewable energy (Amutha, M. W., Harshini, H., & Rajini, V. 2018).

1.3 Type and Configuration of Telecom sites

Numerous telecom sites, each having a unique capacity, design, and kind of equipment, are used by mobile network carriers. Furthermore, the technology used in these towers is quite adaptable. Indoor and outdoor towers are the two main types of telecom towers. As the name implies, indoor towers are erected inside buildings to serve users' telecom requirements. Whereas, Outside towers are placed in open spaces that serve a larger geographic area or on a building's top. There are numerous varieties of antenna structures used by outdoor towers. The tower and pole located on the ground schematics are shown in the figure below.



(a) (b)

Figure 1. 1 (a) Ground-based tower and (b) Ground-based pole (A1 Telekom. 2021)

1.4 Problem Statement

While it is expensive to send power from the national grid to towers that are located far from cities, the production of electricity through diesel engines is linked to degradation of the environment.Therefore, it is necessary to have: - an optimized, sustainable, suitable for the environment, cost-effective, and readily available power supply option. In order to overcome the current obstacles, a less expensive energy source must be used to power the telecommunications infrastructures that would be installed in remote locations where grid expansion is deemed unfeasible. Diesel generators offer a moderate initial investment in power generating, however there are considerable drawbacks to their utilization. First of all, it makes the system reliant on diesel, a finite and non-renewable energy source. Because traditional fuel is expensive to get and difficult to transport and store, the energy produced is costly. Telecommunication companies that rely on diesel engines must additionally deal with significant operating expenses (OPEX) due to fuel price fluctuations and the need to lubricate generator parts. Over time, the total cost of powering BTS will be decreased thanks to this renewable energy technology. to drastically reduce energy supply costs while maintaining the highest level of service quality and coverage. The PV solar power system components utilized at BTS locations need to be efficiently adjusted by using proper MPPT mechanisms like Perturbation and observation.

1.5 Research Objectives

1.5.1 Main Objective

The primary objective of this thesis is to design a Perturbation and Observation based controller of Solar energy with a storage battery for remote telecommunication BTS to replace the existing diesel generator set with an optimized standalone PV power source and battery.

1.5.2 Specific Objectives

- Assess the solar and efficient storage batteries for telecom sites.
- Study and design Perturbation and Observation based technique of MPPT for PV solar energy.
- Prepare a Mathematical model for the PV solar parameters
- Design MATLAB Simulink model of P & O MPPT technique for PV solar
- Design appropriate boost converter for PV solar output.

1.6 Limitation of the Thesis

This thesis is restricted to the specific application of powering remote telecom sites. The outcomes may offer valuable insights, the study acknowledges certain limitations, like assumptions made in the sizing of batteries and PV that holds specific loads in telecom BTS.

1.7 Significance of the Thesis

The telecoms sector can offer uninterrupted, smooth services to consumers thanks to off-grid and renewable power choices. Businesses can achieve environmental sustainability and lower CO2 emissions while simultaneously improving power quality and dependability. Telecommunications firms can lower their electricity bills and boost their earnings by utilizing off-grid options. Economical and effective Solar and storage battery resources are frequently used in conjunction with off-grid power solutions. These are made to supply renewable energy in a variety of settings, such as harsh weather and distant installations that are frequently neglected for extended periods. As the usage of renewable energy sources rises, renewable power systems not only become more economical and energy-efficient, but their installation costs also decrease. These renewable and off-grid power systems can supplement, and frequently even replace, diesel-only power supply because of their reduced cost and environmental impact.

1.8 Scope of the Thesis

The overall a standalone solar power solution optimized is purposely applicable for telecommunication BTS loads. The feasibility of this proposal includes both rural areas with poor national grid connections and applicable for urban area telecom BTS. The power model from a literature source is used to construct the micro BTS load, which is then generalized for the system under study. Based on its net present cost, the proportion of renewable energy in the electrical energy output, and carbon emissions (in kg), the best renewable power system for telecommunication BTS is investigated. Lastly, a comparison between the ideal design and the traditional diesel/battery system used in off-grid areas has been made.

1.9 Thesis Outline

The following is how the thesis is structured: There is an introduction and information about telecom towers in Chapter 1. Chapter 2 presents the load requirement of telecom and related works. The methodology and Modelling of different components in P&O-based MPPT for solar power sources for telecom loads power supply was presented in chapter 3. Perturbation and Observation based on solar power supply for telecom towers and fundamental concepts will be present in section 4. System simulation, Results, and discussion of the overall system were discussed in Chapter 5. The last section contains the Conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Electricity Requirement

Typically, active equipment in a telecom site uses about 60% of the power used, mostly for BTS. Passive device uses the leftover electricity. which includes feeder load (line losses) and radio frequency (RF) load (about 1% each), DC power systems (about 11%), cooling equipment (about 25%), and other equipment (Fudholi et al., 2018). Telecom towers, for instance, need roughly 10 kW to process receiving signals from subscribers' cell phones and produce 120W of broadcast radio signals. The graphic below illustrates the average percentage of electricity used by each telecom tower equipment (Abdulkareem et al., 2014). It is important to note that a telecom tower's active equipment configuration is determined by the volume of calls and the number of tenants.

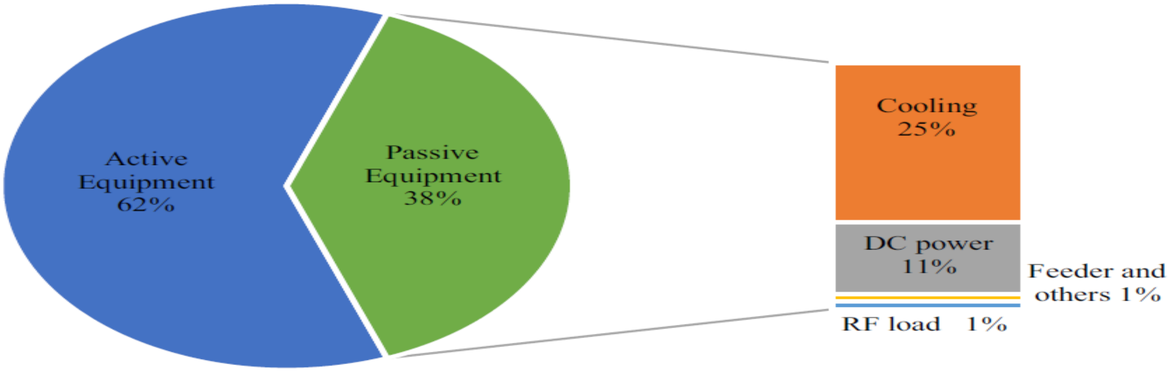


Figure 2. 1 Share of electricity consumption of telecom devices (Akuon, 2019)

A telecom tower that gets power from the grid also frequently needs an automated transfer switch, SMPS, batteries, and an inverter. Additionally, a DG is installed to guarantee telecom towers receive a constant power source. The telecom tower's BTS is connected to a DC bus and operates at 48V DC. Through controllers, the DC bus powers every piece of electronic equipment. BTS receives power from the grid or distributed generation (DG) via a DC bus bar that uses SMPS. The AC bus bar is connected to all auxiliary loads and cooling loads. An illustration of the electrical equipment's interconnection at a typical telecom tower location is shown in the following figure (A1 Telekom. 2021).

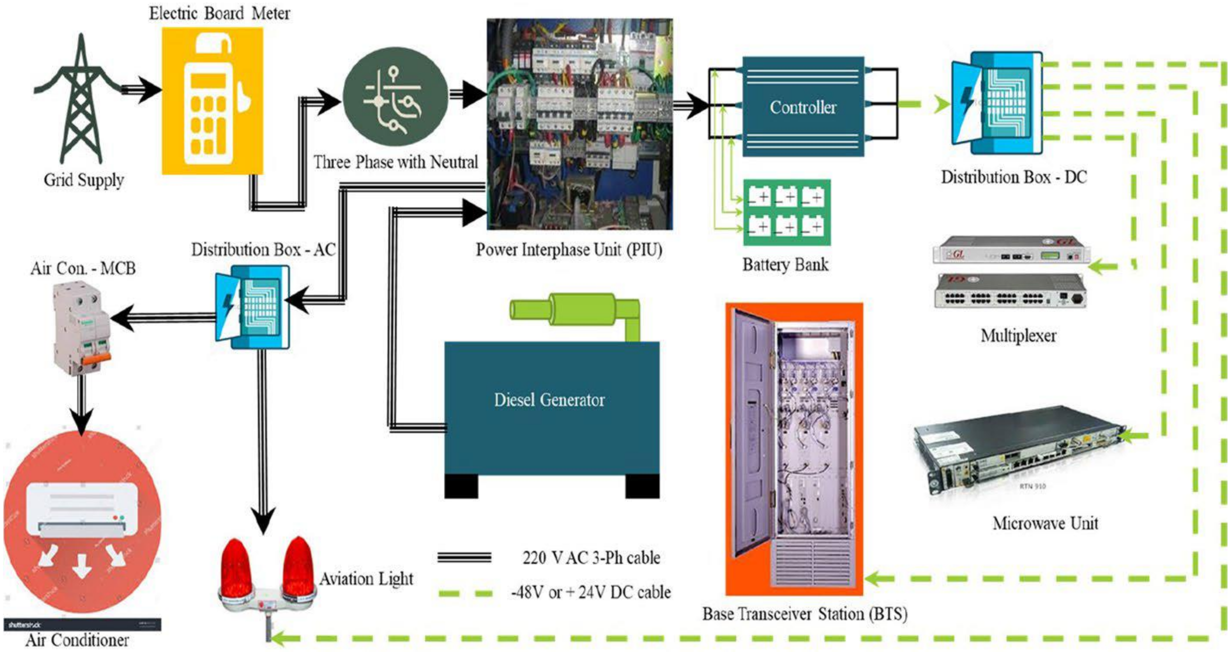


Figure 2. 2 Interconnectivity of electrical telecom equipment (Deevela et al., 2023)

When a power outage happens, Batteries are used to supply electricity to the priority loads. The loads are then transferred from the energy storage system (battery) to the DG by an automatic transfer switch. Therefore, to maintain power during grid power outages, a telecom tower's grid-based conventional power supply system often relies on a distributed generator (DG) and batteries. Both direct current (DC) and alternating current (AC) loads are utilized in telecom towers, and these are covered in detail in the paragraphs that follow (Deevela et al., 2023).

2.2 AC and DC Loads

Telecom BTS has both AC loads and DC loads. AC loads contain critical and non-critical loads. Non-critical AC loads don't need a backup power source because they are powered by the utility grid. Rectifiers and a DC bus bar are used to supply DC loads such as switching equipment, BTS, multiplexers, and other devices. A standard telecom tower that is both indoors and outside, including a 4 + 4 + 4 BTS arrangement has the load breakdown of its AC and DC equipment displayed in the following figure (AM. 2020)

A MATLAB simulation tool has been developed to evaluate different approaches of lowering the following:

- ✓ Operating cost,
- ✓ Energy consumption and
- ✓ Telecom tower carbon emissions.

Capacity of different electrical supply choices regarding telecom towers with different BTS configurations' electricity needs. These strategies include using better BTS cooling techniques, utilizing renewable energy sources like solar photovoltaic (PV), and utilizing better batteries that have a 10,000-cycle lifespan or more.

A unique BTS shelter may accommodate up to three BTS units in addition to one BTS. The BTS can be divided into 2 + 2 + 2, 4 + 4 + 4, and 6 + 6 + 6 TRX (transceiver) configurations based on the telecom tower's range, the quantity of voice calls, and data transfer at any given time.(Lecture 15: Pv System Sizing Grade: 4 Th Class, n.d.). A cell tower typically spans an area that is generally circular and may be divided into three sectors, each of which is separated by 1200, according to the arrangement (2 + 2 + 2). This suggests that there are two transceivers in each of the three sectors of the BTS. There is effectively a standby transceiver for emergencies out of the two transceivers in each sector. It is frequently necessary to cool the BTS shelters, especially for indoor systems. An energy-intensive process like this needs a lot of energy. The system's battery bank must also be kept at the ideal temperature. To prolong the life of batteries, it is customary to place the complete battery bank and BTS equipment under shelters and cool them. For instance, to maintain the battery temperature within the allowed ranges in an indoor BTS shelter for a single tenant, two 0.9-ton air conditioning units and battery chillers are needed, each of which uses between 2.2 and 4.5 kW of electricity per hour. The considerable amount of energy required for cooling telecom loads is generally attributable to the use of conventional controls and poor cooling equipment.

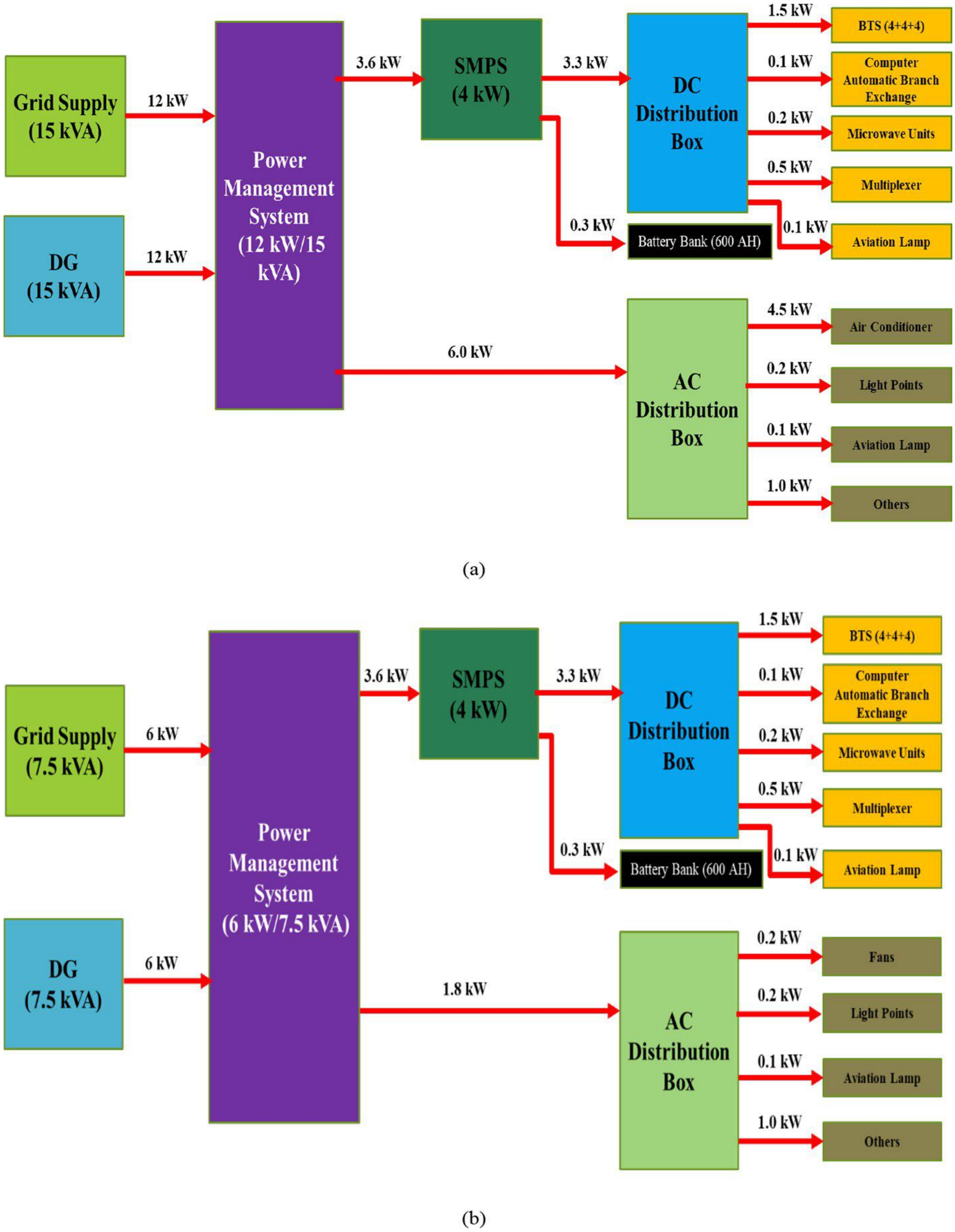


Figure 2. 3 Typical break-up of the load due to AC and DC equipment (AM. 2020)

2.3 Related Works

Numerous international studies have been carried out to investigate the use of renewable energy systems to power communication stations or microgrids. A few of these studies include:

A comparison of a solar-powered base station across several mobile communication technology generations was investigated for various system architectures (AM. 2020). Between 32% and 66% were saved in operational expenditures (OPEX) for 3G Node B 4/4/4 and 2G BS 2/2/2, respectively. The unreliability of renewable sources in general is the drawback of using solar power as a lone renewable energy source. A mixed setup is always advised because seasonal volatility is a significant problem.

(Amina, 2022), Proposed an off-grid hybrid power system for a specific remote mobile base station located in Oromia, Ethiopia. This study only used HOMER pro for modeling, simulation, and techno-economic analysis. To evaluate which hybrid configuration is closest to the optimum system, a feasibility study was done. Similar to this, in Soshanguve, Pretoria, South Africa, a feasibility study was carried out to determine whether a solar photovoltaic PV/Battery could power a particular mobile cellular BS site. The goals of this study was to guarantee the sustainability of base station (BS) power generation sources, reduce operation costs, and lessen the harmful environmental effects of carbon emissions.

(Akuon, 2019) Demonstrated how to supply telecom base stations with an independent microgrid that generates electricity from sun, wind, and PV panels and stores energy for up to 10 days of backup power in a regenerative hydrogen fuel cell. The system is designed for a 25 kW microgrid near Dakar, Senegal, and is verified with real meteorological data and MATLAB/Simulink software.

(R. Kaur, 2018) examined recently constructed telecom towers located in isolated or rural places. These towers must be ecologically sustainable due to worries about environmental issues. In order to supply telecommunication towers in remote and rural locations with reliable, economical, and eco-friendly electricity, a wind-photovoltaic (PV) based DC microgrid is recommended. Therefore, techno-economic analysis is carried out to determine the viability and cost of energy (COE) per unit of the proposed DC microgrid.

(Rahman) evaluated the possibility of using fuel cells for the cellular BTS in combination with a photovoltaic (PV) array and battery, considering the extended backup time (up to 30 hours). In order to ensure optimal BTS power management during regular and emergency situations, it is also advised to put in place a dynamic Energy Management System (EMS). With MATLAB/Simulink, the suggested system's viability is quantitatively confirmed.

(Acharya, 2013) presented the integrated solar, wind, and battery energy systems with grid integration. The system that was designed incorporates both DC and AC loads. Matlab/Simulink is used to model each component of different systems such as solar, wind, battery and converters separately.

(Alsharif, 2017) showcased the fuel cell-powered off-grid radio base stations that are fueled by locally accessible renewable energy sources. Fuel cells have been combined with an energy storage system and a photovoltaic system to create a programmable power generator. Energy storage options such as locally produced hydrogen using an electrolyzer and electrochemical batteries have also been tested.

(Avikal, 2021) built a grid-connected system utilizing wind and photovoltaic electricity. The voltage of the bus to the grid is maintained constant by a new kind of converter control that is formed when the combined solar and wind system is connected to the AC bus. The model is designed to monitor the maximum power at each location, regardless of changes in irradiance, temperature, or wind speed, all of which affect how much electricity is sent into the system.

(Anoune, 2018) recommended a few configurations for hybrid energy harvesting systems, including solar-solar storage DC power systems with cascading BOOST converters, wind-wind storage DC power systems with SEPIC and BOOST converters, wind-solar storage DC power systems with BOOST and cascading BOOST converters, and wind-solar DC power systems with SEPIC and BOOST converters. Many different kinds of systems have built-in models in Matlab/Simulink, and state-space mathematical models of integrated renewable energy systems have also been created.

(Amutha, 2015) sought to examine how different hybrid power systems performed in terms of economics, technology, and the environment when it came to powering remote telecom. HOMER program is used to simulate and determine the Initial Capital, Total Net Present Cost (TNPC), Cost of Energy (COE), and System Capacity Shortage of the different supply options. The results of the simulation suggest a feasible hybrid system that would be perfect for generating electricity for remote communication.

(Amutha, 2013) demonstrated the modeling and simulation of a hybrid power system made up of fuel cells, wind turbines, and solar cells that were created utilizing a unique topology to complement one another and lessen the effects of environmental changes. The methods for producing power using photovoltaic (PV) and wind energy, as well as the MPPT for each method. Next, a brand-new standalone wind-photovoltaic hybrid generating system is suggested for use in isolated and distant locations.

(Aris, 2015) focused on figuring out how big and how to set up a hybrid power system so that it can power distant Base Transceiver Station (BTS) locations while saving money on operational and capital costs of system components. Three different configurations of the system are assessed and compared in terms of performance, cost of energy (COE), and emissions to the environment. This analysis is done using the HOMER program.

2.4 Gaps From Different Literature Reviews

With minimal component optimization analysis, MATLAB/Simulink has been used to study the dynamic behavior of the system. The authors of related studies looked at the best ways to size different hybrid system designs to power a mobile base transceiver station. Without using any kind of simulation to examine the systems' ephemeral behavior, their research was centered on the best sizes for the different systems. An extensively explored topic in mobile base transceiver stations is the techno-economic study of alternative hybrid power system configurations in comparison to the conventional power system (diesel generator and grid). Prior research concentrated on the hybrid system's economics in comparison to the traditional system. Regarding the simulation of these systems, nothing is done.

Unfortunately, there is a dearth of literature on the dynamic simulation of many hybrid systems to power a base station site. In order to bridge this gap, this thesis would offer a comprehensive examination of P&O based MPPT technique for PV solar system that powers the outside base transceiver station site. System sizing, component analysis, simulation results, discussion, and conclusion drafting take up the remaining portion of the study..

2.5 Renewable Power Systems

Renewable energy sources (RES) include solar, wind, hydroelectric, geothermal, bio, and ocean energy. Energy sources that are not naturally renewable have other options. Compared to prior technologies, these make better use of the current energy supply even if they are classified as "alternative energy" as opposed to "renewable energy." Using alternative and renewable energy sources can help save money, preserve energy, protect the environment, and lessen reliance on foreign energy sources.

A hybrid power system combines two or more electricity-generating technologies, such as fossil fuel generators, wind turbines, photovoltaic cells, micro hydro, and/or solar panels. They can be utilized in isolated or rural locations and are often not dependent on integrated power networks. The use of renewable energy sources (RES) in hybrid power generation systems allows for cleaner electrical power production while reducing the need for costly fuels. HPS tackles limitations concerning fuel economy, flexibility, reliability, effectiveness, and economy as well as the removal of fuel transportation expenses. The schematic diagram of a basic HPS with several sources is displayed in Figure (AT & T. 2021).

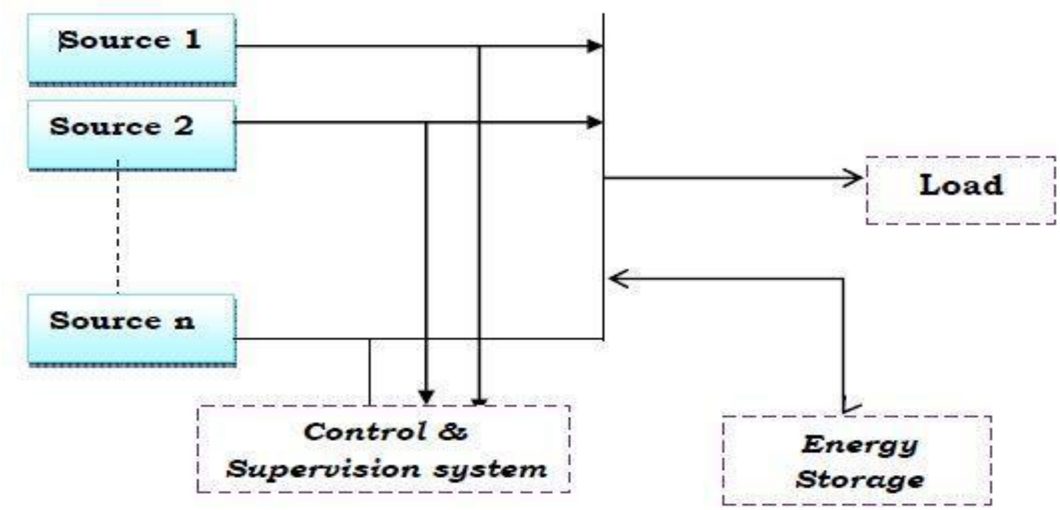


Figure 2. 4 Basic of HPS (AT & T. 2021)

Generally, a hybrid power system holds different sources, AC distribution system, DC distribution system, loads, RES, energy storage, power converters, and load management options or a supervisory control system.

CHAPTER THREE

PV SOLAR ENERGY MODELLING

3.1 Introduction

An apparatus that directly converts sunlight into energy is known as a photovoltaic (PV) cell, sometimes referred to as a solar cell. Sunlight is composed of photons, which are solar energy particles. The different wavelengths in the solar spectrum are reflected in the energy contents of these photons. The components of a PV cell are semiconductors. Photons in a photovoltaic cell have three possible outcomes: they can either absorb by the semiconductor material within the cell or reflect off of it. Only absorbed photons are required to produce energy for electricity. Because electrons migrate toward the front surface of a solar photovoltaic cell, which is negatively charged, there is an imbalance in electrical charge between the back and front surfaces of the cell. The voltage potential becomes comparable to the positive and negative terminals of a battery as a result of this imbalance. The cell's electrical conductors absorb the electrons. A battery is an example of an external load through which electricity flows when an electrical circuit's wires are connected.

The most significant energy source is photovoltaic (PV) energy since it is clean, pollution-free, and limitless. The output efficiency of PV arrays can be increased by operating PV energy conversion systems close to the maximum power point, thanks to the quick advancement of power electronics and semiconductor technologies. The weather, which includes solar radiation and air temperature, constantly affects the output power of photovoltaic arrays.

P&O, or perturbation and observation, is one of the MPPT approaches that moves the operating point closer to the maximum power point by varying the PV array voltage on a regular basis. It was observed that the P&O technique control system occasionally deviated from the maximum operating point. Once the MPP is attained, the P&O approach will oscillate around it.

3.2 Methods

In order to achieve the thesis's goals, the following methods and tactics have been used..

- ✓ Review literature related to control and optimization of renewable power solutions for telecom.
- ✓ Design of standalone solar power supply by considering modern telecom loads to get mathematical models that help me to design a controller.

- ✓ Analyze the performance of the solar power solution subjected to Telecommunication loads.
- ✓ Discussion about the results has been made, an evaluation and analysis of the performance of the proposed system were made and finally, relevant conclusions and recommendations for future work have been given.

Generally, the method followed to accomplish the goal of this thesis can be shown in the following Figure.

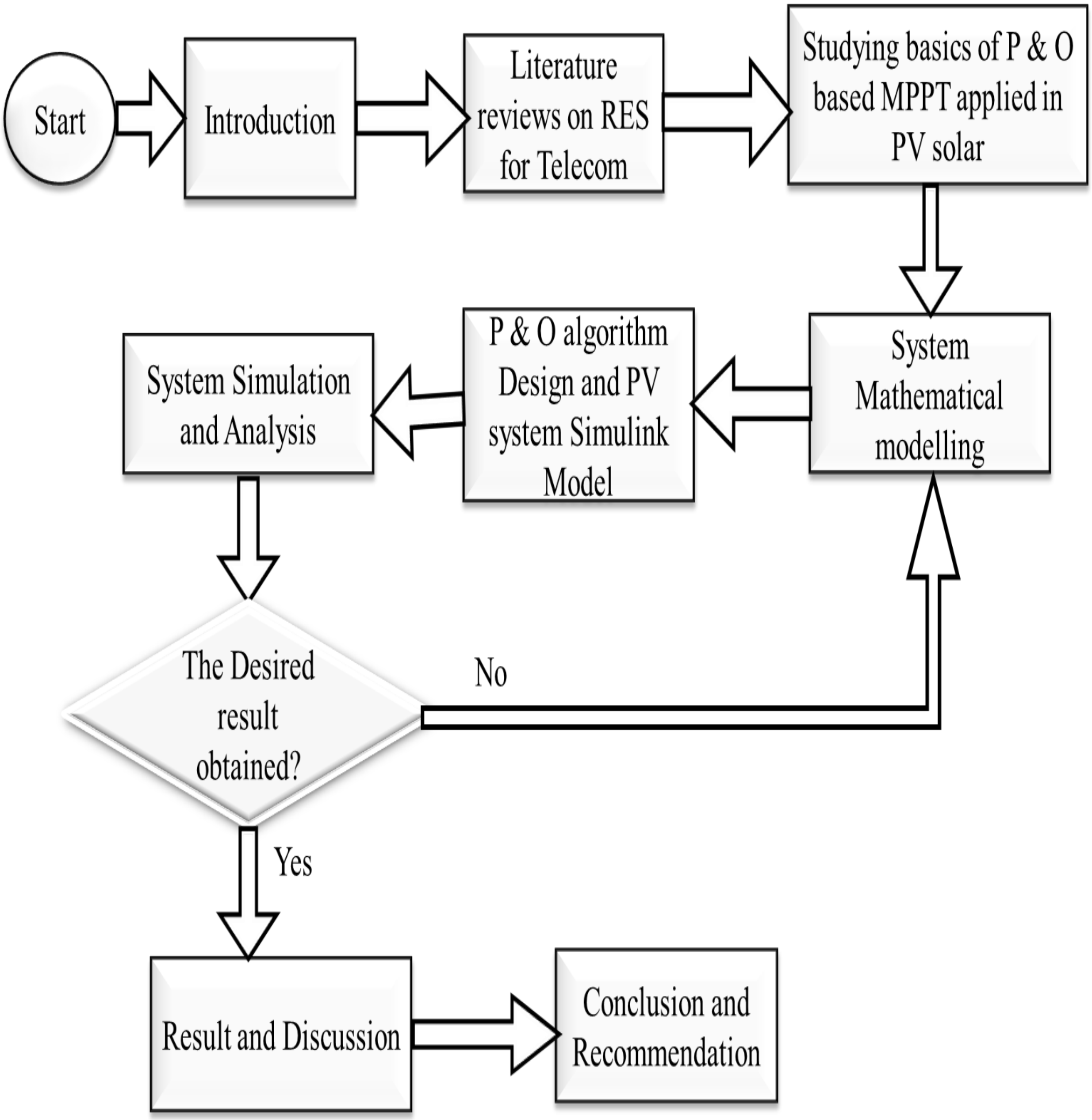


Figure 3. 1 The Overall Work Flow

3.3 Basics of Solar Energy

Sunlight can be transformed into power using a photovoltaic system. The solar system's core component is the photovoltaic cell (Deevela et al., 2023). Larger solar arrays can be produced by grouping panels or modules, which are made of cells. Generally speaking, an "array" is a group of solar panels or a photovoltaic panel made up of several cells connected in parallel or series. In this context, "array" refers to any photovoltaic system made up of many base cells. An alternate strategy for demand-side control, energy saving, and renewable green electricity is employing modern, very effective photovoltaic solar cells (PVSCs). The operating environment, solar cell quality, and array design all affect a photovoltaic system's performance. A PV array's output voltage, current, and power vary according to the amount of solar radiation it receives. (Raj & Gopinath, 2015).

3.3.1 Solar Cell I-V Characteristic

Characteristics of Solar Cells I-V curves, which show the current and voltage (I-V) characteristics of the device, give a comprehensive description of the solar energy conversion capacity and efficiency of a particular photovoltaic (PV) cell, module, or array. To determine a solar cell or panel's output performance and solar efficiency, one must comprehend its electrical I-V characteristics, in particular, its P_max. The information required to set up a solar system to run as near to its optimal peak power point (MPP) as is practicable is provided by I-V curves. (Soursos & Suuronen, 2019.)

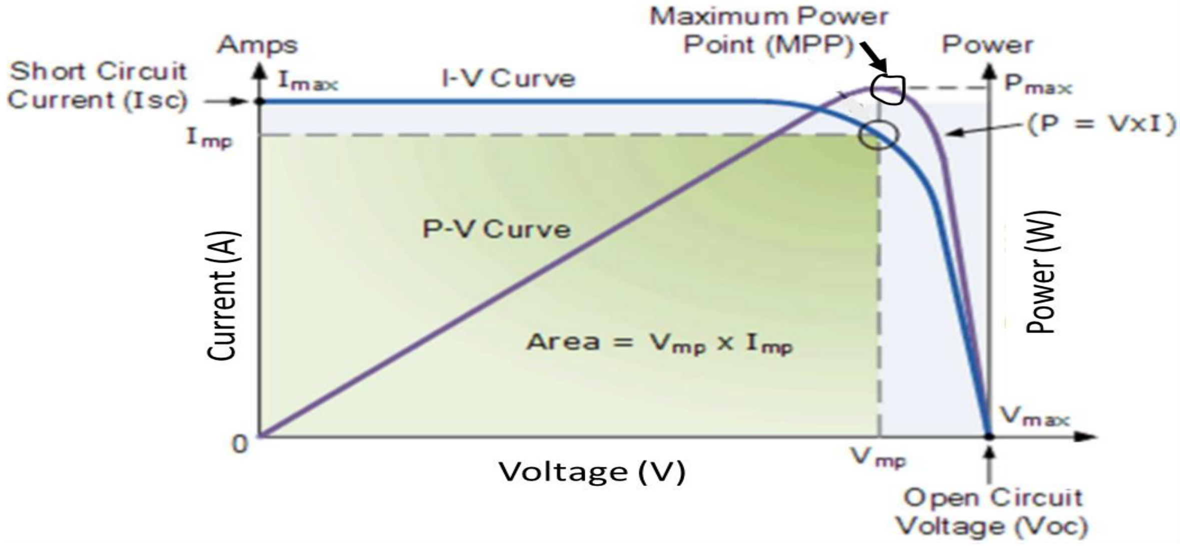


Figure 3. 2 Solar Cell I-V Characteristic Curve (Soursos & Suuronen, 2019.)

3.3.2 Solar Array Parameters

- **Open-circuit voltage**: - This is the highest voltage the array can produce in the event that there is no load connected to the terminals (an open circuit state). Compared to Vmp, which is determined by the load and is associated with the functioning of the PV array, this number is much greater. The number of PV panels linked in series determines this value.
- **Short-circuit current: -** the maximum current that the PV array can produce if a short circuit occurs between the output connectors. Compared to Imp, which stands for average working circuit current, this number is substantially larger.
- **MPP (maximum power point): -** This is related to MPP = Imp xVmp, the point at which the power supplied by the array connected to the load (batteries, inverters) reaches its maximum value. A solar array's peak power is expressed in Watts (W) or peak power (Wp).
- **Fill factor: -** Indicates the maximum power that the array can actually supply under normal working conditions, is calculated by multiplying the open-circuit voltage by the short-circuit current (Voc x Isc). The array's quality can be inferred from the fill factor value; the closer the fill factor is to unity the better the more power the array can offer. Values typically range from 0.7 to 0.8.
- **Percent of efficiency: -** The ratio of a photovoltaic array's maximum power production to the amount of solar radiation that reaches the array is known as the array's efficiency. The efficiency of a solar array typically falls between 65 and 85%, contingent upon the type of cells employed (Fudholi et al., 2018).

3.4 Mathematical Modeling of PV Solar System Components

3.4.1 Mathematical modelling of PV System

We begin by modeling a PV elementary cell, which is a basic model, to create a PV panel. It is made up of a parallel resistance and a variable source of current that is coupled in parallel with a diode that represents the junction of semiconductors that make up the solar cell. An additional resistance is connected in series with this assembly. The PVG model derived from this schema is represented by the subsequent formulas. (Fudholi et al., 2018).

$$I = (I_{PVn} + K_i * \Delta T) * \frac{S}{S_n} - [e^{(\frac{q*(V+R_s*I)}{a*N_s*K*T})} - 1] - \frac{V + R_s * I}{R_p} \tag{3.1}$$

$$I_o = \frac{I_{sc,n} + K_i * \Delta T}{e^{(\frac{V_{oc,n}+K_v*\Delta T}{a*V_t})}} \qquad (3.2)$$

Where:-

a: Ideality factor of the solar cell.

$\Delta T = T - T_n$ (Kelvin),

T: Actual cell temperature

T_n : The cells' nominal temperature in the STC is 1000 W/m^2, or 25˚C.

S : Actual irradiation level (W/m^2).

S_n : Standard Test Conditions Nominal Irradiation (W/m^2).

I_o : Reverse saturation current(A) of a diode.

$I_{PV.n}$: Current measured using conventional test parameters (A).

V, I: PVG voltage (V) and current (A).

$I_{sc,n}$ And $V_{oc,n}$: Measured under standard test conditions are the open circuit voltage and short circuit current.

$V_t = \frac{N_s*K*T}{q}$: Temperature differential.

N_s : The quantity of cells connected in series.

K : Boltzmann constant ($1.38x10^{-23}$ J/K).

K_v : open circuit voltage's temperature coefficient is 80 ± 10 mV/˚C.

K_i : The short circuit current's temperature coefficient (=0.065 ± 0.015) %/˚C.

q : Electron charge ($1.6x10^{-19}C$).

R_s, R_p : Resistance in series and parallel respectively.

The PV module's maximum power determines its performance and operation. So, for the purpose of assessing PV systems, data that describes the maximum power output behavior of the PV module is more valuable. The ambient temperature, the amount of solar radiation present on the designated surface, and the PV modules' manufacturer's data will all be used to determine the output power (PPV) of the SPV (Sami & Mahmood, 2021b).

$$P_{PV} = \eta_g * N * A_m * G_t \qquad (3.3)$$

Where η_g is instantaneous PV efficiency.

A_m Is a single module area in m^2.

G_t Is global irradiance incident on the tilted plane (KW/m^2).

N is the number of modules.

Assuming that there are no energy losses at all in the PV array (wiring and connection loss). This is how the instantaneous PV efficiency is determined as:-

$$\eta_g = \eta_r * \eta_{pt} * [1 - B_t * (T_c - T_r)] \qquad (3.4)$$

Where η_r is PV reference efficiency.

η_{pt} is the effectiveness of power tracking equipment

T_r is the reference temperature of a PV cell.

T_c is the PV cell's temperature

B_t is Efficiency temperature coefficient for silicon cells, which varies from 0.004 to 0.006 per °C.

3.4.2 Mathematical model of the solar charge controller

A charge controller for solar panels regulates the quantity of electricity that comes from PV modules into the batteries, senses when the batteries are fully charged, and guards against overcharging during a battery bank's discharge. (Deevela et al., 2023). The charger regulator rating is displayed below:

$$Q_{pv} = I_{sc} * N_p * 1.3 \qquad (3.5)$$

Where:- the oversizing factor for charge controllers is 1.3., I_{sc} total number of panels linked in parallel, as well as the PV array's total short circuit current. Equation 3.6 computes the charge controller's energy.

$$E_{cc\_out}(t) = E_{cc\_in}(t) * \eta_{cc} \qquad (3.6)$$

Where $E_{cc\_out}(t)$ is the charge regulator's energy output, $E_{cc\_in}(t)$ is the regulator's input energy measured in KWH and η_{cc} is charge regulator efficiency.

3.4.3 Mathematical Model of Battery

When charging, the battery functions as a load, and when discharging it functions as an energy supply. The battery's net capacity, expressed in Ah/day, needs to be:-

$$B_{cn} = \frac{E_{tot}}{V_{nom\_batt}} \tag{3.7}$$

Where B_{cn} the net capacity of the battery is, E_{tot} is total energy, and V_{nom_batt} is nominal battery voltage.

The following formula can be used to determine how many batteries must be linked in parallel in order for the system to have the necessary capacity:

$$B_s = \frac{V_{n\_batt}}{V_{batt}} \tag{3.8}$$

Where:- B_s is the nominal battery voltage and V_{n_batt} is the number of series-connected cells in the batteries, and is the battery voltage. When the total generation output energy exceeds the load demand during the charging process, the available battery bank capacity at time (t) can be found using Equation 3.9.

$$E_{batt}(t) = E_{batt}(t-1) - E_{cc\_out}(t) * \eta_{charge} \tag{3.9}$$

Where, $E_{batt}(t)$ is battery stored energy at hour t, kWh, $E_{batt}(t-1)$ is energy stored in a battery at hour t-1, kWh, and η_{charge} is battery charging efficiency.

Conversely, the battery bank is depleted when the load demand exceeds the energy generated thus far. Consequently, the battery bank capacity that is available at time (t) can be written as

$$E_{batt}(t) = E_{batt}(t-1) - E_{needed}(t) \tag{3.10}$$

Where, $E_{needed}(t)$ is the energy required at a specific time or the hourly load demand. Let d be the proportion the maximum state of charge voltage across the battery terminals at full charge to the minimum permitted state of charge (SoC) voltage limit. The Depth of Discharge (DoD) is:-

$$DoD = (1 - d) \times 100 \tag{3.11}$$

DoD is a metric that represents the amount of energy removed from a storage device as a percentage of its total capacity. The minimum SoC is established by the maximum DoD, and the highest value of SoC is 1.

$$SoC_{\min} = 1 - \frac{DoD}{100} \tag{3.12}$$

3.5 Perturbation and Observation Technique for PV Solar MPPT

MPPT often makes use of P&O algorithms due to their simple structure and low requirement for measurable parameters (Ch et al. 2021.). Important elements of this method include varying the voltage of the PV array on a regular basis and comparing the PV output power to the previous perturbation cycle. The perturbation will continue in the same direction during the next cycle if the power is growing; otherwise, it will change direction.. In other words, when the P&O algorithm reaches its goal, it bounces around the P&O because each MPPT cycle adjusts the array terminal voltage. PV power may be lost as a result of this, particularly in situations where the air conditions are steady or shift gradually (Soursos & Suuronen, 2018). Enhancing the P&O algorithm's logic to compare the parameters of two previous cycles can help alleviate this issue by determining when P&O is attained and avoiding the perturbation step.

Perturbation and Observation (P&O) may follow the Maximum Power Point (MPP) continuously by analyzing actual PV voltage and current values, independent of external factors, PV panel type, or even age. Larger PV arrays are typically used with on-line MPPTs since the necessary circuitry is more expensive. The P&O method's simplicity and ease of implementation make it a popular choice for PV systems. Its shortcomings include poor response times, steady-state oscillation about the MPP, and even incorrect tracking in situations where the atmospheric conditions are quickly changing. If the computation is done quickly, the aforementioned P&O method limitations can be solved. Typically, they are predicated on the comparison (Salman et al., 2018). Future research will focus on the a newly developed P&O algorithm that lessens the primary problems associated with the P&O Method.

3.6 System operation and configuration

The system includes a solar system that powers to charge the battery and also hold other loads. It is connected to battery storage using a DC-Bus. For providing electrical equipment in telecom, this signal specification is ideal. Thus, this system is being built in MATLAB, and a discrete simulation using Powergui is being run. Photovoltaic cells are connected in series and parallel to create the solar PV module. They are utilized as a storage system when there is no sunlight, such as at night or in low solar radiation, by being connected to a backup battery. (Ch et al. 2021).

It has been decided to employ a MOSFET switch, which is a device that changes the properties of an electrical path to either block or generate one. It is used to allow power to flow in the ON condition and to halt power flow by applying its voltage to a semiconductor component.

The gates to turn on and off with the required quantity of power are depicted in the following figure. This can be achieved by the parallel inductive (L) and capacitive (C) compilation. To obtain the necessary filtering of a pure sinusoidal signal of the current-voltage and current-voltage, try various values for L and C. This filter is also referred to as a low pass filter or an LC filter. Nevertheless, the capacitance value of this system is 0.0013f, while the inductor value is 1.3mH.

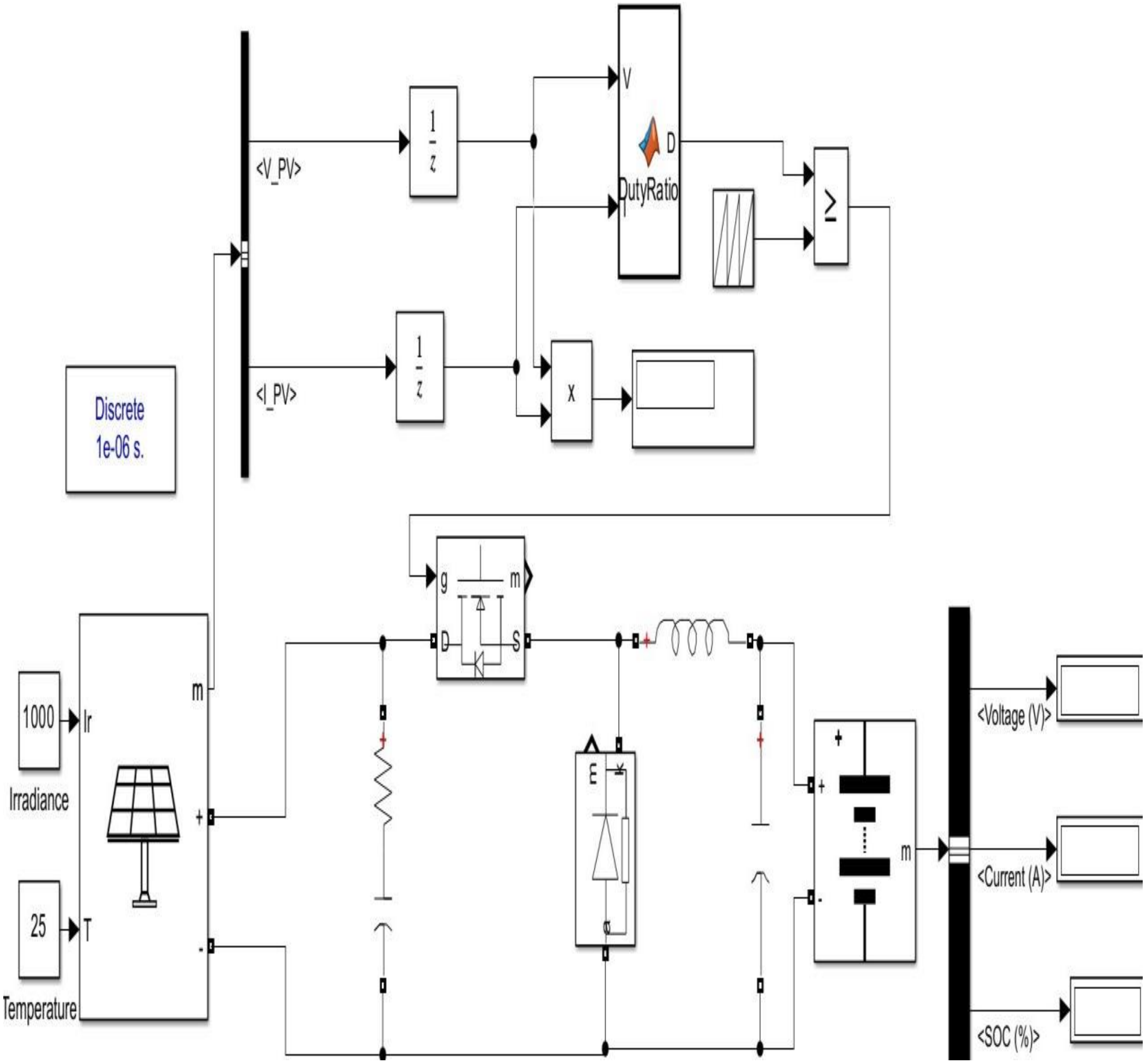


Figure 3. 3 Battery with boost Converter

3.7 The designed solar energy and parameters specification

Before designing the boost converter, let's determine the input and output voltage requirements, as well as the expected load current. In this case, the input voltage ranges from 174V to 190V from the solar panel, and the output voltage is 200V DC and above which is used for powering telecom the main bus bar. Designing an off-grid solar power solution for a telecom base transceiver station (BTS) involves a more specialized approach due to the continuous power demand and critical nature of telecom infrastructure.

Table 3.1 DATASHEET OF KYOCERA KC200GT MODULE (Salman et al., 2018)

I_{mp}	7.61 A
V_{mp}	26.3 V
P_{max}	200.143 W
I_{sc}	8.21 A
V_{oc}	32.9 V
K_v	-0.1230 V/K
K_i	0.0032 A/K
Power Factor	0.98

Determine Load Requirements: Calculate the total power consumption of the BTS equipment, including transceivers, routers, UBT, RRH, and cooling systems. This should be in terms of watts (W) or kilowatts (kW). In this thesis I have chosen total power from solar energy to be designed as 15KW, every time it feeds 6KW for the system and it is required to charge batteries of 48V capacity with 1000AH for 6 hours per day. So, the system consumes an average of 144KWH /day and 48KW/day will used to charge batteries. Total power Consumption per day is 192KWH/day.

All the main components have been addressed in detail with the related functions and equations. The designed solar energy in this thesis contains the following basic components:-

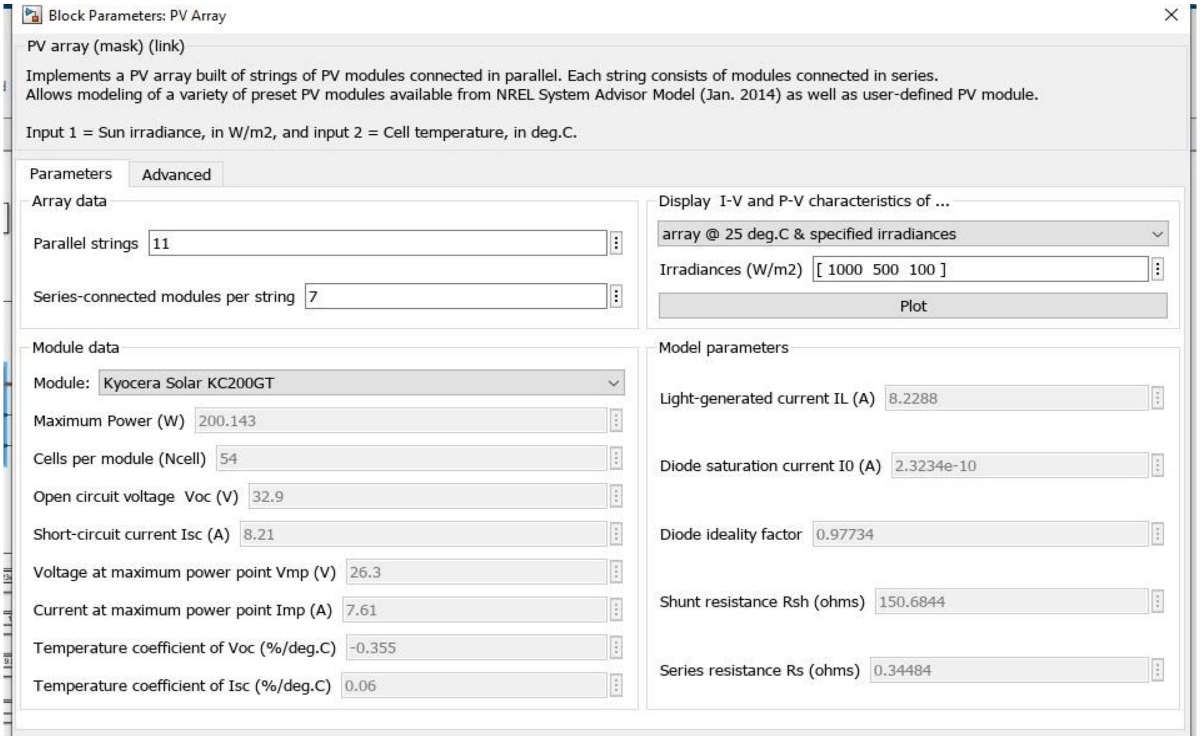
Number of Series (Ns) and number of Parallel (Np) panels are calculated as shown below. We have input Voltage from solar (Vsolar) as 174V. From the DATASHEET OF KYOCERA KC200GT MODULE, we have an open circuit voltage (Voc) of 26.3V (Ch et al., 2021). Since the pf of the selected solar panel is 0.98, the apparent power possible to be generated from this PV system is 15.306KVA. So, the reactive power is 0.306KVAR.

Series panels Ns:-

$$\begin{aligned} N_s &= \frac{V_{Solar}}{V_{oc}} \\ &= \frac{174}{26.3} = 6.6 \approx 7 Panels \end{aligned} \tag{3.12}$$

Parallel panels Np:-

$$\begin{aligned} N_p &= \frac{P_{Solar}}{N_s * P_{rate}} \\ &= \frac{15000}{7 * 200} = 10.6 \approx 11 Panels \end{aligned} \tag{3.13}$$



Block Parameters: PV Array

PV array (mask) (link)

Implements a PV array built of strings of PV modules connected in parallel. Each string consists of modules connected in series.
Allows modeling of a variety of preset PV modules available from NREL System Advisor Model (Jan. 2014) as well as user-defined PV module.

Input 1 = Sun irradiance, in W/m2, and input 2 = Cell temperature, in deg.C.

Array data

Parallel strings: 11

Series-connected modules per string: 7

Display I-V and P-V characteristics of ...: array @ 25 deg.C & specified irradiances

Irradiances (W/m2): [1000 500 100]

Module data

Module: Kyocera Solar KC200GT

Maximum Power (W): 200.143

Cells per module (Ncell): 54

Open circuit voltage Voc (V): 32.9

Short-circuit current Isc (A): 8.21

Voltage at maximum power point Vmp (V): 26.3

Current at maximum power point Imp (A): 7.61

Temperature coefficient of Voc (%/deg.C): -0.355

Temperature coefficient of Isc (%/deg.C): 0.06

Model parameters

Light-generated current IL (A): 8.2288

Diode saturation current I0 (A): 2.3234e-10

Diode ideality factor: 0.97734

Shunt resistance Rsh (ohms): 150.6844

Series resistance Rs (ohms): 0.34484

Figure 3. 4 Specification of the PV solar designed

3.8 Design of Boost Converter

Before designing the boost converter, determine the voltage of the input and output requirements, as well as the expected load current. In this case, 174V is the input voltage the voltage generated from the solar panel, and the output voltage is 200V DC. Key components needed to be selected for the boost converter:

Input current or output current from solar panel

$$I_{PV} = N_p * I_{mp}$$
$$= 11 * 7.61 = 83.71A \tag{3.14}$$

Where,

I_{mp} is current at maximum power point of single cell

Current ripple = 20% of Ipv = 83.71*0.2A = 16.6A

Output Current or Load Current

$$I_{output} = P_{output} / V_{outpout}$$
$$= 15000W / 200V = 75A \tag{3.15}$$

Duty cycle

$$D = 1 - V_{in} / V_{out}$$
$$= 1 - (174/200) = 13\% \tag{3.16}$$

Inductor (L): Determines the energy storage capability of the converter.

$$L = \frac{(V_{in} * D)}{f * \Delta I_L}$$
$$= \frac{(174 * 0.13)}{10000 * 16.6} = 0.13626mH \tag{3.17}$$

Where,

- V_{in} = Input voltage from the solar panel (174V)
- V_{out} = Output voltage (200V).
- D = Duty cycle (13%).
- f = Switching frequency which is 10 kHz.

ΔI_L = Ripple current in the inductor (usually 20_30 %) of the solar current.

Ripple voltage = 1% of Vout = 0.01*200V=2V**.**

Capacitor (C): Smooths the output voltage.

$$C = \frac{D * V_{out}}{f * R * \Delta V_c}$$
$$= \frac{0.13*200}{10000*2*2.74} = 0.65mF \tag{3.18}$$

Load resistance

$$R_L = \frac{P_{out}}{pf * (I_{out})^2}$$

$$= \frac{15000}{0.98*(73)2} = 2.87\Omega \qquad \textbf{(3.19)}$$

Load inductance: The load in telecom BTS (Base Transceiver Stations) is typically inductive. The inductance of an inductive load can be determined from the reactive power (Q) and switching frequency (Fs). So, the inductor can be calculated by using:

$$L_{out} = \frac{Q}{2 * \pi * f * (I_{out})^2}$$

$$= \frac{306}{2*3.14*10000*(73)2} = 0.9144\mu H \qquad \textbf{(3.20)}$$

The main components that contribute to the inductive load in a BTS include:

Power amplifiers: The power amplifiers used to transmit the radio frequency (RF) signals to the antennas have an inductive component due to the inductors and transformers in their circuits.

Radio frequency (RF) filters: The filters used to condition the RF signals before transmission also have an inductive component.

Cooling fans: Any motors or inductive loads used for cooling the BTS equipment also contribute to the overall inductive load. The inductive nature of the BTS load is important for the power distribution within the BTS system. Power factor of PV solar.

Transistor (MOSFET): Controls the current flow.

Diode (D): Freewheeling diode to allow current flow during the off state of the transistor.

Control IC or Controller: Provides control and regulation of the boost converter. These components are integrated to form one smart solar power solution for telecom loads as shown in the following figure

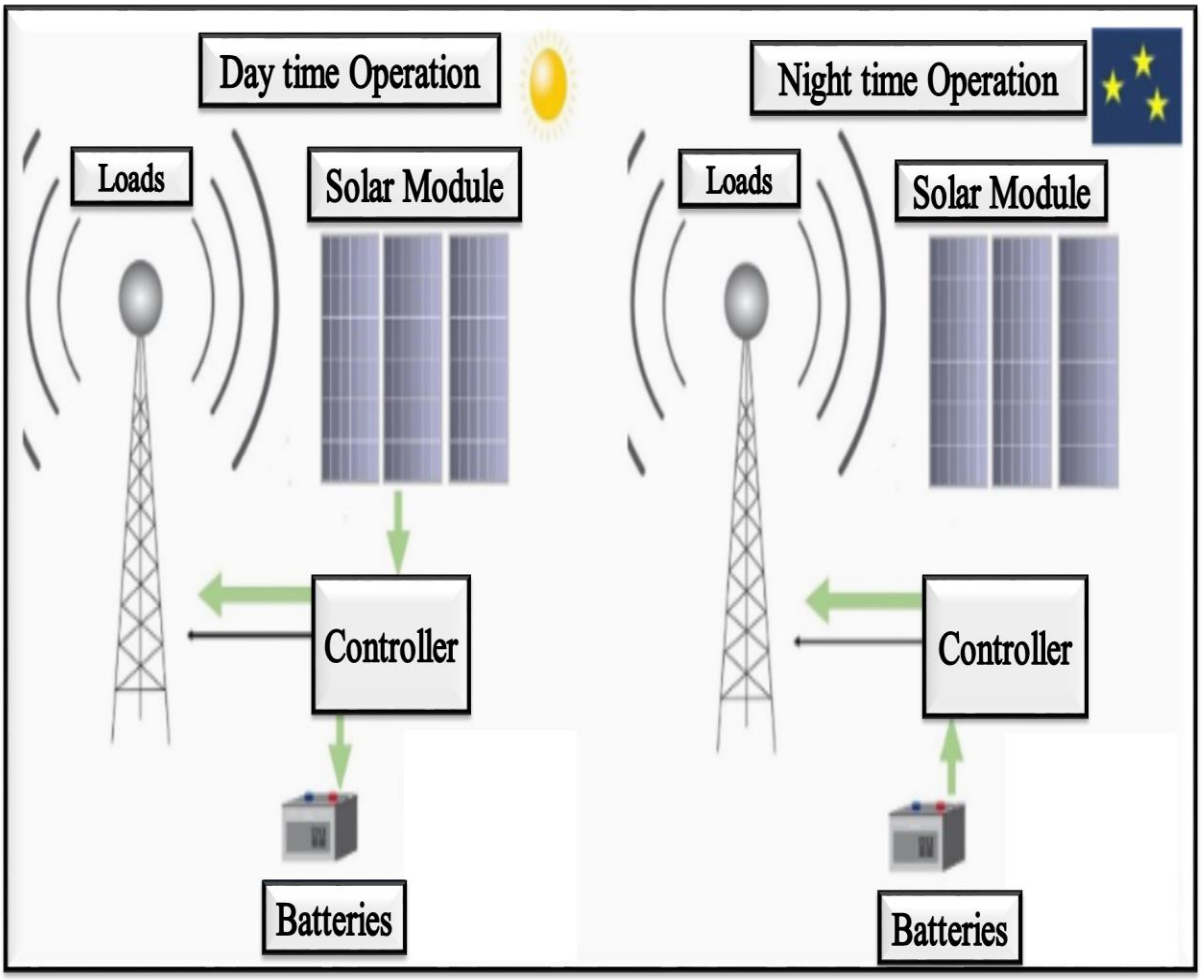


Figure 3. 5 Operations Off-Grid Solar-Powered Telecom System (Ch et al., 2021)

The full picture of the solar energy system will be modeled with all components to harvest energy to support the overall loads and BTS. The following figure shows the model of solar power solutions for telecom loads.

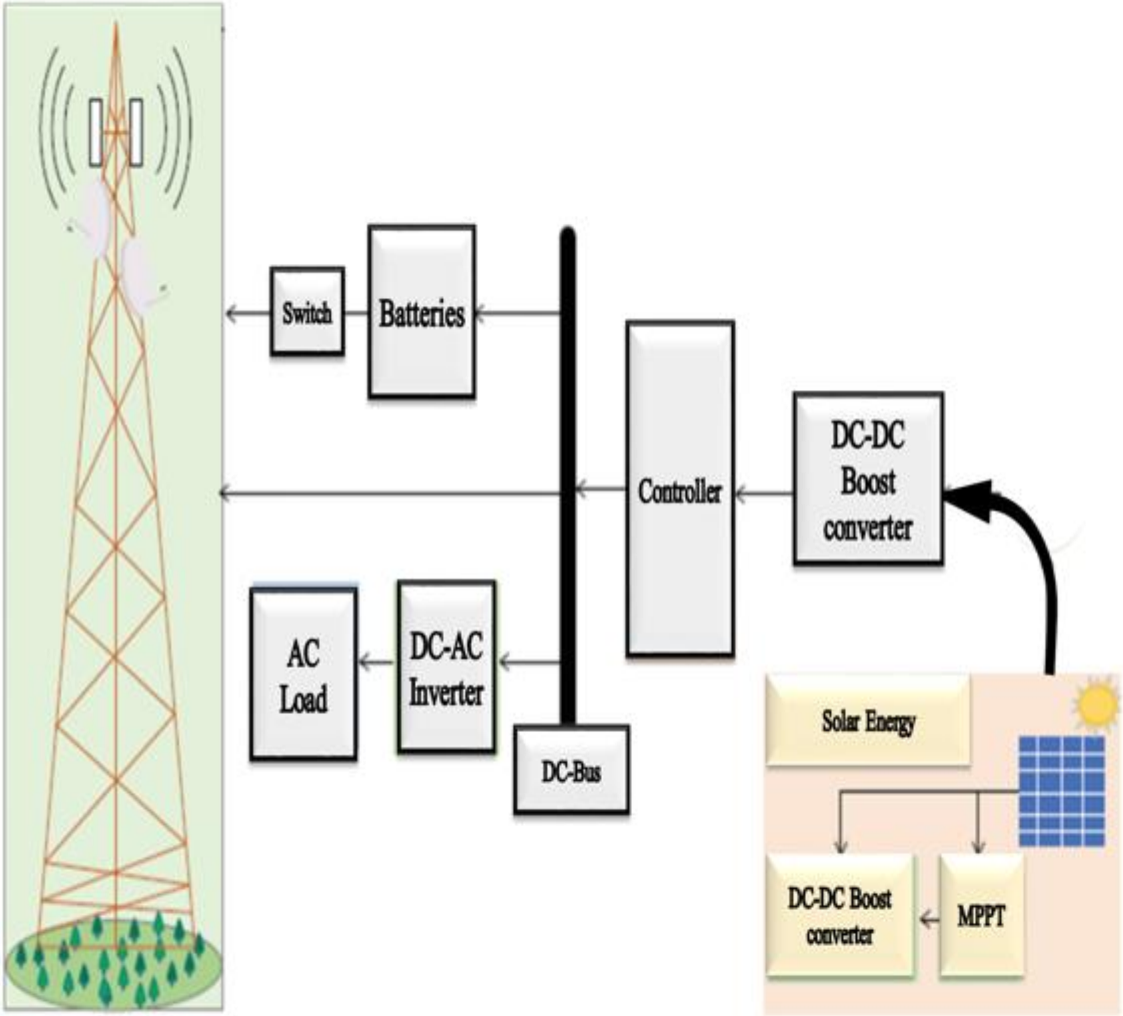


Figure 3. 6 Solar Energy with all Components (Ch et al., 2021)

The primary components of the solar system are the MPPT, backup batteries, control system, DC-DC boost converter, common DC bus, and solar cells. Photovoltaic (PV) arrays are the components of the solar energy system. To attain high voltage, they will modify the boost converter's duty cycle using the maximum power point tracking (MPPT) technique. The matching circuit's (DC-DC boost converter) primary job is to increase the source's input voltage to a level that is significantly higher than what the loads require. For AC loads, the inverter is utilized to convert DC-AC voltage. To raise these voltages to a greater level, the boost converter will receive the voltage outputs from the solar cells. The mechanism of stabilization.

3.9 P&O MPPT Algorithms

One well-liked Maximum Power Point Tracking (MPPT) technique for solar power systems is the Perturb and Observe (P&O) algorithm. To make it function, the operational point of the solar panel system is changed, and the impact on the electricity generation is monitored. The algorithm adjusts the operating point in response to this discovery, tracking the maximum power point (MPP), or the point at which the power output is maximized. The P&O algorithm operates as follows: the Perturb and Observe (P&O) method serves as the foundation for the Maximum Power Point Tracking (MPPT) technique, with computed parameters as follows:

Initialization:

- Start at an initial operating point Vstart (voltage) or Istart (current).
- Measure the power output Pstart of the solar panel system at this operating point.

2) **Perturbation**:
    - Perturb the operating point by a small increment (ΔV or ΔI).
    - Calculate the new operating point Vnew or Inew.
3) **Measurement**:
    - Measure the power output Pnew at the new operating point.
4) **Comparison**:
    - Compare the new power output Pnew with the previous power output Pstart.
5) **Decision**:
    - If Pnew>Pstart, continue perturbing in the same direction.
    - If Pnew<Pstart, change the direction of perturbation.
6) **Adjustment**:
    - Adjust the perturbation step size based on the decision.
    - Update the operating point to Vnew or Inew.
7) **Repeat**:
    - Repeat 2_6 steps iteratively to track the Maximum Power Point (MPP).

Parameter Calculation:

1. **Perturbation Step Size** (ΔV or ΔI):
    - Typically chosen as a percentage of the operating voltage or current.
    - For example, ΔV=0.1×Vstart or ΔI=0.1×Istart.
2. **Sampling Rate**:
    - The rate at which the algorithm iterates through the steps.

- Determines the speed of tracking and responsiveness of the algorithm.
- Typically defined by the system requirements and control loop implementation.

3. **Threshold for Change Detection**:
    - Define a threshold ϵ to detect significant changes in power output.
    - For example, if $|P\text{new} - P\text{start}| < \epsilon$, the change is considered insignificant, and the direction of perturbation may need adjustment.
4. **Direction Change Threshold**:
    - If the power output decreases below a certain threshold for a certain number of iterations, change the direction of perturbation.
    - This prevents oscillations around the MPP.

CHAPTER FOUR

P&O DESIGN FOR MPPT

4.1 Perturb and Observe (P&O) MPPT

The detailed design of P&O MPPT is covered in this section. More accurate and steady MPPT is possible when a PI controller and the P&O algorithm are integrated. This technique modifies the perturbation amount according to the difference between the intended and measured power values, while the P&O algorithm determines the direction of perturbation. This combination allows for improved rejection of disturbances like temperature or irradiance variations as well as faster convergence to the MPP.

In actuality, P&O MPPT is integrated into the power converters (a DC-DC boost converter) for photovoltaic systems. The PV array's operating point is continuously adjusted by the controller to maintain maximum power output in a variety of environmental circumstances. Two requirements must be met to design P&O-type MPPTs with higher current (I) refresh rates:

First, the P&O algorithm must function at high sampling rates, and the sample voltage and current values must represent the output power's tendency when the reference signal for the MPPT power converter is increased or decreased.

Second, the MPPT power converter must to have a very fast response time and low switching losses (frequency). Instead of comparing the average values to further enhance system performance, this can be accomplished by comparing the instantaneous values of Vpv and peak current control, which indicate the one-cycle speed of response for small fluctuations in the reference current. The peak current control method is used by the MPPT system architecture. A clock signal activates the switch, and it shuts off when the real current equals the reference current. As a result, every switching cycle has the potential to disturb the reference current (increase or decrease), indicating that the refresh rate or perturbation cycle is equal to the switching cycle. This technique generates a tiny disturbance, which results in power fluctuations from the PV module. Regular monitoring and comparison of the PV output power with the prior power is conducted. The same procedure is followed if the output power rises; otherwise, the perturbation is reversed. The PV module or array's voltage is changed using this technique. To determine whether the power is increasing or decreasing, the voltage of the PV module is changed.

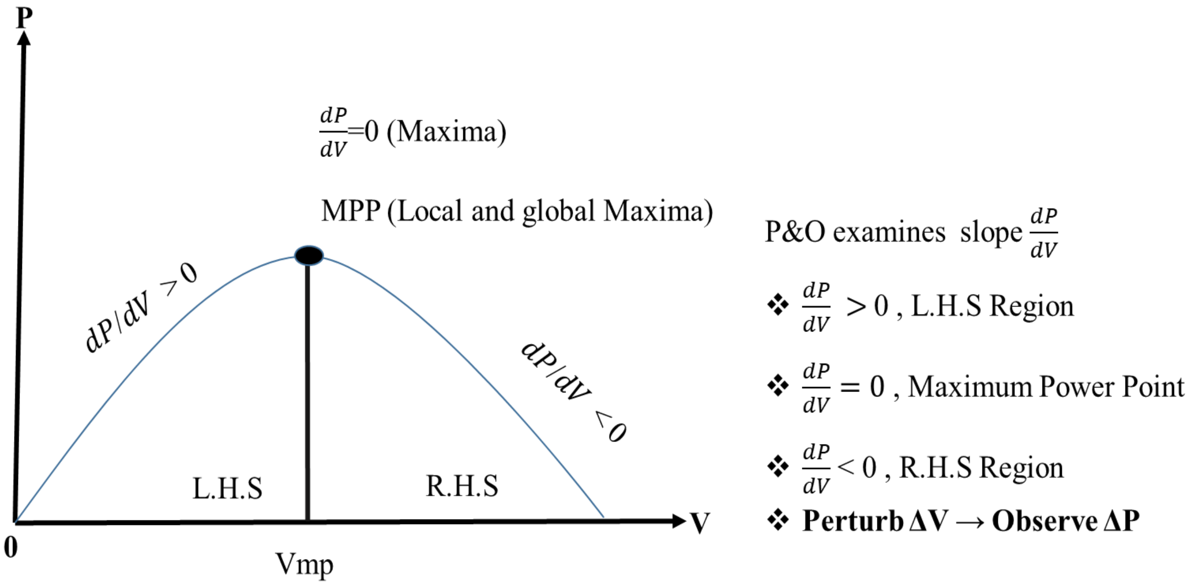


Figure 4. 1 Graphical demonstration of P& O for MPPT

4.2 P & O Flow Chart

The graphical representation below shows the flow chart for the P&O algorithm that the charge controller has selected. The MPPT charge controller detects voltages between the battery and PV module when they are connected. It keeps an eye on the voltage and assesses the battery's level of charge. In order to prevent overcharging, the battery stops charging when it reaches 52 V at the battery connector, which indicates full charge. In the event that the battery still has some charge, the DC/DC converter is turned on to begin charging it. Following the voltage and current sense, the controller computes the output power Pnew and compares it with the power Pold that was previously recorded. In order to optimize the PV panel's power output, if Pnew exceeds Pold, the PWM duty cycle is raised. In order to make sure the system restarts at maximum power, the duty cycle is reduced if Pnew is smaller than Pold. Simple to use, affordable, accurate, and uncomplicated is this MPPT algorithm.

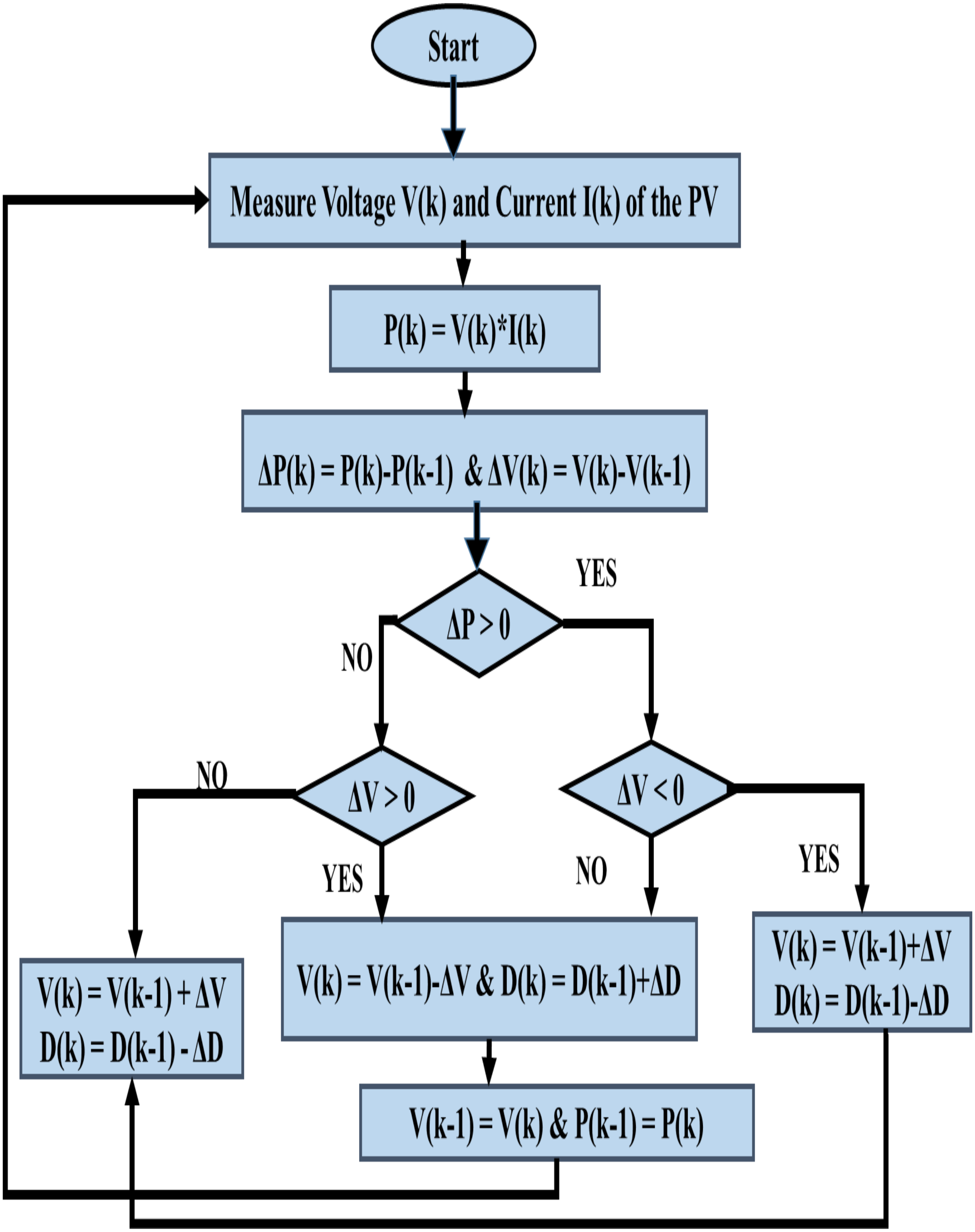


Figure 4. 2 P & O detailed algorithm

If a voltage rise results in an increase in power, the PV module's operating point is to the left of the MPP; therefore, additional disturbance to the right is necessary to reach the MPP. The PV module's operating point lies to the right of the MPP, but, if a voltage rise causes a power loss; as a result, further disturbance to the left is required to achieve the MPP. Creating a Simulink model of a Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) is a great way to simulate and understand the behavior of such a system.

The system contsins:

- The "Solar Panel" block represents the behavior of the photovoltaic array.
- Observing the power output, the "P&O Algorithm" block modifies the solar panel's operating point..
- The Power Measurement block measures the power output of the solar panel.

It is possible to build a basic structure by adding modeling of the solar panel behavior, refining the control algorithm, and incorporating additional components such as a battery or load. Simulink provides a range of blocks and tools to help for creating and simulating control systems like this one.

4.4 P & O Simulink Model

Here, I start by simulating how a solar panel will behave. This can be accomplished by using pre-built Simulink blocks, like the PV array block, or by using the required mathematical formulae covered in the previous chapter. Next, the P&O algorithm simulation is used to change the solar panel's operational point and track the impact on power output. Simulink comparison blocks and simple arithmetic operations can be used for this. Using this method, the perturbation magnitude is modified according to the discrepancy between the desired and measured power values. Lastly, the P&O algorithm is employed to continuously monitor the solar panel's highest power point. To see how the MPPT system behaves, simulate the model under various circumstances (such as temperature changes and varying irradiance levels). Utilize Simulink's analytic tools to assess the system's performance.

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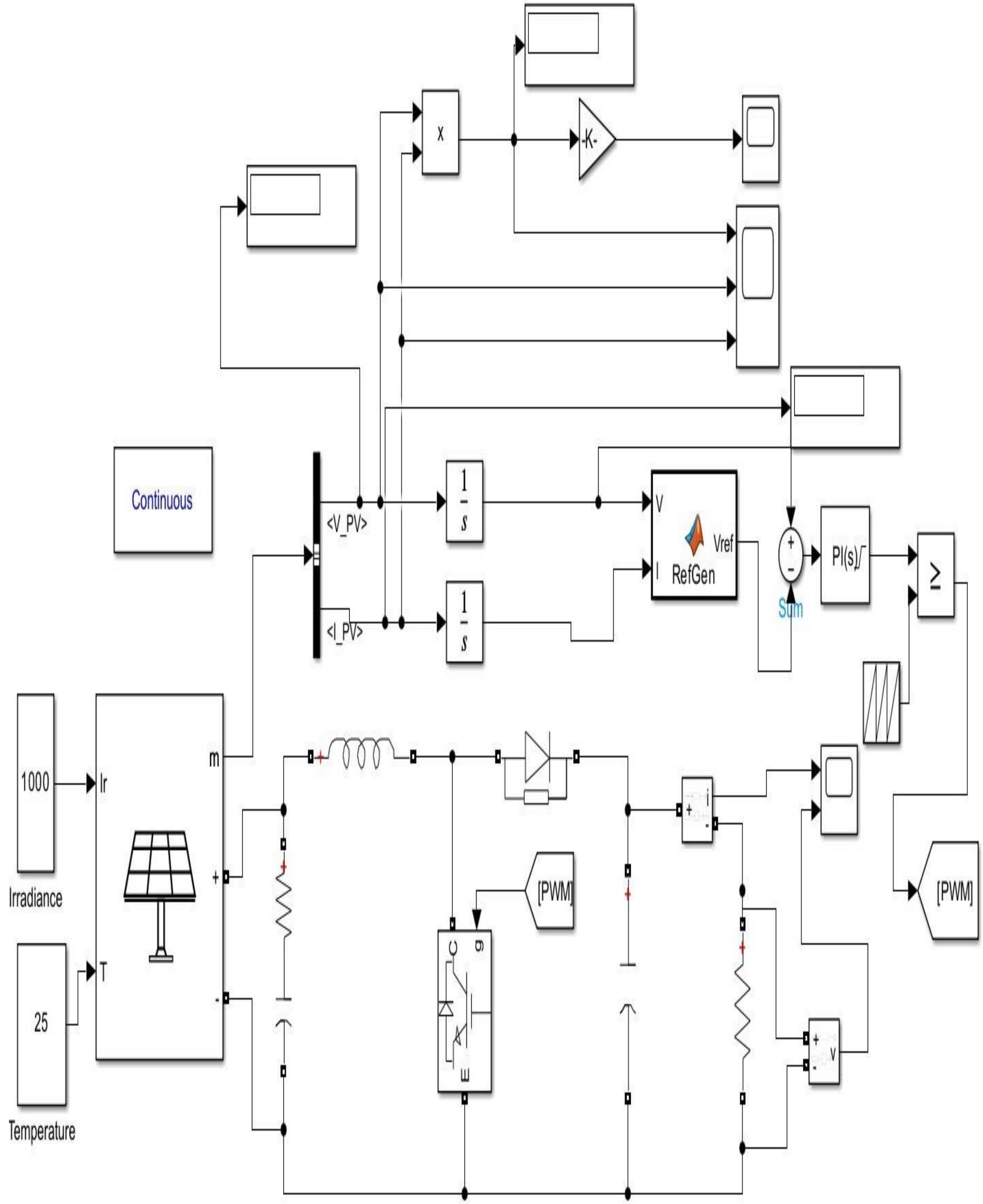

Figure 4. 3 P&O Simulink model design

CHAPTER FIVE

SIMULATION RESULTS AND DISCUSSION

5.1 Simulation Setup

In solar energy systems, one of the popular MPPT method is Perturb and Observe (P&O) algorithm. The findings and a review of the P&O MPPT solar energy controller's performance are presented in this part. A simulation model is created in the Matlab/Simulink environment, as seen in figure 5.1. This simulation setup includes all required settings. After that, the system is examined in depth under the following meteorological circumstances.

- Consistent weather
- Variable weather

The following list contains the simulation setup's parameters:

- ✓ PV Array: The simulation makes use of the PV array model that was created in the previous chapter. PV arrays are made up of eleven parallel strings, each of which has seven series-connected modules, or 11 * 7. The module used is the Kyocera KC200GT, whose electrical characteristics parameters are displayed in Table 1 under standard testing conditions (STC). Every PV array has a 15 kW power output under STC.
- ✓ DC-DC boost converter: Here are its component values:
    - Input Capacitor = 1.3mF
    - Output Capacitor = 1.3mF
    - Inductor = 0.13626mH
    - A resistator =2.74ohm is connected on load side.

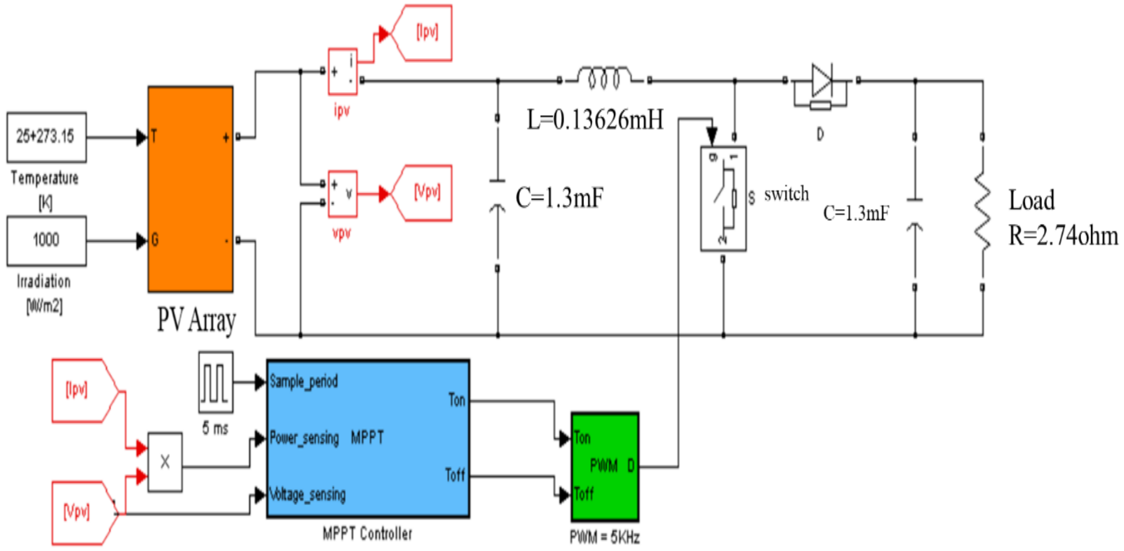

Figure 5. 1 Simulation setup

5.2 MPPT Controlling Parameters

The P&O approach uses a 5 ms sampling rate (the interval between voltage steps). Techniques like Voc and Isc have discrete values. After a 20 ms time delay, the open-circuit voltage and short-circuit current were measured using the Voc and Isc procedures, respectively. With this method, the converter's duty cycle is altered at a switching frequency of 10 kHz.

The primary regulating factors to take into account are:

The size of the Perturbation Steps is the amount that each perturbation step increases or decreases the boost converter's duty cycle. An increased step size may result in the MPP tracking more quickly. MPP tracking is more accurate when the step size is smaller, but the response time could be slower. Values typically fall between 0.01 and 0.1.

Sampling Frequency: The PV array voltage and current are sampled at this frequency by the P&O algorithm. Elevating the sampling frequency can enhance the algorithm's capacity to monitor swift alterations in the surrounding circumstances. It is best to select a moderate sample frequency, usually between the range of 10 Hz to 1 kHz, as choosing a frequency that is too high could cause instability and oscillations.

P&O algorithms come with an adaptation mechanism that allows them to dynamically change the perturbation step size according to the operating environment. The adaptive mechanism modifies the power variation or the separation From the MPP.

Reduction of noise and filtering: To lessen the effect of noise and oscillations, the voltage and current measurements must be properly filtered. Techniques for low-pass filters can be utilized to smooth the input signals.

Figure 5.3 is a MATLAB/Simulink diagram of the proposed Perturb and Observe that illustrates how this algorithm tracks the maximum power point by regulating the duty cycle of the boost converter.

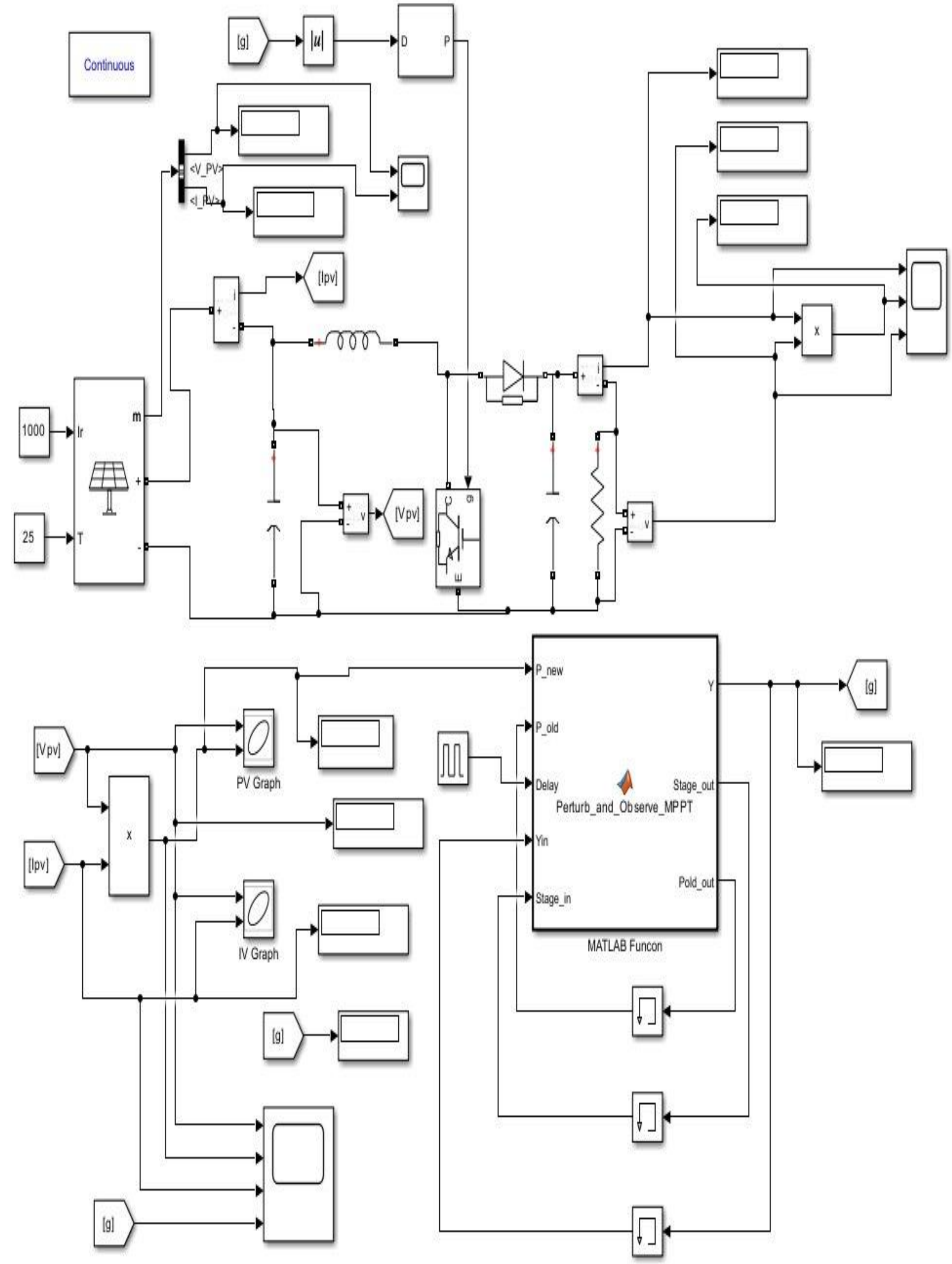

Figure 5. 2 Perturb and Observe Simulink Model

5.3 P&O Simulink Model Simulation

An MPPT (Maximum Power Point Tracking) system that uses perturb and observe (P&O) can be simulated in Simulink to get an understanding of how it behaves in various scenarios. The P&O method intended for solar photovoltaic (PV) systems to monitor the PV array's maximum power point (MPP) is depicted in Figure 5.3. Validating the MPPT (Maximum Power Point Tracking) algorithm's performance is the aim of the P&O Simulink model simulation. Voltage, current, and power are the main boost converter outputs displayed on the Simulink model that follows.

The power requirements of the P and O-based MPPT controller with the boost converter are shown by these output values.

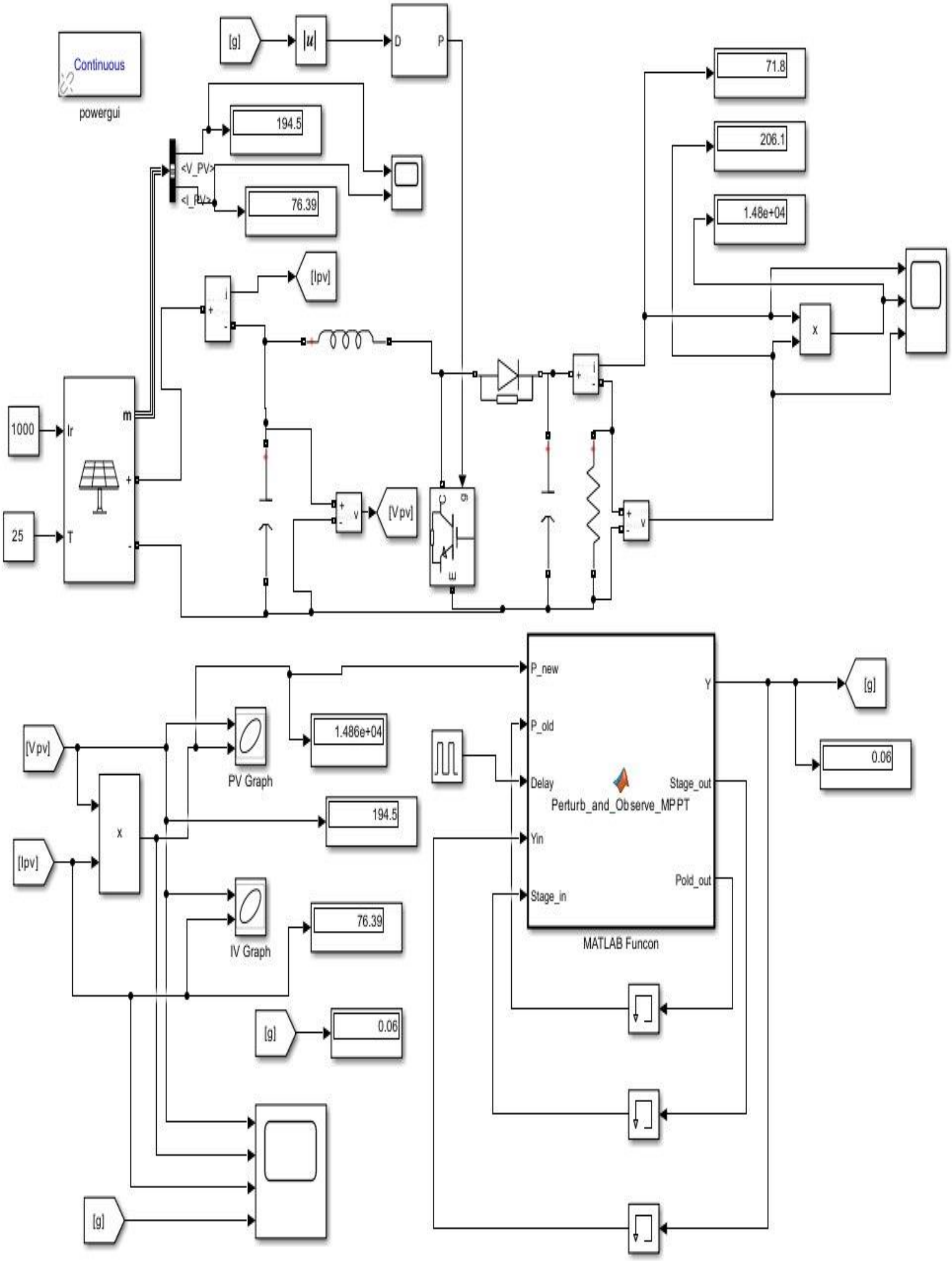

Figure 5. 3 Perturb and Observe the Simulink model with the boost converter

5.4 Comparison of P&O with Incremental Conductance Technique For MPPT

The power curve of the solar panel has a zero slope at MPP, which is the basis for the incremental conductance approach. To ascertain which way the operating point should be adjusted, it compares the incremental conductance to the instantaneous conductance (current/voltage). When choosing the right MPPT algorithm for a particular solar PV system design, it is important to consider the added complexity and possible disadvantages of the Incremental Conductance approach, even if it can provide better MPPT performance in some situations. The simulation result has been examined, and the Simulink model for the incremental conductance technique-based MPPT approach is displayed in Figure 5.4.

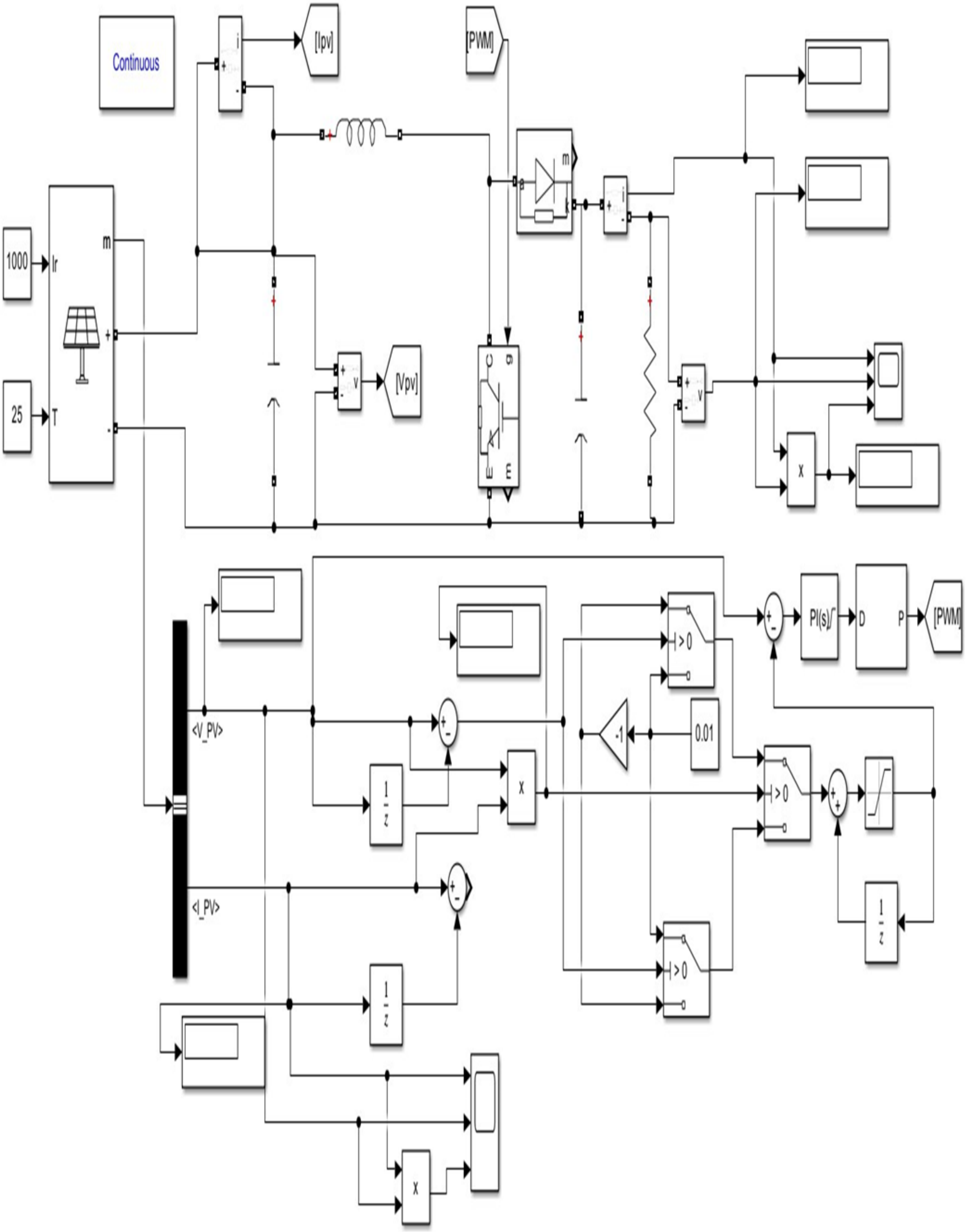

Figure 5. 4 Incremental Conductance-based MPPT technique

Based on the final simulation result shown in figure 5.6 and when compared to P&O, there are some drawbacks of the Incremental Conductance method for MPPT in solar photovoltaic systems:

The complexity of implementation: - The Incremental Conductance algorithm is more complex compared to the Perturb and Observe (P&O) method. It requires more sensors and more sophisticated control algorithms.

High computational requirement: - This method involves more mathematical operations. This requires a more powerful processor and it increases the overall system cost.

Sensitivity to noise and fluctuations: - This can lead to instability and oscillations under rapidly changing environmental conditions.

Because of these drawbacks, the incremental conductance technique is less appropriate in some situations, especially in systems with limited resources or a tight budget.

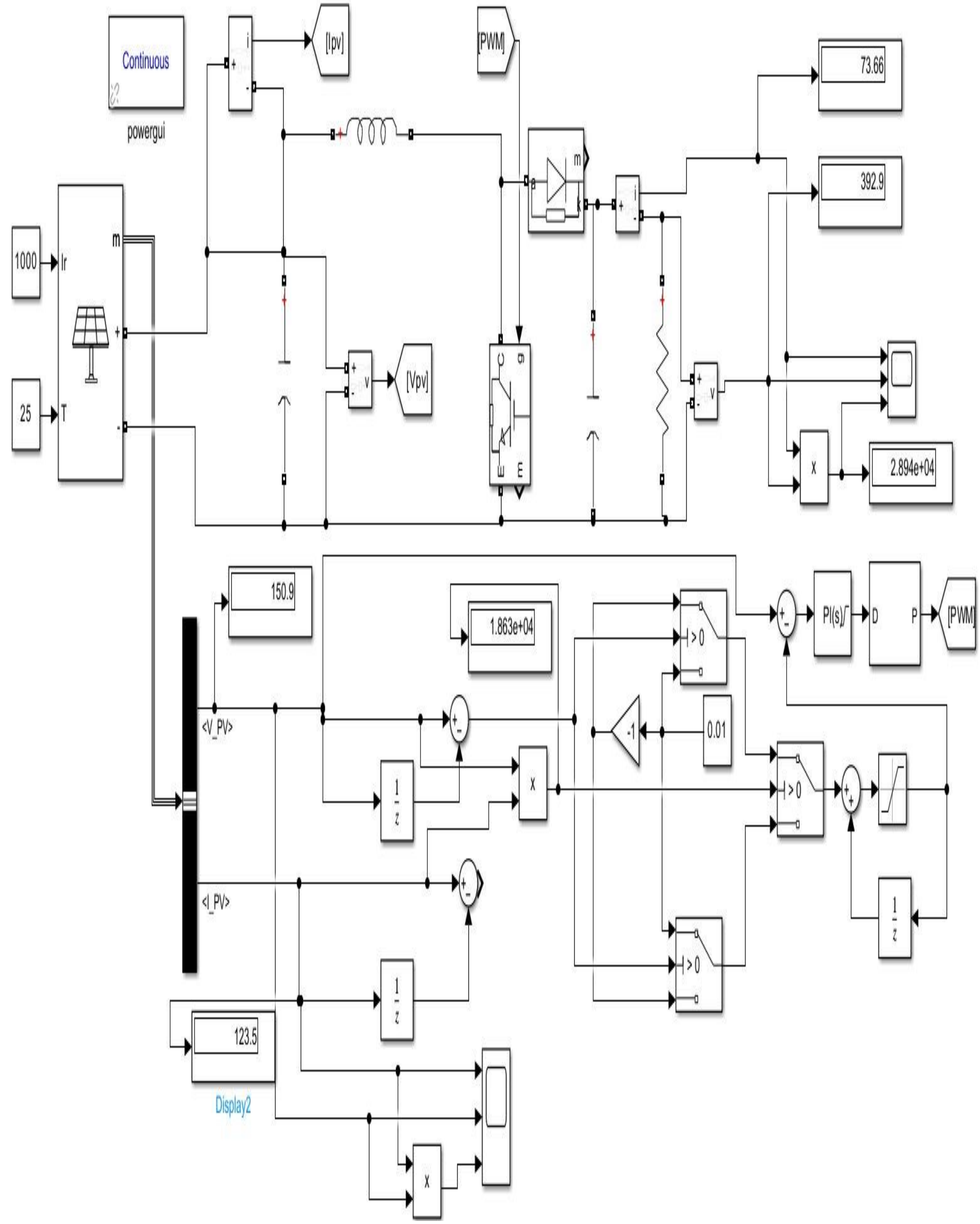

Figure 5. 5 Incremental conductance Simulink model

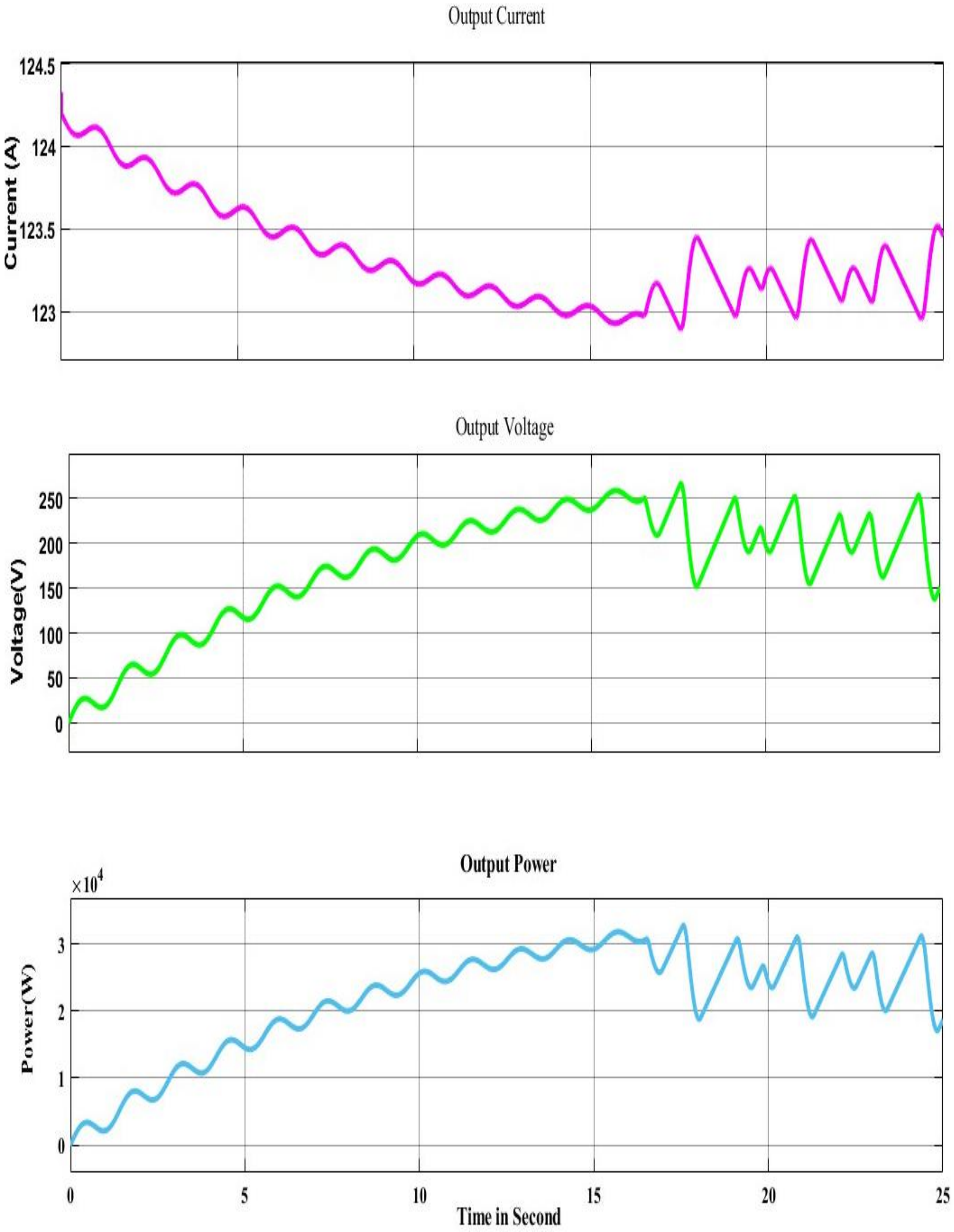

Figure 5. 6 Simulation result of Incremental conductance-based MPPT

5.5 Result and Discussion of Boost Converter Parameters at MPP

The P&O-based solar energy controller successfully tracked the PV array maximum power point (MPP) in the majority of operating situations, as demonstrated by the simulation result of P&O displayed in Figure 5.7. The operating point was successfully adjusted by the algorithm by varying the voltage or current to get closer to the MPP. High power output from the PV system resulted from the P&O algorithm's based MPP tracking capability under steady and gradually changing environmental conditions. To optimize power extraction, the controller adjusted the operating point in response to changes in temperature, shade, and sun irradiation.

The P&O MPPT algorithm in this simulation monitors the solar panel's maximum power point (MPP) in response to variations in irradiation levels. The algorithm modifies the operating voltage to meet the MPP as the irradiance rises, increasing the output's current and power. The boost converter's input parameters, also known as the PV terminal output terminal parameters, and the gate signal that regulates the boost converter's duty cycle are displayed in Figure 5.8.

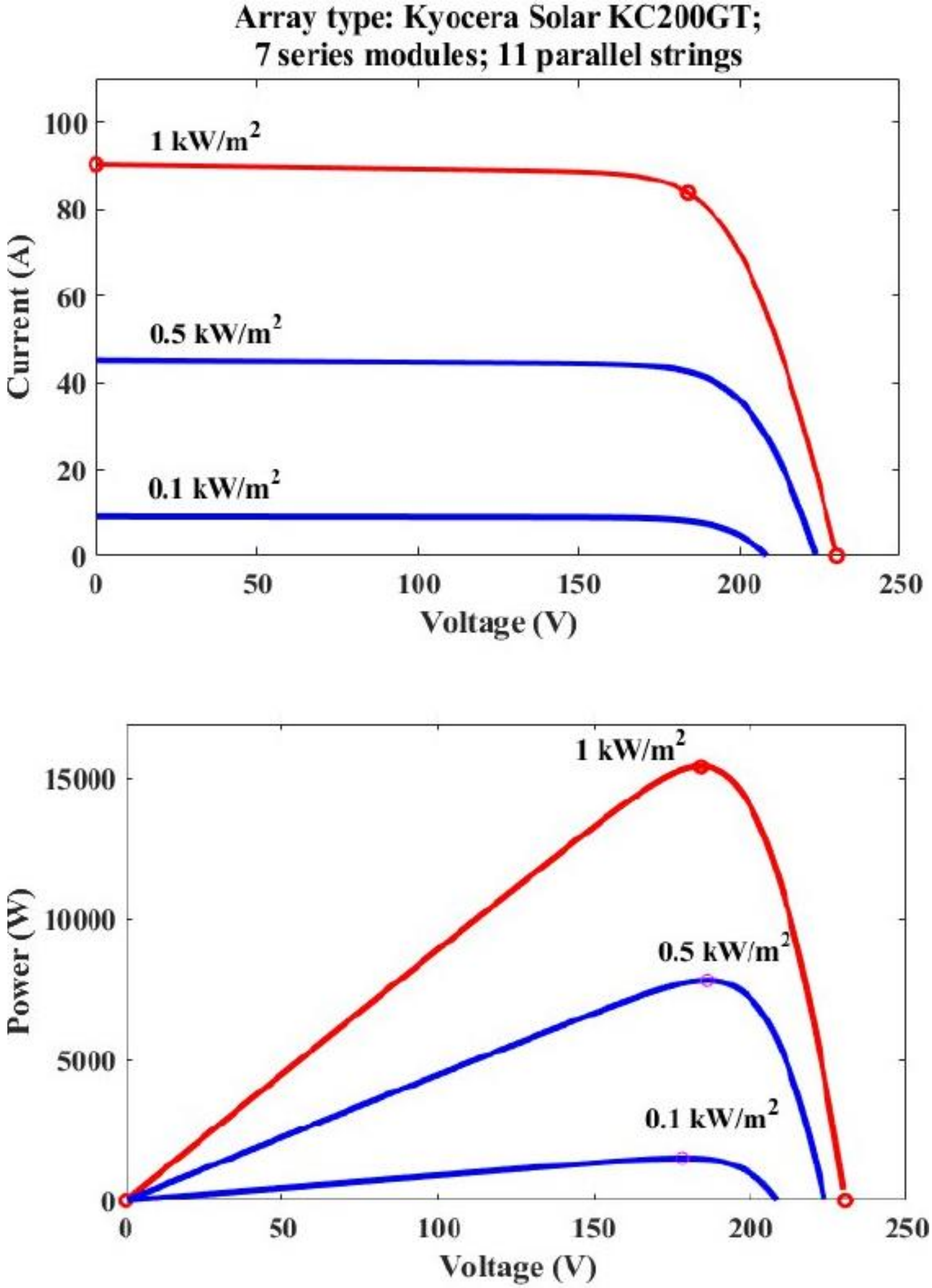

Figure 5. 7 Voltage and current level at MPP

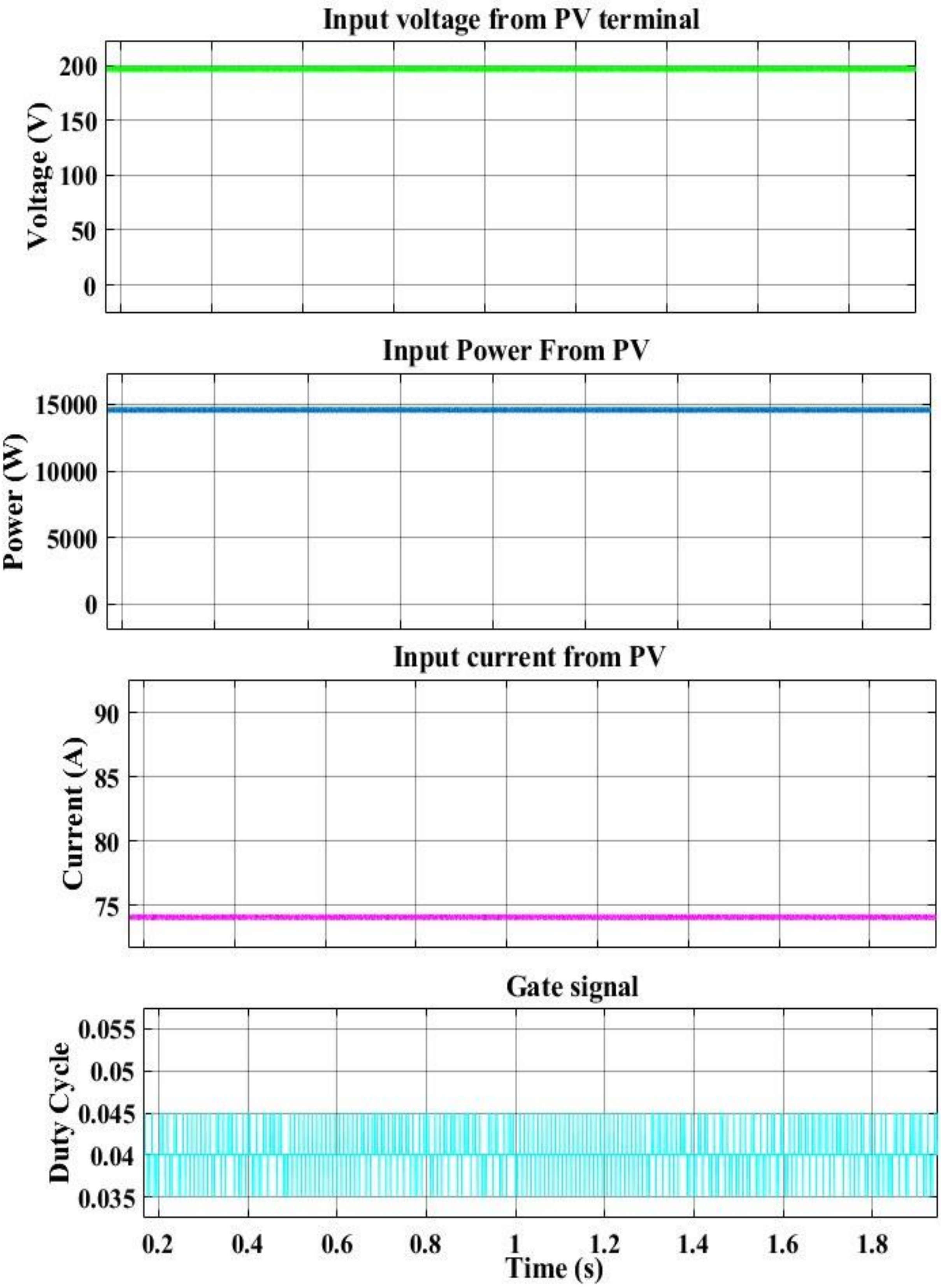

Figure 5. 8 Input Voltage, Current and Power

5.6 Simulation result of output parameters

P&O MPPT algorithm are displayed in figures 5.9 and 5.10, illustrating the output of power, voltage, and current. Let's talk about the simulation data's implications and trends that have been noticed. The P&O method starts with a starting voltage value and modifies it to observe the resultant power at an irradiation of 200 W/m². The voltage is disturbed by the algorithm repeatedly until it notices a drop in power, which suggests that the prior voltage value was nearer the MPP. Next, the voltage is adjusted by the algorithm to return to the MPP. Nonetheless, the voltage and power values stay comparatively low throughout the simulation because of the low irradiance level. The low irradiance limits the current, which likewise stays constant. Upon reaching 500 W/m² of irradiance, the P&O algorithm promptly modifies the voltage to follow the MPP. An increase in voltage and power leads to a rise in the output current. The method produces a stable power output by keeping the voltage near the MPP. The P&O algorithm efficiently tracks the MPP, producing the maximum output of voltage, current, and power when the irradiance surpasses 1000 W/m². To keep the system at the MPP and maximize the amount of electricity extracted from the solar panel, the algorithm modifies the voltage. These simulation results demonstrate how well the P&O MPPT algorithm works to track the MPP by varying the operating voltage. The algorithm reacts to an increase in irradiance by raising the voltage to maximize power output. On the other hand, when there is low irradiance, the algorithm modifies the voltage to preserve the maximum power output within the constraints imposed by the reduced irradiance level. It's crucial to remember that the precise voltage, current, and power numbers seen in the simulation depend on several variables, such as the PV system's specifications, how the P&O method is applied, and the surrounding circumstances.

Overall, the simulation results provide insights into the behavior of the P&O MPPT algorithm and illustrate its ability to optimize the power output of a PV system by tracking the MPP.

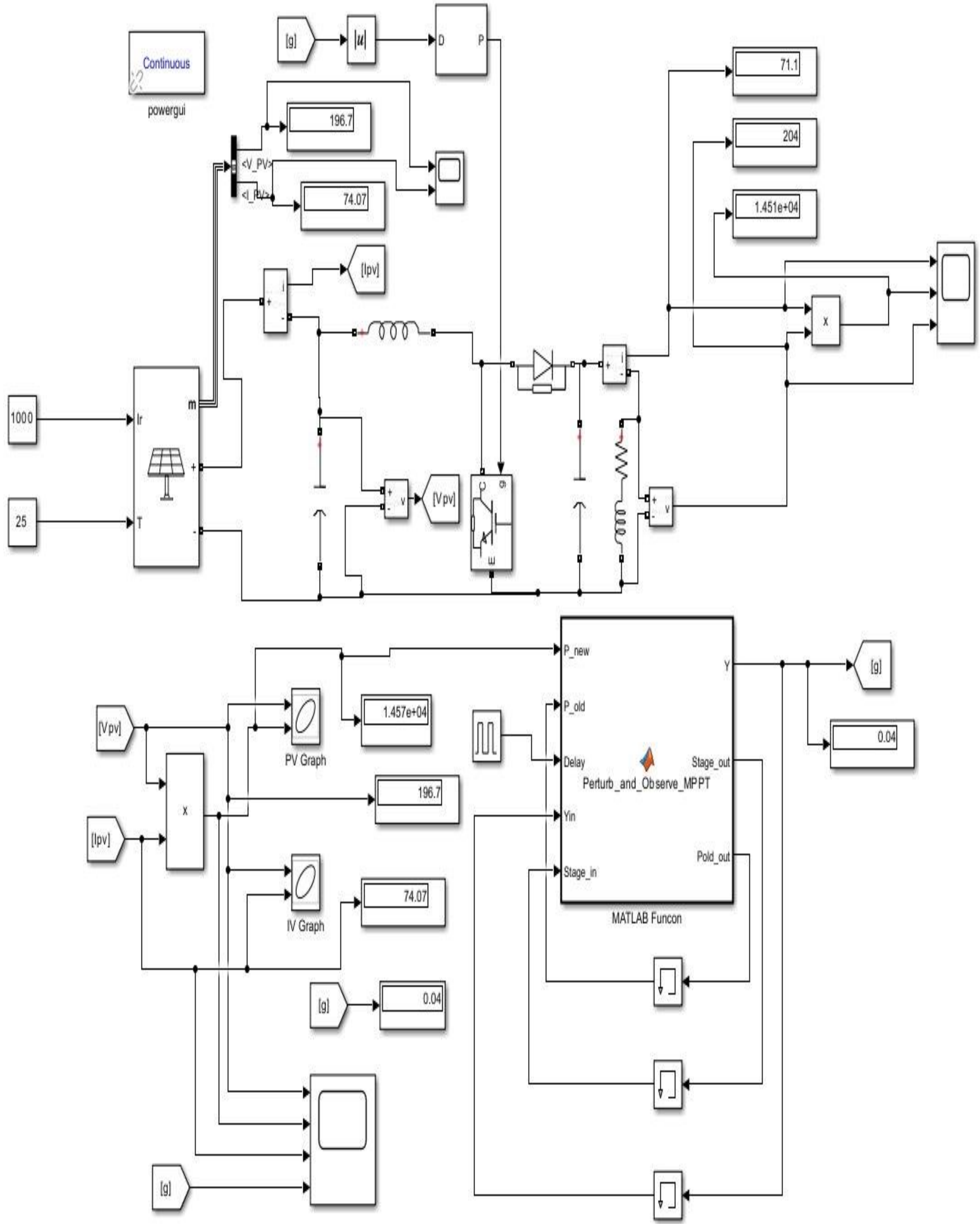

Figure 5. 9 Simulation result of P&O Simulink Model

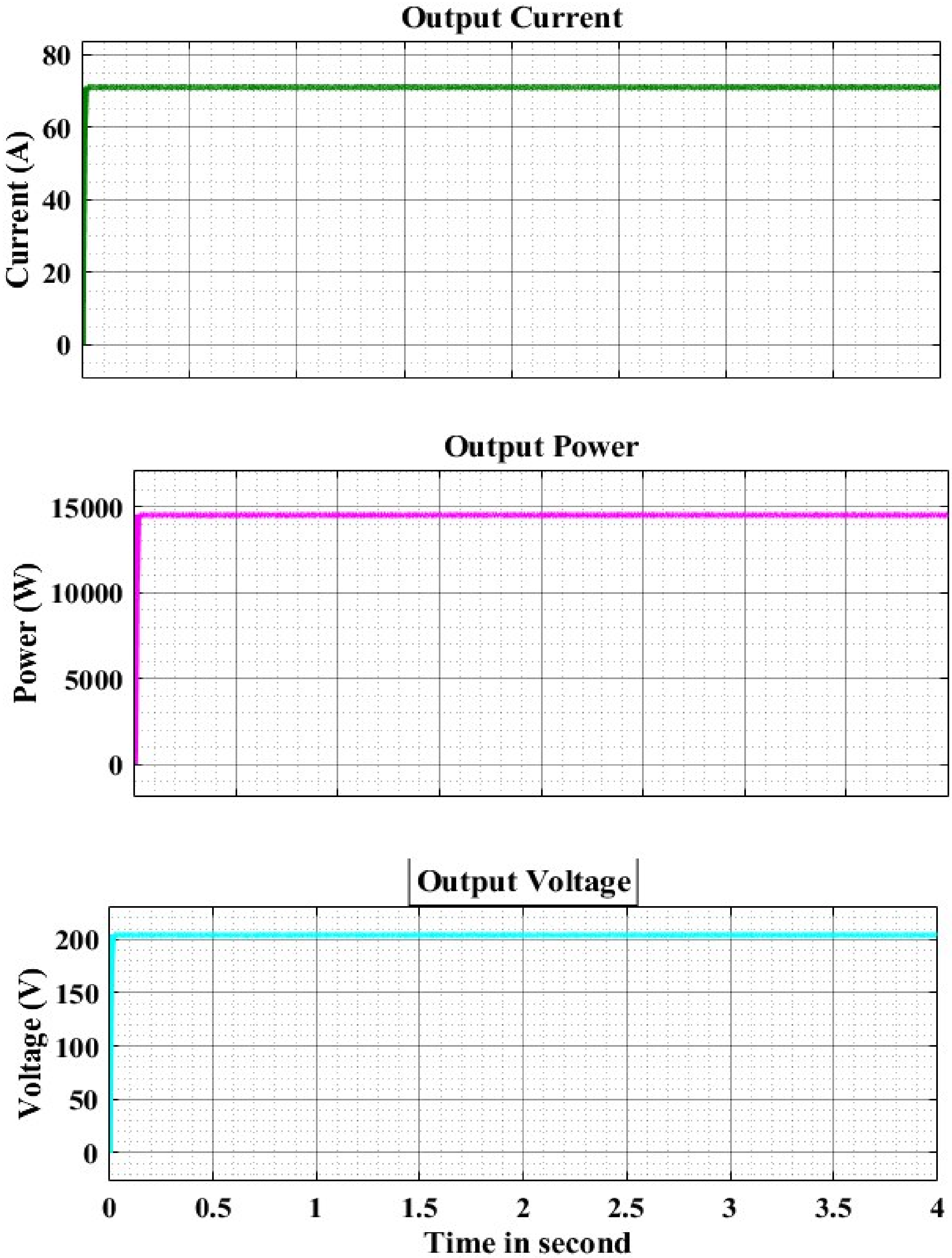

Figure 5. 10 Output Current, Voltage and Power

CONCLUSION AND RECOMMENDATION

1 Conclusion

I have designed a perturbation and observation-based controller that uses the MPPT technique in my thesis. Matlab/Simulink is used in the simulation study to examine the MPPT technique's performance in both steady-state and dynamic weather scenarios. In terms of efficiency and power losses, it has been discovered that the P & O method is the optimal technique for steady-state meteorological conditions. P&O is simple to implement using embedded hardware and software. Furthermore, it operates at a modest efficiency level in both stable and fluctuating weather scenarios. The MPPT technique described in this thesis has the potential to benefit future studies in this area and to enhance the scientific community. To extract the maximum power from a PV module, an MPPT based on a P&O algorithm was devised in this thesis. The system's ability to charge batteries is evaluated and it consists of a P&O-based MPPT controller and a high-efficiency DC/DC boost converter. It demonstrates how the P&O algorithm offers a dependable and effective maximum power tracking performance even in the face of abrupt changes in temperature and irradiance. The system is more efficient than the traditional design, according to the simulation results.

All things considered, the P&O based MPPT solar energy controller is a very attractive option for optimizing the performance of solar PV systems since it is easy to use, reasonably priced, and has a moderate degree of environmental adaptation. Even while the P&O algorithm is aware of its limits in dynamic environments, especially in situations where there are frequent shading or irradiance fluctuations it is nevertheless a vital tool for utilizing solar energy in a variety of applications. The P&O MPPT controller implementation promises to produce real benefits in terms of optimal performance and increased energy production provided that environmental considerations and system requirements are carefully taken into account. This will contribute to the global proliferation of sustainable solar energy solutions.

2 Recommendation

I emphasize that the P&O) algorithm is a great option for a solar energy controller that tracks maximum power points (MPPT). The P&O algorithm has demonstrated its efficacy, affordability, and ease of use, making it a dependable method for maximizing power extraction in photovoltaic (PV) systems. The P&O algorithm is a desirable alternative for MPPT control because it provides several significant benefits. First of all, because of its simplicity, it can be easily integrated and implemented into different PV system architectures. The simple nature of the algorithm reduces the amount of work that has to be done computationally and makes it easier to operate effectively in a variety of system configurations and sizes. Moreover, the P&O method is flexible enough to accommodate various PV technologies and installations because it does not necessitate an in-depth understanding of particular PV system factors.

The algorithm is especially useful for retrofitting existing PV systems because it may function well even in the absence of exact parameter information. It's crucial to recognize the P&O algorithm's limits, though. Its susceptibility to quickly shifting environmental factors, such as shadows or sporadic cloud cover, is one of its biggest problems. In these conditions, the algorithm can monitor the maximum power point (MPP) with oscillations or inaccuracies, which could result in less-than-ideal power extraction. However, these difficulties can be lessened by utilizing cutting-edge methods and improved algorithms. It is advised to take into account the integration of sophisticated perturbation techniques, variable perturbation step sizes, or adaptive step size control to optimize the performance of the P&O MPPT controller. These enhancements can improve the algorithm's response to dynamic environmental conditions, enhance MPP tracking accuracy, and reduce steady-state oscillations. By adopting these modifications, the overall efficiency and performance of the P&O algorithm can be significantly enhanced.

To sum up, the P&O-based MPPT solar energy controller has excellent performance and comes highly recommended. It is a sensible option for a variety of PV installations because of its simplicity, versatility, and ease of deployment. Although the algorithm has limits, its track record and interoperability with different PV systems make it a dependable and affordable way to maximize power output.

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APPENDIX

Mat lab Code for Perturb_and_Observe_MPPT Controller

```
function[Z,Step_o,Pol_o]=P_and_O_MPPT(P_nw,P_ol,delay,Zstart,Step_i)

d=0.05;
Pol_o=P_ol;
Z=Zstart;
Step_o= Step_i;
if Delay == 0
    if Step_i==0
                   if P_nw>P_ol
                    Z=Zstart+d;
                    Pol_o=P_nw;
                    elseif P_nw<P_ol
                    Z=Zin-d;
                    Step_o=1;
                    Pol_o=P_nw;
                    end
                    Pol_out=P_nw;
    end
   if Step_i==1
                    if P_nw>P_ol
                    Z=Zstart-d;
                     Pol_o=P_nw;
                    elseif P_nw<P_ol
                    Z=Zstart+d;
                    Step_o=0;
                    Pol_o=P_nw;
                    end
                    Pol_o=P_nw;

   end
end
```