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DESIGN OF MANAGEMENT AND MONITORING SYSTEM FOR RENEWABLE ENERGY SMART GRID BASED ON INTERNET OF THINGS

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Master's Thesis

Supervisor

Assoc. Prof. Dr. Sefer KURNAZ

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The thesis titled DESIGN OF MANAGEMENT AND MONITORING SYSTEM FOR RENEWABLE ENERGY SMART GRID BASED ON INTERNET OF THINGS prepared and presented by MOHAMMED KAREEM JANABI and submitted on 18/12/2023 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering

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ABSTRACT

DESIGN OF MANAGEMENT AND MONITORING SYSTEM FOR RENEWABLE ENERGY SMART GRID BASED ON INTERNET OF THINGS

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Renewable energy sources are receiving more attention as a result of the population's quickening increase and growing worry over global warming. By lowering carbon emissions and generating cheap power, renewable energy sources significantly improve the environment. In comparison to other renewable energy sources, solar energy has lower operating and maintenance expenses and is thus the most widely used renewable energy source. Managing and regulating energy flow in the smart grid is one of the major issues that have to be resolved. Problems with power quality and stability may arise whenever there is a dynamic exchange of energy in a high-power system between different sources, loads, and energy storage devices. Energy flow through the system must be continuously managed in order to satisfy the load demand. The biggest problem with the smart grid's operation is the lack of technical details on the hardware and experimental setup of the energy storage system. This study assesses the power balance in a small-scale experimental SG under various conditions. To achieve Maximum PowerPoint Tracking (MPPT), the PV system efficiency in this work progressively uses artificial intelligence-based techniques. Additionally, this work involves wind turbine MPPT. By employing the Grey Wolf Optimizer GWO algorithm, which is based on the artificial intelligent approach used to achieve MPPT, to optimize the efficiency of the PV-wind turbine-battery system, the goal of this study is to enhance the power quality and energy management system of the PV-wind turbine-battery module. In order to strengthen system dependability, the IoT may also be coupled with the smart grid. In this scenario, the IoT can control load demand if the load increases more than the renewable energy sources over an extended length of time.

Keywords: Energy Management System, Renewable Energy Sources, Energy Storage System, Battery System, Internet of Things.

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ABBREVIATIONS

PV	:	Photovoltaic
RES	:	Renewable Energy Sources
EMS	:	Energy Management System
ESS	:	Energy Storage System
MPPT	:	Maximum Power Point Tracking
INC	:	Incremental MPPT
GWO	:	Grey Wolf Optimizer MPPT
SG	:	Smart Grid
BESS	:	Battery Energy Storage System
IoT	:	Internet of Things
PMSG	:	Permanent Magnet Synchronous Generator
AI	:	Artificial Intelligence
WECS	:	Wind Energy Conversion System
SEPIC	:	Single-Ended Primary Inductance Converter
MPC	:	Model Predictive Control
GA	:	Genetic Algorithm
VSG	:	Virtual Synchronous Generator
DER	:	Distributed Energy Resources
VSI	:	Voltage Source Inverter
HPS	:	Hybrid Power System

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1. INTRODUCTION

1.1 INTRODUCTION

The appropriate application of Smart Grids (SGs) is crucial for enhancing the efficiency of distributed electrical supplies. Opportunities for Renewable Energy Resource (RES) to address electricity generation look to be developing given the increased relevance of climate change as a worldwide concern, increasing prices of fossil fuels, and the falling cost of RES [1]. An effective Energy Management System (EMS) strategy needs to be created, nevertheless, in order for the system to be made available for purchase and be extensively used. Electric infrastructure for electricity has lately successfully adopted the idea of an SG. Figure (1.1) depicts the SG components, which also comprise RES and conventional energy sources. Availability is the main problem with RES; wind, water, and solar energy are not always available where and when they are needed [2].

Compared to conventional electrical power sources, such RES cannot be "dispatchable" and their power output cannot be managed due to discontinuous production caused by regular and periodic impacts, like shortage in generation. SGs are anticipated to have further benefits in addition to their promise to make the inclusion of RES simpler [3]. Information and communication technologies are used by SGs to transmit data among control centers and other equipment utilized by the power system. Information regarding supplier and customer behavior is automatically gathered [4] to increase the system efficiency, economy, sustainability of the supply and delivery of energy.

Due to the unpredictability and uncertainty of the RES, increasing RES output requires creative solutions to maintain grid stability and dependability. Localized use of SGs may contribute to a rise in the grid's reliability and stability. In order to provide the loads by electricity at any given time or to provide the loads from the ESS, RES employs a range of strategies [5]. Since they may avoid costly cable construction and grid connection expenses while also stabilizing the system, SGs that utilize RES are viable alternatives for places wishing to create green power outside the grid [6]. Due to improvements in high-performance controllers and power electronic converters, many RES types may now be incorporated into the SG [7].

To incorporate RES such as solar and wind energies, a variety of converter topologies and control strategies have been developed [8]. Providers may utilize the Internet of Things (IoT) to collect data on the SG and to carry out continual self-evaluations so they can solve any problems right away. A crucial aspect of the relationship between the SG and RES is data collecting. These data are then quickly transferred to the grid to alert the utility of any concerns, hence enhancing service security and dependability [9]. Serious questions are raised about the existing fossil fuel-based power system's ability to continue providing fairly clean, dependable, and affordable energy services to people and companies [10].

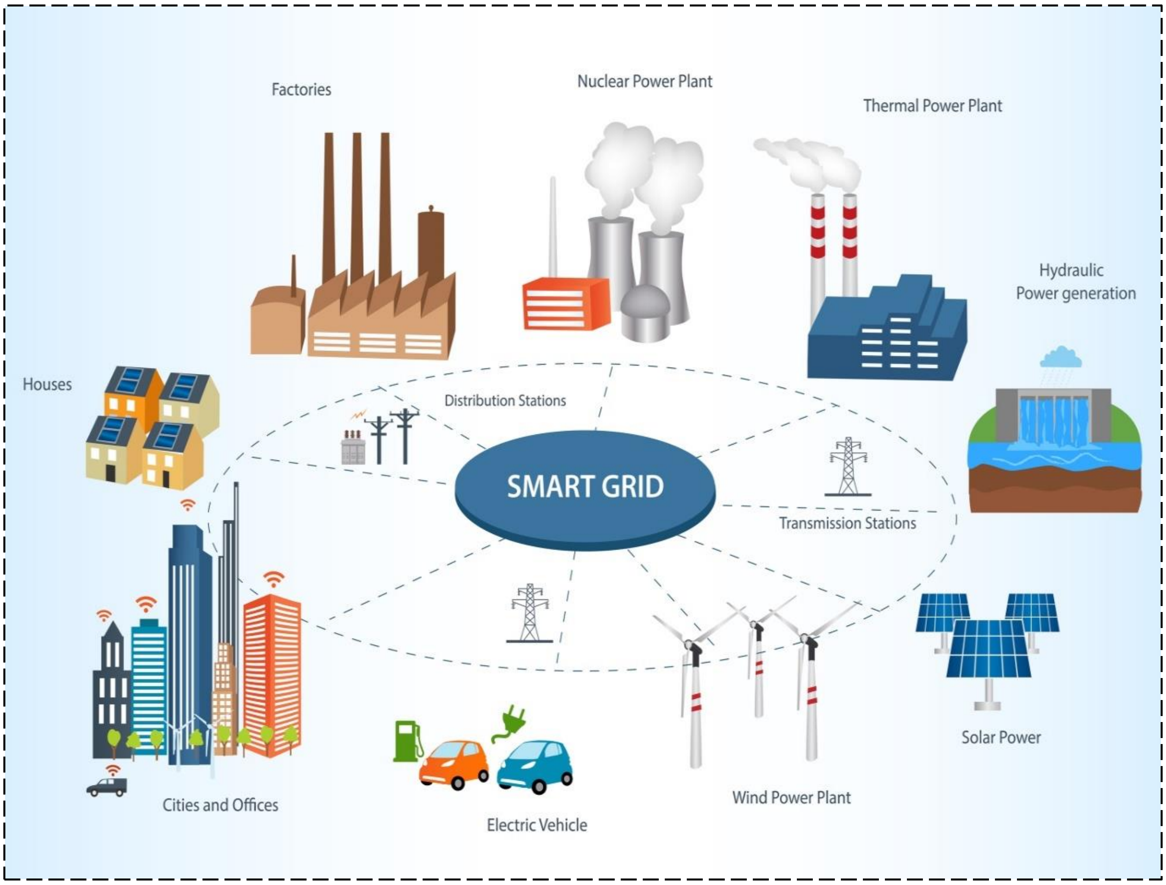

Figure 1.1: Smart Grid Configuration.

Due to limitations in monitoring technology, the average peak costs are no longer dispersed across all consumers fairly. When SGs are incorporated into the traditional power system, there are significant changes that occur. Previously, electricity was generated and used right away at the grid boundaries, but in SGs, it can be stored and used as needed, and electricity costs are rapidly declining [11].

In this work, the proposed SG is composed of PV, wind turbine, ESS, and grid, the EMS of the proposed system is present by controlling the common DC bus. In PV systems, DC-DC step-up converters are employed to regulate the PV panels' unstable and subpar output voltage. To enhance the system's power reliability for the grid connection, a DC-AC (three or three-phase) inverter is utilized to generate the requisite constant voltage and constant frequency. The control circuit of the proposed inverter is depending on droop control techniques. Similarly, AC-DC-AC (rectifier - boost - inverter) converters are necessary for the proposed wind turbine since wind energy fluctuates. A Permanent Magnet Synchronous Generator (PMSG) is employed as a wind turbine generator. The ESS is controlled to charge the power when the generation of the RES is exceeding the demand, and ESS can discharge in case of the demand is exceeding the RES production.

1.2 SMART GRID DEFINITION AND BENEFITS

A smart grid is described as an electrical network that intelligently combines electricity producers and customers to effectively supply power that is accessible, safe, affordable, dependable, efficient, and sustainable. It also has adequate capacity and coverage area. One of the two main concepts for improving electric power exchanges for both utilities and consumers tends to be the impetus for the development of the SG. From the design stage down to the electronic equipment utilized for power generation, distribution, ESS, and consumption, the expanding installations of RESs demand a concerted effort [12].

Following is a summary of the advantages of SG based on RES [13, 14]:

a. Making it a possibility for RES to support greater penetration while enhancing electricity quality and reliability and remaining cost-effective.
b. Involving consumers as vital contributors to the electricity supply. Reducing load peaks and improving energy utilization provide cost reductions, and decreasing carbon dioxide issues.
c. Load monitoring and voltage control make it possible to lower operating expenses based on minimal production costs.
d. Smart grids increase the overall system efficiency as compared with traditional power system.

Legal limits, technical constraints, and the requirement for the product supplier and the customer to stand by the worth proposition all hinder the implementation of SG technologies. Figure (1.2) illustrate the briefly of the benefits of the SG as explained in details in the abovementioned points.

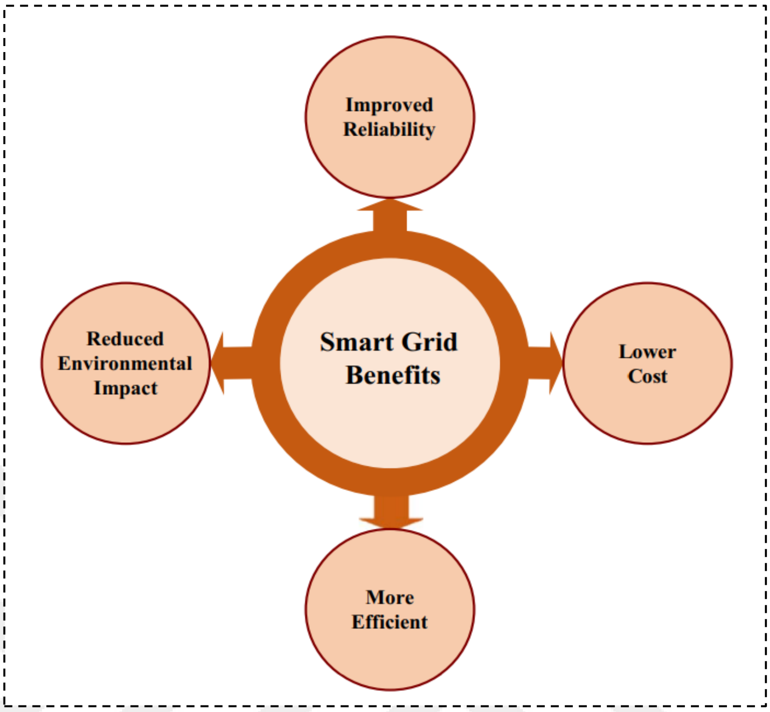

Figure 1.2: Smart Grid Benefits.

1.3 INTERNET OF THINGS in SMARD GRIDS

One of the main and important technical developments of the twenty-first century is the creation of the Internet of Things (IoT). IoT is defining as hardware network linked nodes, software, and hardware that enable data dissemination and collection. The "IoT" is a term used to describe the exchange of data among various infrastructures and devices [15]. Access to the Internet is not feasible without them. Internet devices are watched over by the Internet Protocol. Online user-to-user communication is possible thanks to the Internet. The goal of networked "things" is to enable routine items to exchange data and information autonomously and on a regular basis. An "intelligent building" is a construction that employs electronically connected machinery, data, and technology.

Some suggestions for improving the functionality of SG include the incorporation of RES, EMS, trading, pricing, and SG monetary transactions, which may result in a flatter load profile and a competitive advantage. An SG might be created from a power grid employing sensors or smart meters. These reliable sensors send out a lot of information. This aids in understanding network dynamics and forming hypotheses. This is not achievable due to the enormous amount of data needed to connect and store thousands of IoT nodes [16].

Through real-time monitoring, novel pricing strategies, dynamic EMS, and self-healing, IoT devices and technologies may enhance SG. In network elements and services that have been changed to SG, intrusions are increasingly important. To improve convenience, safety, and energy efficiency, SGs utilize automation, sensors, and remote controls. IoT sensors keep an eye on "smart" building components. This information can improve interiors. Tablets and smartphones increase the use of IoT-based "SGs," which keep track of a building's temperature, security, and maintenance. Due to the IoT's capability to connect several sensors, data could linked and analysed in life-time, resulting in more inventive and user-friendly structures. Here, in this work, the IoT can work as a load shedding device to balance the load demand with generation and keep the battery system safe as possible [17].

1.4 PROBLEM STATEMENT

One of the main problems that have to be solved is managing and controlling energy flow in an SG. Different sources, burdens, and ESS dynamically interchange electricity in a high-power network, problems with power quality and stability may occur. To meet the load requirement, there must be constant management of energy flow over the system. The main issue with the SG's functioning is the absence of technical information regarding the equipment and exploratory configuration of the EMS. The availability of the primary power grid, the ESS's current condition, the fluctuation of RES output, and this difficulty must all be taken into account. The EMS approach is difficult to integrate into the control system, thus this study proposes an EMS with a wide range of modes to operate the SG efficiently in a variety of situations. These flaws may be fixed by adding the EMS technique to the control system. This study evaluates the power balance in an experimental small-scale SG under different circumstances. In this work the PV system efficiency is increasingly using artificial intelligence-based methods to achieve Maximum PowerPoint Tracking (MPPT). This work also includes wind turbine MPPT. The importance of the many operating modes that might occur during system operation is illustrated by this work. The optimization factor derived using an Artificial Intelligence (AI) technique will be used to calculate how much grid electricity is needed to meet the load demand. The purpose in study is to improve the energy quality and EMS of the PV-wind turbine-battery employing the Grey Wolf Optimizer GWO algorithm, which is based on the AI technique used to accomplish MPPT, to maximize the efficiency of the suggested system. The IoT is also can , be integrated with SG to improve the reliability of the system, here IoT can control the load demand in case in the load increased more than the RES for long time period.

1.5 LITERATURE REVIEW

The fundamental drawback of wind and PV energy as RES is their intermittent nature, which results in fluctuating and unpredictable production. Different dispersed generating of RES, electronic converters, and variable demands with ESS systems are all included in an SG, a sort of autonomous grid. Both off-grid and grid-connected functioning of the SG is possible. While there are several definitions of a microgrid based on its capacity, which can range from a few megawatts (MW) to tens of kW, this research defines an SG as a small controlled electricity system with a rated output is less than 100 kW.

Investigations on the simulation of combination PV-wind configuration have been carried out conducted in several ways. For example, the authors of [18] created and optimized an Islanded SG using Particle Swarm Optimization (PSO), which employed a faster calculation time than the Genetic Algorithm (GA) to achieve minimal expenses. A bidirectional DC-DC converter regulator for ESS was used by the author of [19] to study the SG. A three-phase VSI controls output frequency and voltage simultaneously by utilizing a sophisticated vector-control system. In Ref. [20], the authors list various PV-wind hybrid system configurations along with component modeling parameters and computer programs for sizing.

For the purpose of distributing load power among solar and wind energy, Ref. [21] proposes the distributed inverter control technique, whereas Ref. [22] authors employed switched Model Predictive Control (MPC). A PMSG was utilized in certain research, like [23], to model and simulate general RES that are not particular to a microgrid. For example, the microgrid system is discussed in Refs. [24]. In Ref. [25], the authors model a battery-ESS employing theoretical and circuit-oriented methodologies, whereas in [26], they model a lithium-ion battery utilizing state-of-charge estimation.

In Ref. [27], an extremely powerful boost DC to DC with an MPC-MPPT technique is used in a PV system, introducing the ideas pertaining to the design of DC-DC step-up converters. The various switching frequencies, nevertheless, led to issues with optimal design. Interleaved DC-DC (IBC) are compared to traditional boost DC-DC converters in an overall scenario described in Reference [28], and IBC is contrasted to Cuk-Converter for PV in Reference [29], these two emphasized the advantages of IBC. Additionally, [30] implements an overlapped DC-DC step-up converter of the Single-Ended Primary Inductance Converter (SEPIC) kind to a two power directions DC MG, and [31]'s three-phase parallel IBC illustrates the ripples at the outputs diminish as the amount of parallel converters increases.

The System Advisor Model [32] provided a framework for gaining utilization of technical information on real SG components as well as data for case study development. P&O for the off-grid PV [33], P&O with constrained search area in Ref. [34], and P&O for the on-grid PV system in Ref. [35] are only a few of the MPPT methods that are described for PV systems. The authors of Ref. [36] and Ref. [37] present the MPPT techniques for a PMSG-based wind energy conversion system (WECS) employing P&O MPPT and PI controller, respectively. Additionally, writers in Reference [38] examined several MPPT techniques for WECS. The investigators in Ref. [39] modelled the microgrid system's components using MATLAB/SIMULINK.

The incorporation of RES and distributed energy resources (DERs) into the SG has been extensively studied in the past. On the incorporation of RESs into the SG, many special journal editions have been produced; for example, see [40]. Additionally, a few books [41] have been written about this subject. These earlier works looked at the RESs' incorporation with the SG from various angles. For instance, [42] studied communication systems for connection to the grid. In [43], a road map for integration is shown. In [5, the virtual power plant (VPP) idea and the incorporation of RESs into VPPs are presented.

Modern discussions of major technologies for combining of various RES kinds may be found in [44]. The study [44] specifically addressed the multi-time-frame robust scheduling/dispatch issue. The incorporation of dispersed RES into the SG has been taken into account in [45]. We offer a current summary of the communication issues resulting from the incorporation of RESs into the SG as an addition to these earlier publications.

1.6 THESIS OBJECTIVE

Different RESs with ESS, and loads at variable ecological input resources are present in the proposed SG. Even with this crucial control, it is difficult to provide sufficient energy transfer and management regulations in SG among these resources and loads. In many of their previous efforts, researchers in this subject employed control algorithms; nevertheless, these algorithms had numerous shortcomings as compared to independent SG. Therefore, the purpose of this study is to provide energy management control algorithms for the proposed circuit using RES that works at MPPT (both PV and wind turbine).

To meet the issues at hand, the following objectives were established also in this work:

a. Conduct an extensive examination of the books, journals, and conference papers on PV, wind, and ESS that linked SG with their controllers.
b. A critical assessment is done of the principal converter topologies employed in PMSG-based PV and wind turbine systems.
c. Outlining several situations for a power management strategy using battery ESS.
d. Different MPPT algorithms, including (INC.) and (GWO), are used to raise the output efficiency in PV.
e. To regulate the device that keeps an output voltage and frequency steady as much as feasible, VSG was designed and simulated.
f. To look at the construction of the battery's bidirectional controller unit with DC/DC converters.
g. To examine the DC/DC step-up converter design for the PV system.
h. To examine the wind turbine systems' AC-DC and DC/DC step-up converters are designed.
i. Put into place and modify SG's hybrid EMS.
j. To confirm the theoretical analysis, the suggested SG based on RES and IoT is simulated using MATLAB software.

1.7 THESIS STRUCTURE

This thesis is organized into four chapters for presentation:

a. The study's aims, objectives, thesis structure, and related literature are all covered in Chapter 1, along with a quick overview of SG based on RES with IoT.

b. Chapter 2 covers technical and theoretical descriptions of the (PV, wind turbine, ESS, and EMS) systems in addition to examining the inverter, converters, and their controllers.

c. A three-phase inverter, a bidirectional converter, a battery-ESS, a step-up converter, a three-phase inverter, and their controllers are all included in the recommended design of a RES that is discussed in Chapter 3 of this work.

d. Chapter 4 covers the recommended architecture of the SG with RES and ESS simulation using the MATLAB/Simulink program.

e. An overview of the research's outcomes, including its conclusions, is also provided in Chapter 5. The different disruption circumstances listed will be accompanied by the necessary visuals and performance.

2. THEORETCIAL BACKGROUND

2.1 INTRODUCTION

The increasing of RES in the electrical system has grown during the last several decades [46]. These sources require the usage of an ESS since they are intermittent and their output profile doesn't exactly match the load profile. EMS is an inherent challenge for grid-connected scattered RES in this environment [47]. The challenge is caused by factors including irregular supply, pricing, sizing solar panels and/or wind turbines and batteries to suit demand, and restrictions on battery charging and discharging rates.

The integration of ESS into the power network is one of the suggestions made in this study to improve the dependability and effectiveness of these networks [48]. One of the most important components that may be utilized to increase dependability is the PV-wind-Battery combined module [49]. A power source known as a PV cell converts solar energy from sunshine into electrical energy. A large number of panels, cells, and arrays make up the PV system. Large-scale PV systems provide electricity that is used by loads linked to power system [50]. To transform the DC energy into AC energy with the necessary values, a DC/DC step-up, DC/AC power converters, and MPPT are needed. The wind turbine is employed in this work as a wind turbine generator to transform the kinetic energy of the wind to electrical energy. When the PMSG output is AC, an AC to DC converter is required to change the energy to DC for situations that are more stable.

For system balancing or EMS reasons, the ESS is essential [51]. To control the energy transferring between various RES, which regulates the bidirectional that connected to the battery and permits charging or discharging, energy transfer management is needed. The battery's state of charge affects the energy transfer management controller [52]. Artificial intelligence (AI) that maximizes power is utilized to improve PV battery system efficiency [53]. This chapter will cover topics such as the operation of a PV solar system, the PMSG wind turbine, concepts, construction, smart grids, and the Internet of Things. This study will also examine the EMS that is suggested in addition to the many EES kinds that may be employed in power systems.

2.2 ENERGY MANAGEMENT SYSTEM

The latest and greatest current innovations in energy generation technologies are now going through a highly complex evolution, which is closely tied to RES [54]. Increasing the reliability of the MGs generators and reducing grid losses are two of the key objectives of this project's management of the utilization of adjacent energy sources.

The great majority of contemporary smart grids, it seems, are MGs. As a result of the dispatching units' inability to operate manually because of the unusually elevated degree of supervision and difficult growth, the MGs will be responsible for the electrical systems' stability, dependability, and cost-effectiveness. [55].

Power controllability and forecasting are main problems in electrical grids with incorporated RES. Because of that, the ease of control for RES generators must be equal to that of traditional generators. Because of lower inertia and energy stores, off-grid MGs have a harder difficulty sustaining stability, particularly in highly dynamic settings [56].

As a result, enhancing RES generation management, especially in transitory systems, is a problem in addition to boosting MG stability in case of ESS present. This study will includes PV and wind systems for energy generation due to their significant promise in terms of control speed and the ability to handle stability concerns [57].

This option looks into ways to increase energy production by using a battery as an ESS. The main problem that has to be explored in this research is how PV and wind turbine power systems regulate power flow when utilized in addition to the BESS within the power station. This technique is acceptable despite the potential for increased expenses given the increased MG stability and protection [58]. Using BESS in MG is a good alternative because of its high energy density. BESS incorporation is possible in a variety of RES types.

Advantage of using EMS:
The categorization of no-cost and low-cost energy-saving options in day-to-day operations to save money:

a. Decreased released greenhouse gases.
b. Decreased vulnerability to fluctuating energy costs.
c. Decreased environmental impact.

d. Improved reliability of supplies through decreased reliance on imported fuels.
e. Improved energy consciousness and engagement.
f. More important knowledge of energy usage and utilization, as well as possibilities for enhancement.
g. Acquainted with decision-making processes.

Additional advantages of EMS that can be called as indirect benefits can be listed as below:

a. Increased public awareness.
b. Enhanced company image.
c. Increased operating efficiency.
d. Enhanced maintenance processes.
e. Increased health and security.

2.3 ENERGY STORAGE SYSTEM

Power generation processes need to provide power that is both outstanding in terms of quality and reliability in order to fulfil the increasing electrical load. Petroleum and coal have served as the primary energy sources used to meet these loads for a variety of decades due to the fact that they easily can be altered to supply the needed quantity of power and due to their highly concentrated electricity can be delivered to the site of consuming through pipelines, rail, or roads and then kept there for as lengthy as necessary. Energy sources are now required to fulfil the additional criteria for being free of pollutants and sustainable in order to satisfy the demands for autonomy from the depletion of fossil fuel supplies as well as the limitations imposed by environmental regulations.

Because of their erratic and unpredictable RES supply of electricity, most RES cause issues with the generation of energy. It is extremely hard to expand the amount of RES and finally phase out conventional power sources due to daily and yearly fluctuations in energy consumption. It is not possible for typical coal or nuclear power facilities to quickly alter their energy output [59]. The focus should be on alternate sources that improve the flexibility of electrical systems in order to address this critical problem.

The EES technologies have garnered a great deal of attention since energy is a highly adaptable energy source and can be delivered to consumers over extended distances with incredibly low losses. EES technologies may be categorized based on a variety of factors, including the many forms of energy that are saved, the optimal duration for storage (short, medium, or long term), the rate at which responses occur (rapid or slow), the size (small, medium, or large scales), and how quickly they respond. Figure (2.1) uses an increasingly current method to categorize EES equipment. EES technologies can be classified as chemical, electrical, magnetic, or mechanical based on how electricity may be stored [60].

The ESS classifications are illustrated as in Figure (2.1) [61].

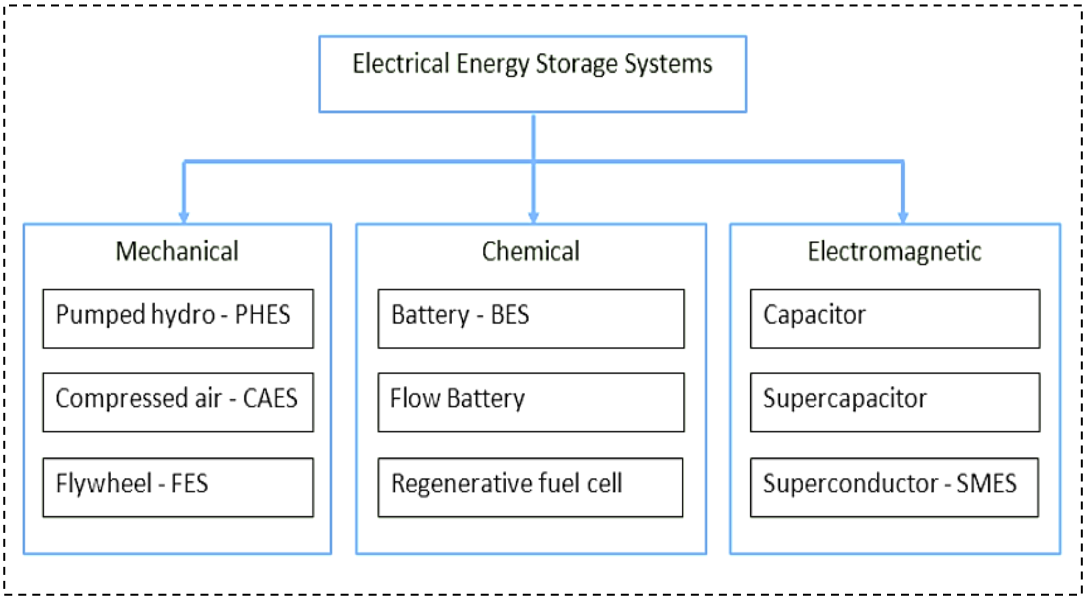

Figure 2.1: Classifications of ESS.

2.4 WIND TURBINE

Wind turbines are classified into two categories: the ones that rotate along a axis, known as Horizontal Wind Turbines (HWTs), as well as ones that rotate along a vertical axis, known as vertical wind turbines (VWTs), they may be used in two cases which are onshore and/or offshore [62, 63]. The effectiveness of an HWT is certainly superior to that of a VWT, owing to the shape of their vanes, which are comparable to aviation wings and may be employed in conditions of heavy wind. However, they require a sturdy tower that can withstand the weight of the nacelle, which is quite expensive. VWTs, on the other hand, are less costly and produce less noise than HWTs [62].

Wind turbines provide mechanical energy after converting wind energy, and its kinetic energy may be calculated using the equation (2.1) below [63]:

$$P_{wind} = ½\, \rho\, A\, V^3 \quad (2.1)$$

Where "ρ" indicates air density in (kg/meter), "A" indicates the total area created by the turbine's blades or wings while revolving in (meter), and "V" indicates wind speed in (meter/second). The energy conversion effectiveness (λ) of a wind turbine has been proved to be the operation of the tip speed ratio, which is also known as "Cp" which reflects the wind-turbine dependence on the tip speed ratio and may be expressed as follows:

$$\lambda = w\, r \,/\, V \quad (2.2)$$

Where "r" denotes the half diameter of the area created by the turbine fans' revolution and "w" denotes the velocity of the revolving wings in radians per second. The true power that may be sent to the wind turbine rotor is calculated using the following equation:

$$Pwind = ½\, \rho\, Cp\, A\, V3 \quad (2.3)$$

The power coefficient, denoted by "CP," is the proportion of the energy from motion converted into electricity that a wind turbine receives. It is calculated employing the following equation [64]:

Where "β" is pitch angle "λ" is tip speed-ratio, during the MPPT algo

$$Cp\ (\lambda,\beta)=0.5\ [116/\lambda\text{-}0.4\beta\text{-}5]\ e\text{^}[21/\lambda] \quad (2.4)$$

$$1/\lambda\_i=1/(\lambda+0.08\beta)\text{-}0.035/(1+\beta\text{^}3\ ) \quad (2.5)$$

Where "β" is pitch angle "λ" is tip speed-ratio, during the MPPT algorithm, the curve between the "Cp" and the "λoptimal" should be achieved to ensure that the wind turbine generator within maximum power. Figure (2.2) shows the variance in "Cp" as an expression of "λ" for various amounts of "β". It has been proved that "Cp" has a maximum amount for every possible angle value, which is denoted by a '*'. Figure (2.3) depicts the variance in turbine aerodynamic power for varying values of turbine speed, but is held constant at zero.

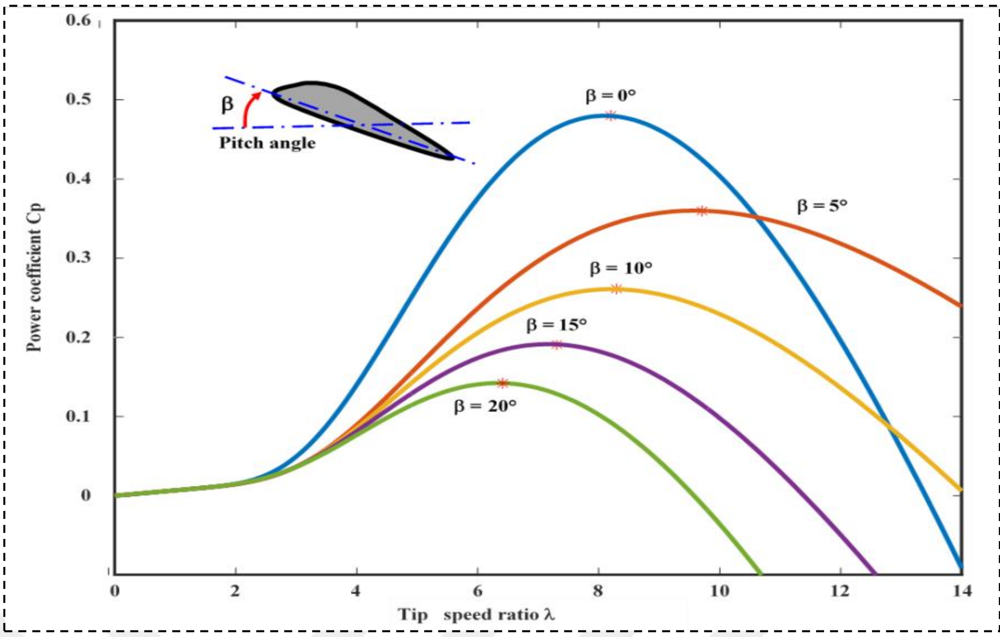

Figure 2.2: Power Coefficient as A Function of Specific Speed and Pitch Angle.

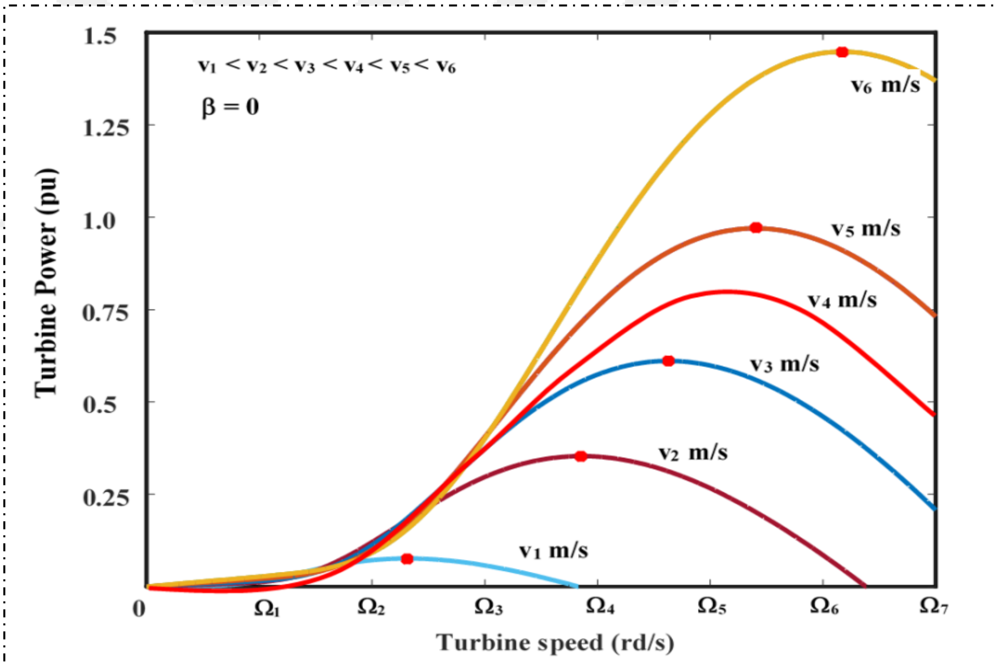

Figure 2.3: Wind Turbine Aerodynamic Power.

Based on the Betz restriction, the maximum possible amount for the coefficient "Cp" is 0.59. However, this amount is never attained since the computation is conducted under a variety of assumptions, such as assuming that thermal energy is minimal and fluid density stays constant. Figure 16 depicts the "Cp" of several current wind turbines. The turbine is connected to the shaft of a generator to generate power. In overall, the turbine's rotational speed is low, necessitating the installation of a speed gearbox across the turbine and the generator. Figure (2.4) depicts this. Nevertheless, in some circumstances wherein the generators have a large number of poles, this gearbox is removed. The total weight of the wind turbine is reduced as a result of this method [62].

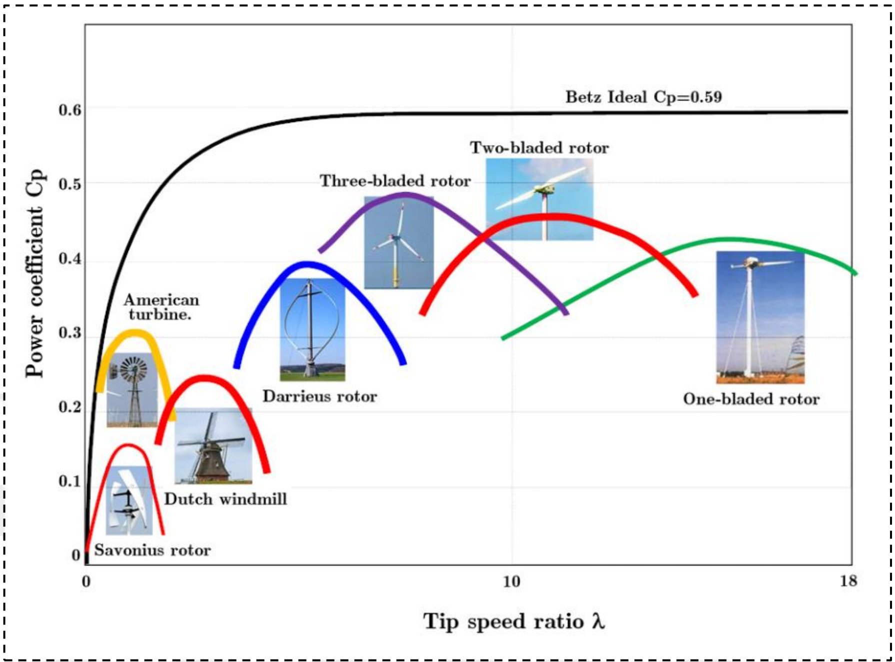

Figure 2.4: The Power Coefficients of Multiple Kinds of Wind Turbines.

The Block Diagram of The Control System of Wind Turbine Can Be Explained as in Figure (2.5) [62].

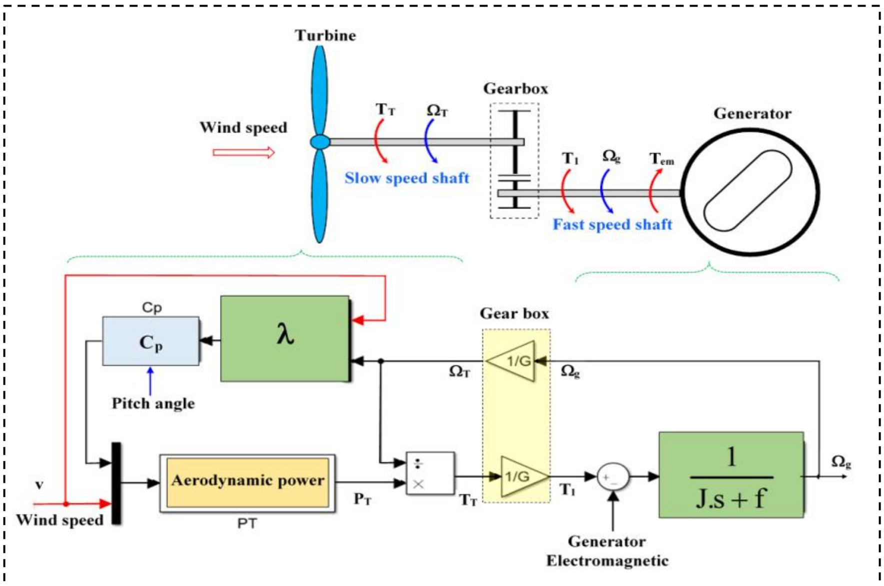

Figure 2.5: The Wind Turbine System is Depicted as A Practical Block Schematic.

Three-phase PMSGs based on controlled pitch wind might be the most important wind energy producers because of their great efficiency and dependability. The three-phase uncontrolled rectifier is used to convert the produced alternating current power to direct current electricity. To boost the voltage and satisfy the necessary DC bus, a step-up converter is also necessary; Figure (2.6) depicts the key elements of the WECS [65].

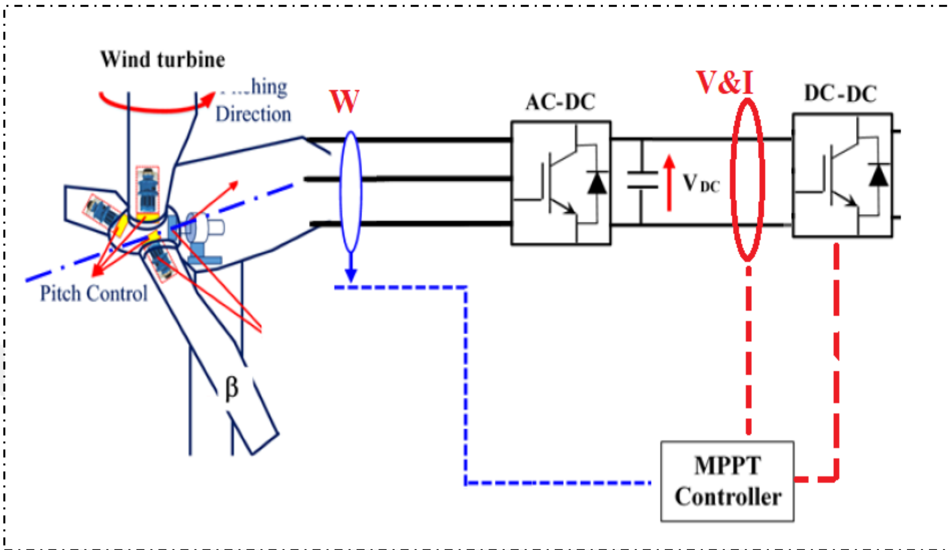

Figure 2.6: The PMSG Wind Turbine with MPPT.

In term of the d–q axis the dynamic emulate of the PMSG wind-turbine as demonstrated in Figure (2.7) can be given in the following equations [66]:

$$d\psi_{sd}/dt = -V_{sd} - R_s I_{sd} - \omega_e \psi_{sq} \quad (2.6)$$

$$d\psi_{sq}/dt = -V_{sq} - R_s I_{sq} - \omega_e \psi_{sd} \quad (2.7)$$

Considering Eqs 2.6 and 2.7,

$$\psi_{sd} = (L_{sd} + L_{md})\, I_{sd} + \psi_m \quad (2.8)$$

$$\psi_{sq} = (L_{sq} + L_{mq}) I_{sq} \quad (2.9)$$

where "V_{sd}" and "V_{sq}" are stator voltages, "R_s" is the stator resistance, "I_{sd}" and "I_{sq}" d and q are the currents in the stator, "ω_e" represent wind generator rotational speed of the," ψ_{sd}" and "ψ_{sq}" are the stator circuit flux linkages, "L_{sd}" and "L_{sq}" are represent the leakage inductances stator wind, "L_{md}" and "L_{mq}" are represent the magnetizing inductances, and "ψ_m" is represent the machine's permanent magnet linkage flux.

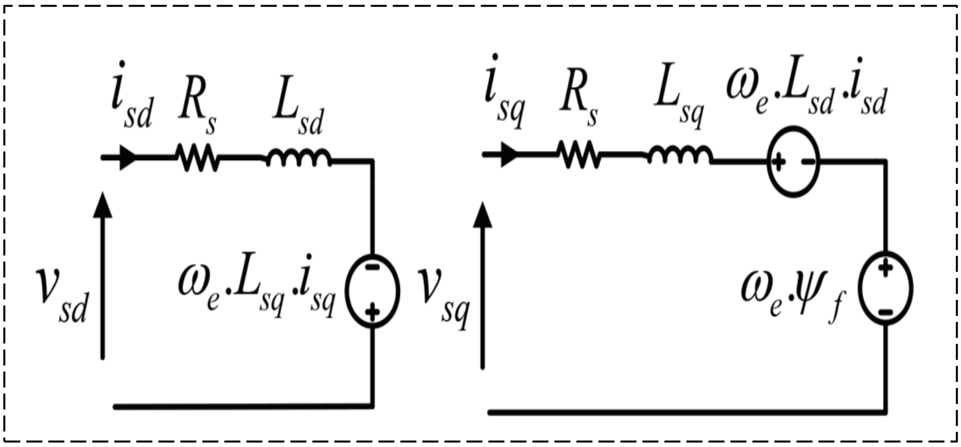

Figure 2.7: Equivalent Circuits of PMSG in - and Q-Axes.

Use in preference to Eqs 2.6 and 2.7 into Eqs 2.8 and 2.9, the differential equations of the PMSG can be found as [67]:

$$L_d\, dI_{sd}/dt = -V_{sd} - R_sI_{sd} - \omega_eL_qI_{sq} \tag{2.10}$$

$$L_q\, dI_{sq}/dt = -V_{sq} - R_sI_{sq} + \omega_eL_dI_{sd} + \omega_e\psi_m \tag{2.11}$$

$$L_d = L_{sd} + L_{md} \tag{2.12}$$

$$L_q = Lsq + L_{mq} \tag{2.13}$$

The PMSG real and imaginary powers are given as:

$$P_s = V_{sd}I_{sd} + V_{sq}I_{sq} \tag{2.14}$$

$$Q_s = V_{sq}I_{sd} - V_{sd}I_{sq} \tag{2.15}$$

The electrically powered torque of the wind turbine generator is supplied with the number of pole pairs as follows:

$$T_e = 0.5p(\psi_mI_{sq} + (L_d - L_q)\, I_{sd}I_{sq}) \tag{2.16}$$

2.5 PV SYSTEM

PN junctions built of thin silicon wafers or sheets make up the PV panel. The output characteristic, IV, of a photovoltaic cell possesses exponential properties comparable to a diode at nighttime or in dark conditions. Whenever a semiconductor is subjected to sunlight, photons with energies larger than the band gap pass through and produce electron-hole pairs. These charged particles are swept away in a PN junction by the action of internal electromagnetic fields, producing an electrical current proportional to the incoming radiation. This current is domestically circulated by the inherent PN junction diode while the circuit is open and externally circulated whenever the circuit is shorted [68]. In order for a photovoltaic cell to provide the necessary energy and voltage for nearly every application, multiple solar cells must be linked in a combined manner. An array is a group of photovoltaic cells arranged in series on an axis to provide a load with enough power. The state of the forward biased for two kinds of parallel diodes connected to the current source is depicted in Figure (2.8).

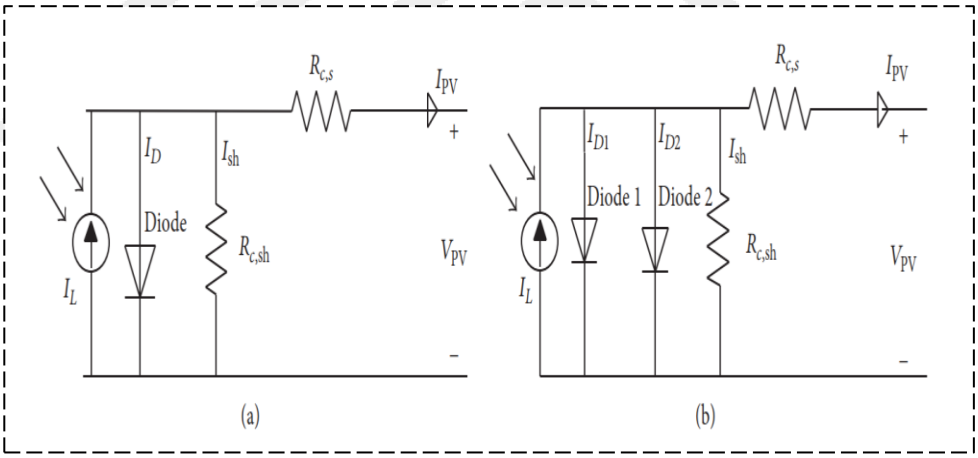

Figure 2.8: PV Simple Circuit (A) One Diode, (B) Two Diodes [68].

The PV-Cell's current during load at its highest point may be found in the formula (2.16):

$$I = I_L - I_D - I_{SH} \qquad (2.17)$$

$$I = I_L - I_0 * [\exp[((q V_D)/nkT-1)-V_D/R_{SH}]] \qquad (2.18)$$

Where "VD" is diode voltage, "I0" is reverse saturation current, "Q" is for electron charge, "k" for Boltzmann factor, "IL" is PV current, "ID" is diode current, and "ISH" is shunt resistor current. The energy output of the photovoltaic cell is given by the next calculation:

$$\text{Power of the PV system} = V*I \tag{2.19}$$

Where "V" denotes the total voltage, "I" denotes the output current of the solar cell, and "Ppv" is the output power. The voltage and current properties in the solar cell differ from the actual values because of losses in the resistors.

In the modeling of the PV system, the concept of connecting a group of solar cells into arrays of cells connected in parallel or series is present. Voltage increases in series with equivalent increases in current. This method raises the series and shunt resistance of the corresponding circuit, as illustrated in Figure (2.9).

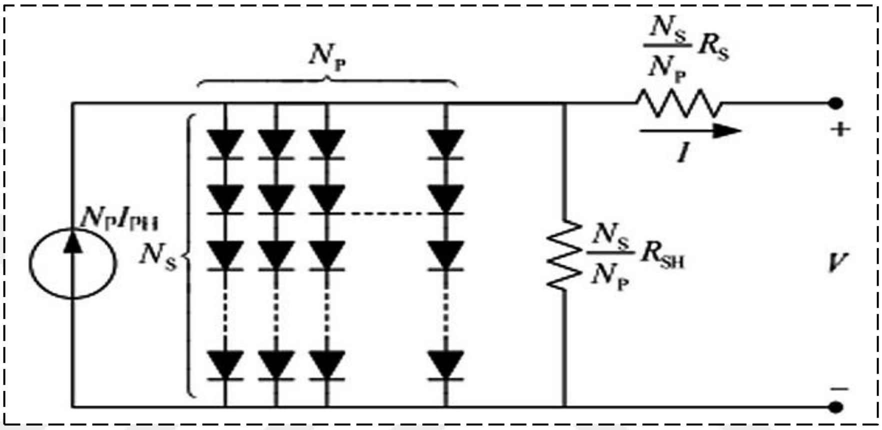

Figure 2.9: Modeling of the PV Array.

Equation of the PV array it can be given as:

$$I = I_{PV} - I_C - I_D - I_{Sh} \tag{2.20}$$

$$I_{sh} = \frac{V_P + R_S I_P}{R_{SH}} \tag{2.21}$$

$$I_{PV} = [I_{SC} + K_O(T - T_{nom})] \frac{G}{G_{nom}} \tag{2.22}$$

Here (I_{SC}) is the short circuit current, which under ideal conditions should range between 25 and 1000 W/m2. T_{NOM} stands for the ideal temperature that the cell should reach. The ideal cell radiation, G_{NOM}, is 1000 w/m2, whereas T stands in for the actual or true temperature of the environment. According to G, the degree of radiation, whether exact or actual and K_O, which is constant at 3 mA/C^0, the increase in short circuit current of 3 mA and a rise in temperature of 1 C^0 from the surrounding temperature are described [69]. The parallel resistance that corresponds to the module is RSh, whereas the series resistance is Rs.

2.6 SOLAR TRACKING

Solar tracking devices are commonly used to maximize PV power output. The creation of a controlling command in traditional tracking systems depends on both data from solar optical detectors and time in the specified location. The precise placement of the panel should be decided at the time of installation for methods dependent on the day and time. The Sun's and PV panel's respective positions are then determined, and the panel is turned towards the Sun. A GPS detector in the system might be used to acquire information about the position of the panel [70].

Maintenance and dependability may become a concern with the guidance and solar sensors in solar tracking devices since these devices may fail to work or their efficiency may decline due to adverse weather and daylight conditions. Although additional sensors could be installed in the system, this would raise the system's complexity and total cost. Because the PV panel detects sunlight, it can also be utilized to determine the direction of sunlight using the MPPT technique and then make control decisions appropriately. In this situation, no extra sensors are required, making the whole system less susceptible to optical sensor failure and smaller because of the ideal size of the photovoltaic panel [71].

The closed and open loop regulation techniques are the two techniques that are described in the solar energy tracking device. A solar sensor is used by the closed-loop control to locate the Sun and orient solar panels. The management command is produced in systems using solar sensors depending on the setup of the sensors to optimize the amount of sunshine that the PV panel receives. On the other hand, this method is useless when the Sun is not present and when there is a lot of bright reflected light. For open loop systems, the orientation of the sun is determined in relation to the position and timing of the solar tracker. Figure (2.10) shows the effect of using the MPPT techniques to maximize the PV power and how the hours of the usage can be increased by comparing the tracking and the stationary PV system panels [70]

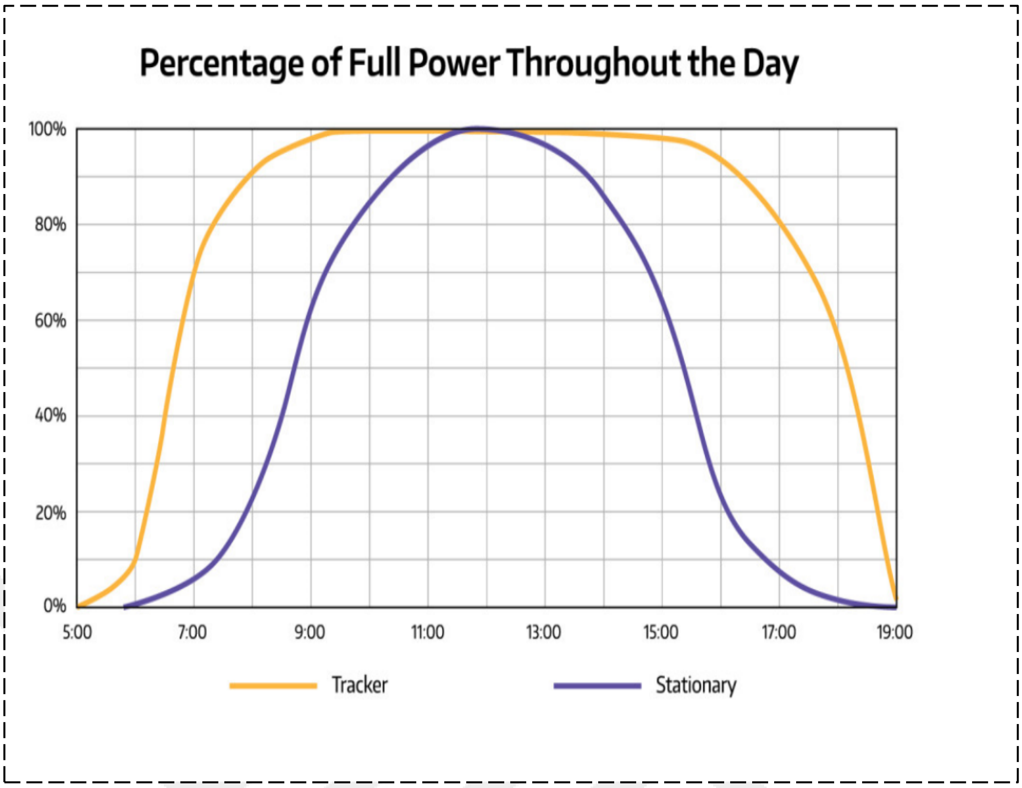

Figure 2.10: Effect of Tracking System.

The fact that solar tracking enhances the manner in which power is supplied in addition to increasing the generation of energy is an additional crucial point to underline. Using solar tracking, users can extend the period of time when maximum power is accessible and generate more efficiently throughout the day. To further comprehend this idea, let's return to the previous image. The blue curve depicts the progression of power output during the day; it progressively rises until noon, when it reaches its peak, before falling back to zero. However, in the orange curve, we can see that output begins to increase as we get closer to the maximum power and continues into the afternoon. Here is an illustration. With a fixed installation process, a solar system that requires its panels to function at 75% of its capacity will only flow for roughly 4 hours per day (during the times of peak solar radiation), however with PV tracking devices, it will push for a maximum of ten hours per day.

Technological drift, manufacturing flaws, geocentric assumptions, and coordinate translations might all have an impact on open-loop systems. The closed loop is frequently incorporated into the open loop to avoid the drawbacks of both strategies. The resultant strategy is occasionally referred to as a hybrid strategy. Figure (2.11) (a) illustrate the one direction moving of the PV panels, while Figure (2.11) (b) shows the two directions moving of the PV panels, this method improve and maximize the output power [70].

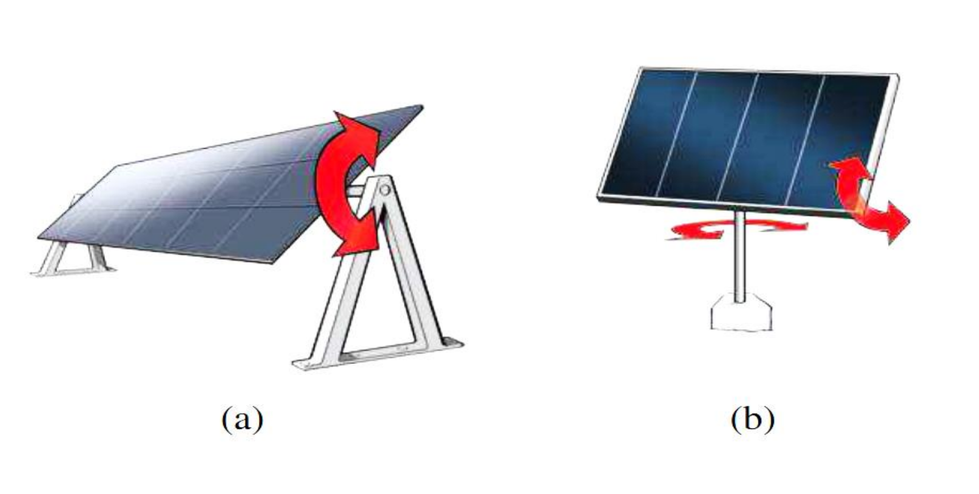

Figure 2.11: One and Two Directions of PV System Tracking.

2.6.1 INC. MPPT

The PV cell is a component that can transform sunlight into electrical energy in the form of DC current. When numerous photovoltaic solar cells are combined, a solar module that may be utilized for certain purposes results. For a particular irradiance and temperature, Figure (2.12) depicts the nonlinear P-V curve of a silicon-based photovoltaic cell with an MPP, which is indicated by its optimum voltage (Vopt), where "Voc" stands for the open circuit voltage (V) [72].

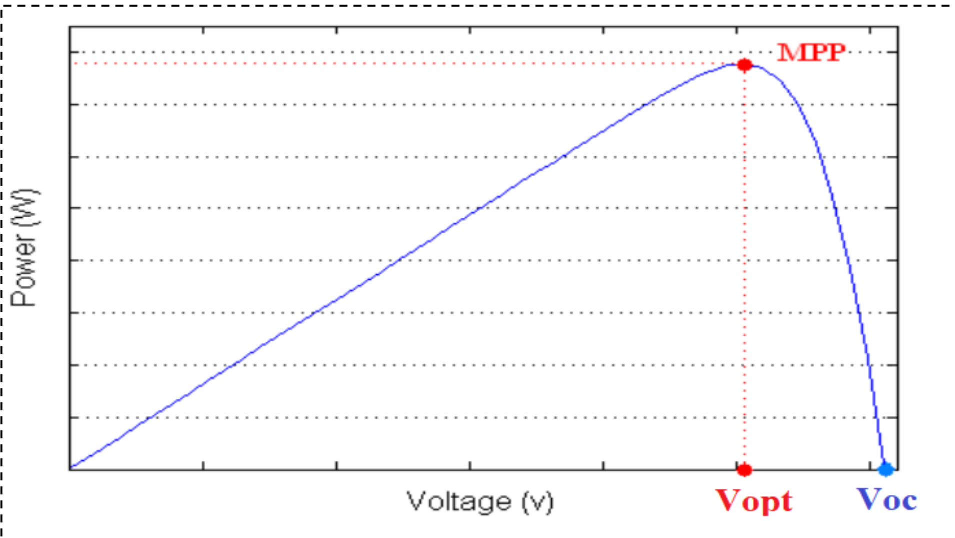

Figure 2.12: P-V Characteristic Curve of PV Cell at A Specific Temperature and Irradiation.

The Incremental Conductance MPPT approach is a method that controls the MPPT using two separate control loops, illustrated in Figure (2.13). The next equation explains why the slope of the P-V characteristic is equal to zero at the MPP [72]:

$$\frac{dP_G}{dV_g} = 0 \tag{2.23}$$

Equation (2.22) can be rewritten as:

$$\frac{dP_G}{dV_G} = \frac{d\,(I_G\,V_G)}{dV_G} = V_G\frac{d\,I_G}{dV_G} + I_G\frac{\Delta V_G}{\Delta V_G} \tag{2.24}$$

$$\frac{\mathrm{dP_G}}{\mathrm{dV_G}} = \mathrm{V_G}\frac{\mathrm{d\,I_G}}{\mathrm{dV_G}} + \mathrm{I_G} \tag{2.25}$$

This implies that:

$$\frac{d\,I_G}{dV_G} + \frac{I_G}{V_G} = 0 \tag{2.26}$$

Inc.'s fundamental concept was motivated by Eq. (2.25). The slope of the P-V characteristic (dP/dV = 0) is usually close to zero at the MPP in actual use. Nevertheless, by permitting a little marginal error—whose amount depends on the desired sensitivity of the MPPT—it is possible to identify this non-zero slope [72].

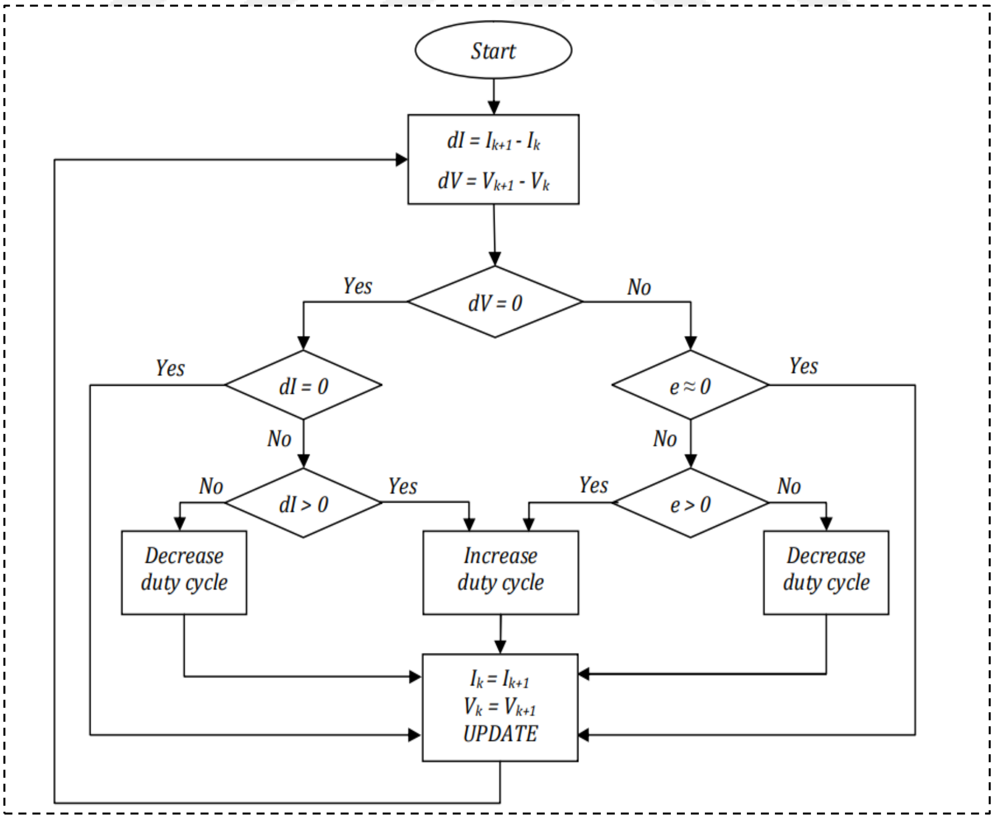

Figure 2.13: The INC. Algorithm Flowchart.

2.6.2 GWO MPPT

To get a superior MPPT, the grey wolf optimization technique is used. Mirjalili initially presented the Grey Wolf algorithm in 2014. It is a mathematical model that imitates the interpersonal relationships of a pack of grey wolves performing prey-gathering. According to their physical condition and level of strength, the wolves in the pack are separated into various groups. The various groups fall under the headings of alpha, beta, delta, and omega. The most physically fit wolf in the pack is alpha (α), followed by beta (β), delta (δ), and the other wolves, which together make up omega (w). The pack subsequently employs an identical framework to track, encircle, and attack its victim. The alpha, beta, and delta wolves are in charge in this situation [73].

The GWO optimization approach takes this issue into account. The model classifies the possible solutions to a given issue into distinct groups based on how closely they match the intended output and also advances the solutions in that direction, much like a wolf pack might pursue its prey, circle it, and then arrive at the desired answer. The mathematical model uses the solution that falls inside alpha (α) to arrive at the best outcome. The following equation was employed by the GWO to do this [74]:

$$\vec{X}(t+1) = \overrightarrow{Xp}\,(t) - \vec{A} \times \vec{D} \tag{2.27}$$

$$\vec{D} = |\vec{C} \times \overrightarrow{Xp}(t) - \vec{X}\,(t)| \tag{2.28}$$

It denotes the current iteration in this case. The intended output is represented by Xp(t), while the existing solution is represented by X(t + 1). The vector parameters, denoted by A, C, and D, are computed using the following equation [74]:

$$A = 2\,\vec{a}\,r_1 - \vec{a} \tag{2.29}$$

$$C = 2\,r_2 \tag{2.30}$$

Whenever r1, r2 are selected at random variables in the range [0, 1], and the coefficients of the vector are linearly decreasing from 2 to 0 as the iterations go.

With the aid of a boost converter, which switches the pulse's duty cycle and can be modified in an ideal manner to get the MPP of PV array, the GWO mathematics model is employed during this study to accomplish the MPPT. To accomplish MPP, the GWO does the required computations. Figure (2.14) depicts the flow diagram for the GWO-based MPPT.

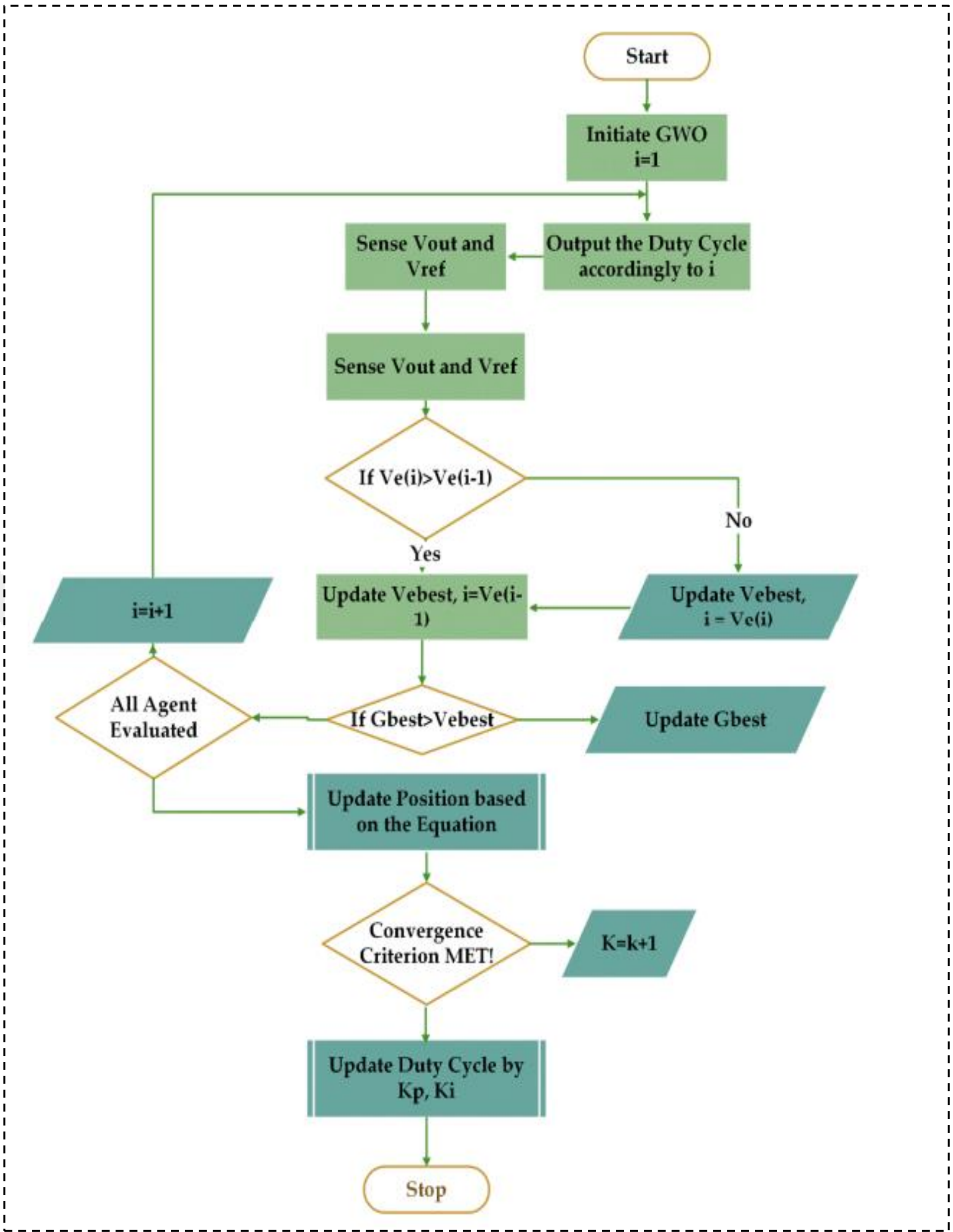

Figure 2.14: The GWO Algorithm Flowchart.

2.7 INTERNET OF THINGS IN SMART GRIDS

The Internet of Things (IoT) is a term used to describe an informational system that links different systems, objects, and components together utilizing cutting-edge Innovation for communication and information access as well as cutting-edge embedded systems like computerized sensors, meters, and regulators. IOT is known as the most recent revolution in information technology in this context. An improvement on the IoT, the Internet of Energy (IOE) focuses on the integration of the energy environment with information and communications technologies. The adoption of IoT in the SG components will be covered in the present study. A network that provides energy and uses digital communications innovation to keep an eye on and react to load fluctuations locally is referred to as SG [75]. The capability of all parts of an SG to exchange information via any type of wireless or wired connection is referred to as the IOT in SG. IOT is viewed as a crucial component in implementing SG and implementing plans for smart cities and smart buildings. Because of the broad spectrum of goods, power shapes, and connected behaviours, the fluctuation of particular electrical field variables, and the unpredictability or disorganized environment of certain phenomena, it is necessary to share and evaluate a significant quantity of information in near actual time and decide choices quickly.

The needed activities must be carried out automatically, and the data may be swiftly and securely exchanged with the appropriate destinations. As a result, the approach is to include IoT technologies in the component design to benefit from networked information technology. IoT-based equipment, which can be sensors, meters, or regulators, are those with power circuits including microcontrollers and microprocessors with the capability to share information. Additionally, it is important to guarantee the accuracy and validity of information, which might be jeopardized by purposeful cyber-attacks or unintended disruptions (disturbances) [76].

A Small-Scale SG (SSSG) is a small-scale combination of loads that are concentrated regarding the distribution system and may satisfy a portion or all of its energy needs employing micro sources such as PV panels, wind turbines, diesel generators, or gas turbines, a few of which can be connected via a hybrid power and heat system. Furthermore, an energy storage facility may be used to store the excess output of small-scale RES when the load is low. ESS units are among the most commonly used kind of storage for maintaining the frequency reliability of the SG. On the other hand, in some circumstances, the use of fuel-cells and flywheel devices is employed. SSSG can be designed with an isolated construction, which is ideal for remote places, or with a linked electrical system. The linked mode is also referred to as collaborative mode, whereas the isolated mode is referred to as standalone mode, islands mode, or off-grid mode. In collaboration with an upstream network, the SG can sell surplus generation of internal resources to the power system. However, contemporary microgrids are plagued by three serious issues: SG efficiency, power quality, and networked SG security [77]. The introduction of IoT can aid in the resolution of these issues, leading to the desired increase in the predominance of microgrid systems. Figure (2.15) illustrate of using the IoT in smart grid.

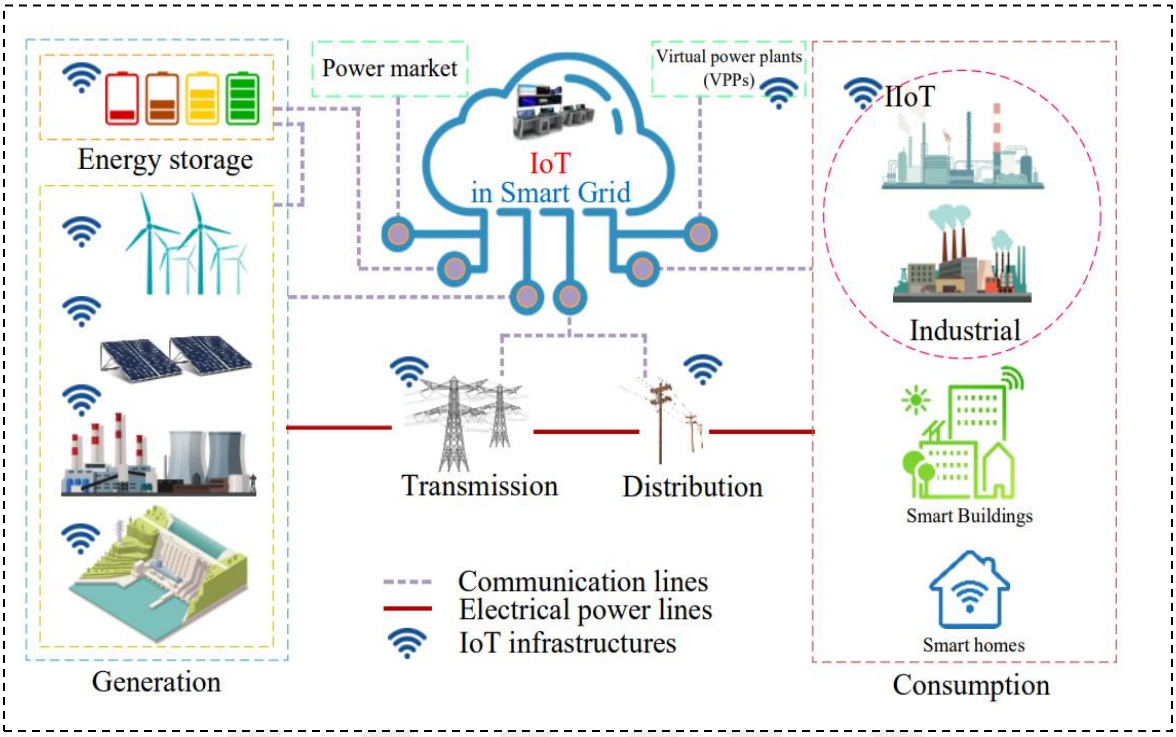

Figure 2.15: The IOT in SG.

The EMS of the SG must be handled separately from the main electrical system. The upstream network has no influence over and visibility into micro-sources. The microgrid manager is responsible for forecasting unknown micro-sources. The internal ESS must correct the imbalances that have been produced. However, because such systems have limited resilience capabilities, the microgrid's operator must apply unexpected load shedding or undesirable curtailment. The introduction of IoT into linked SG enhances the level of observability and controllability of the main grid's operator on SG elements and is capable of taking all micro-source attributes into consideration for the entire system production.

This will result in improved electrical system reliability as well as increased RES penetration. Furthermore, the SG operator may improve storage-renewable cooperation to raise the microgrid's sustainability in line with real-time power market rates. Furthermore, continuous monitoring assists regulating systems in obtaining higher power quality. Furthermore, when two or more SG is linked together, scale mismatch might undermine reciprocal stability. As a result, any significant unbalance in one of them might jeopardize the security of the others. To meet demand continuously, real-time frequency and voltage stability regulating systems must be implemented. This situation needs the use of an internet-based ecosystem that makes use of IoT technology. Data must be collected from all sensors in order to tell the controlling equipment of the real-time condition of vital parameters. The information needs to be analyzed on the cloud, and appropriate action must be taken in accordance with predetermined guidelines.

2.8 INVERTERS IN SMART GRIDS

The SG is a discontinuous power system made up of distributed (RES and traditional) energy sources, ESS technologies, power electronics conversion devices, EMS techniques, and various loads [3]. It is especially suited to areas and populations with access to sufficient RES. The microgrid's energy costs may be sharply cut, and the generation of energy grows more ecologically benign, thanks to the use of RESs. In order to provide an uninterrupted power supply for the nearby loads, microgrids can operate in either a grid-connected or an off-grid mode. The control method is vital in ensuring that the off-grid mode operation specifications are met [78].

In order to meet international requirements, the control method's primary goal is to maintain correct load distribution across distributed generation (DG) inverters with ensuring adequate voltage and frequency stability for local load demand. There are two basic sorts of control methods used in microgrids: those based on communication and those based on droop characteristics. Despite the fact that communication-based control techniques provide outstanding voltage regulation as well as adequate power-sharing between the DG inverters, these management strategies have some disadvantages, such as the need for long-distance communication lines, which raise the cost of the system as a whole and decrease its reliability.

Controlled voltages and power-sharing may be accomplished without communication devices using droop characteristic-based management approaches. These control strategies can help long-distance DG converters achieve effective voltage management as well as adequate power sharing [79]. These methods also get rid of how difficult and expensive communication-based control methods were. The literature has suggested a number of droop-based control approaches for DG inverters in off-grid microgrids to provide adequate load sharing amongst the DGs while managing voltage and frequency control, the control strategy of this type of converter is shown in Figure (2.16). There are certain benefits and drawbacks to each of these methods. The demand for many control loops, which results in complicated controller design and delayed dynamic response, is one of the disadvantages of these droop-based control systems.

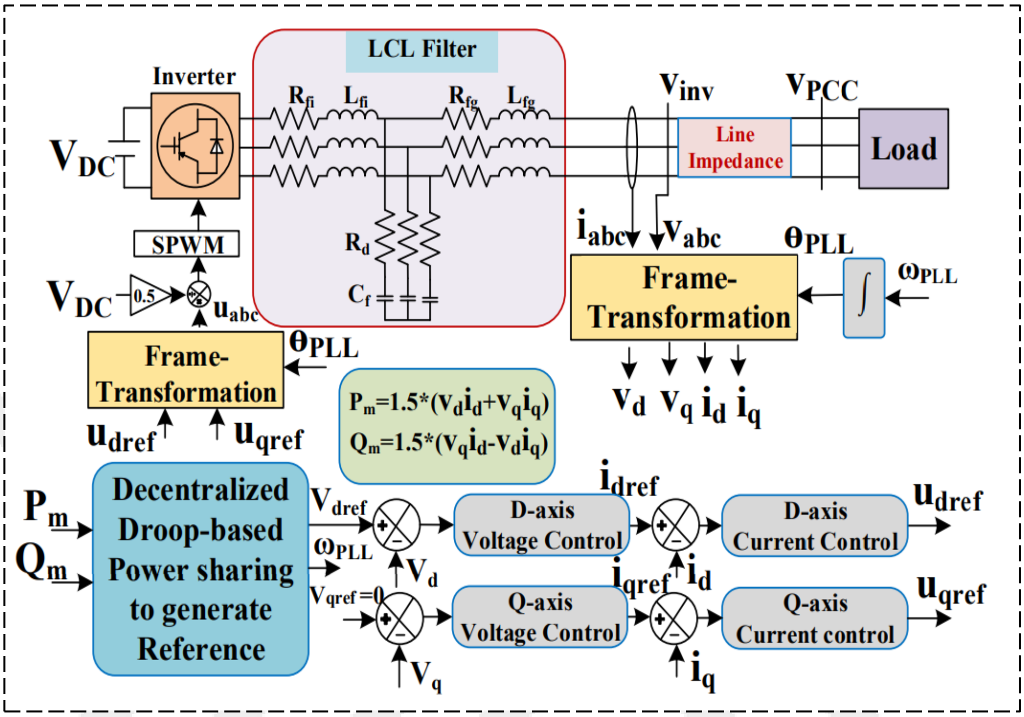

Figure 2.16: Control Strategy of the Inverters in SG.

3. MODELING OF THE PROPOSED SYSTEM

3.1 INTRODUCTION

In Figure (3.1) the proposed SG is illustrated, with the photovoltaic system provided as the system's main electrical source for the duration of the present investigation. To minimize the losses, a step-up conversion device is used to increase the DC voltage and decrease the ampere of a PV photovoltaic. In the present thesis, the PV photovoltaic array uses the GWO and INC. techniques in conjunction with the MPPT methods. The wind turbine system uses PMSG, a rectifier is needed to convert the three-phase AC power of the PMSG into DC power, then a boost conversion device is also employed to boost the DC voltage to be as DC-Bus voltage, the P&O MPPT is employed in this work to maximize the output power of the wind turbine. The battery ESS is used as an additional source of power to supply the necessary power in the unlikely scenario that the main source of electricity fails or is insufficient. A buck-boost bidirectional converter that converts DC to DC is used in a battery ESS for charging and discharging processes.

The suggested EMS technique in the present investigation considers all of the SG's expected operational parameters under various scenarios. This work aims to maintain power balance in a virtual SG under different scenarios. Utilizing realistic, envisioned scenarios, this work examines the necessity of synchronizing the battery ESS with an electrical network. The creation of a rule-based EMS system, which utilize various energy balance techniques to verify the best course of action while taking into account the electrical grid, battery ESS situation, solar power production, wind turbine production, and connected loads, as well as reducing intermittent problems and incorporating an EMS via the implementation of a global method that provides regulation, is another crucial aspect of the work.

Although the RES systems are designed to operate properly have a set of operating variables, they can experience disturbances that interfere with their performance and vary in intensity, duration, and impact. In the present investigation, we will evaluate, analyze, and explain the efficiency and behavior of a hybrid PV-wind turbine on-grid under disturbances, such as an unexpected increase or decrease in demand or an extreme shift in applied irradiance and temperature or changes in the wind speed. A 67.5 kW PV system connected to a 380 V distribution system is modeled using MATLAB Simulink to mimic every possible disturbance. A 27.5 kW wind turbine, on the other hand, is also linked to feed the same inverter and power the load.

The planned SG's EMS met various issues, which may be clarified through the method of charging and discharging the battery-ESS from the electrical network or from PV photovoltaic panels and/or wind turbines. This problem was critical for enhancing power system safety and efficiency by guaranteeing consumers got continuous and high-quality electricity throughout the outages. The purpose of converter control procedures is to detect departures from baseline values in the measurements, which could involve changes in voltage, current, or supplied power.

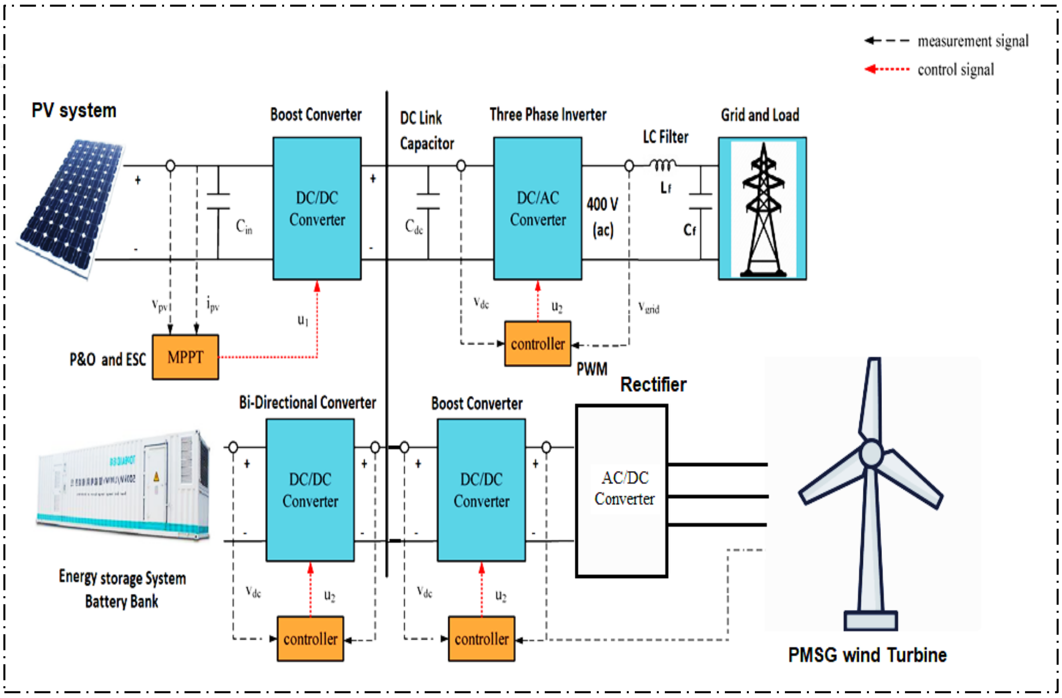

Figure 3.1: The Suggested System.

The major objective of the management techniques is to enhance the efficiency of the SG system under disturbances. An easy way to visualize these techniques is to look at the equilibrium between the electricity produced and loads. As soon as the demand for electricity is low and the photovoltaic system generates extra electricity, the surplus electricity is kept in the battery-ESS. Nevertheless, whenever there is a disruption and the demand unexpectedly rises to a level where it surpasses the solar power system's capacity to generate electricity, the battery-ESS discharges the saved power to meet the increased demand to keep the system's reliability within the appropriate limits. Figure (3.2) shows the proposed system that was put into use employing the MATLAB application.

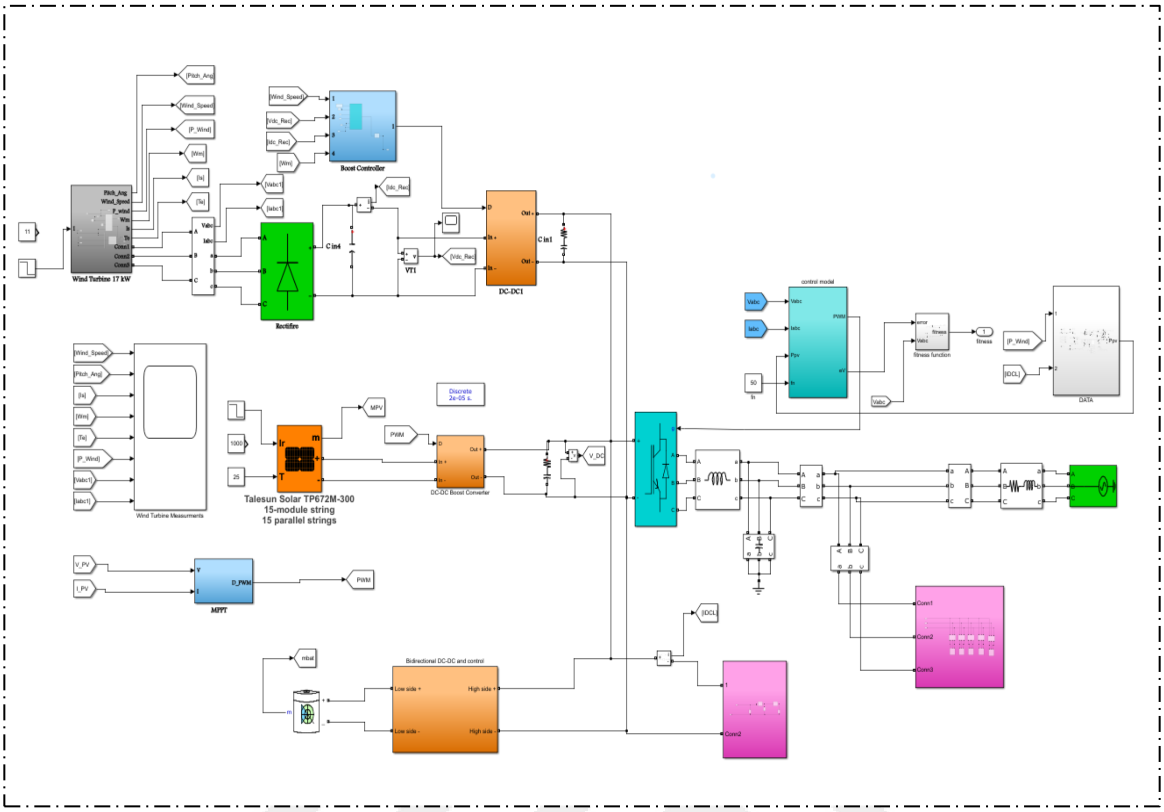

Figure 3.2: The Suggested System Employed the MATLAB.

3.2 DESIGN OF PV SYSTEM

The PV system is used in this work as a main power source, with installed capacity about (67.5 kW). The panel type that used in this work is (Talesun Solar TP672M-300) as selected from the MATLAB program library, the capacity of each panel is about 300.352 W. To get the amount of the PV panels that used to get the (67.5 kW) the following equation is used [80]:

$$\text{No. of PV array} = (\text{Total power}) / (\text{Power of one PV panel}) \tag{3.1}$$

Then

No. of PV panels = (67.5 kW) / (300.352 W) = 224.73

The total number can be consider as (225) PV panels. The arrangement in the farm can be arranged as (15) panels in the parallel and (15) panels in the series. The parameters of the selected array as in the Figure (3.3).

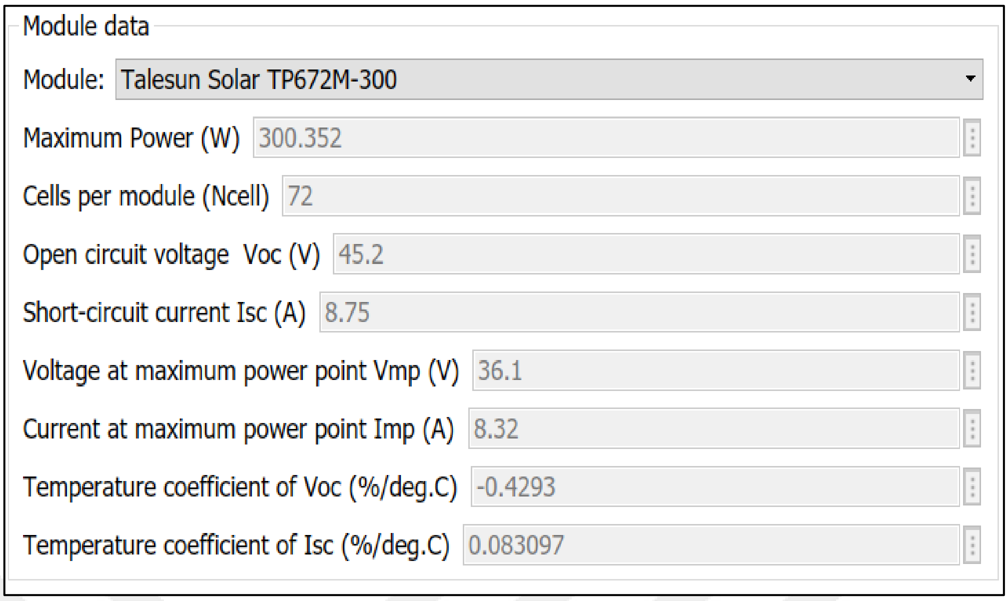

Figure 3.3: The PV Array Parameters.

The total PV voltage can be calculated by adding the voltage of the individual PV panels in series, while the total current can be calculated from the PV parallel panels, as illustrated in Figure 4.3.

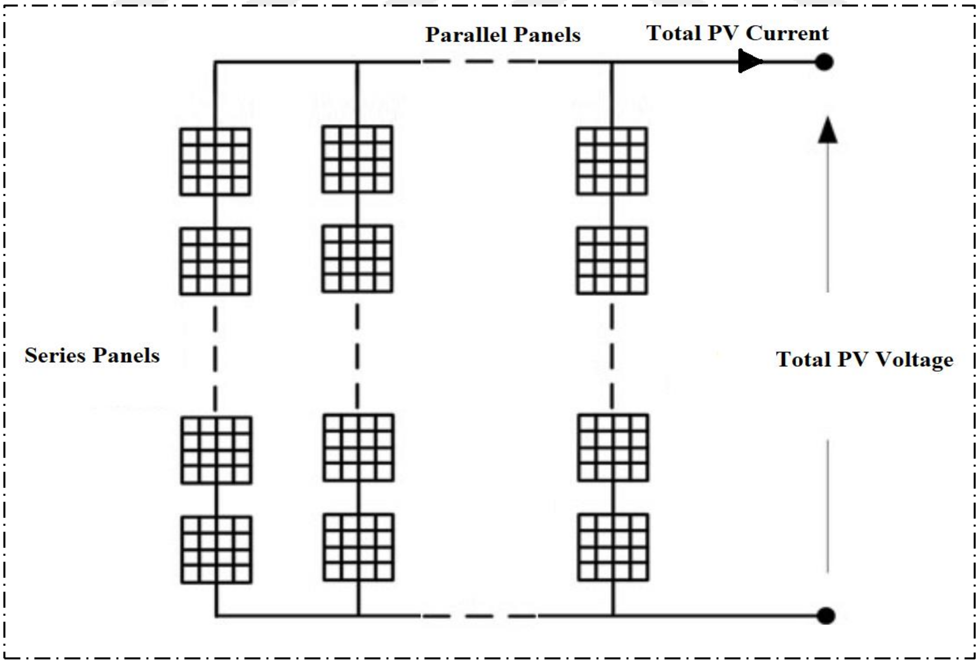

Figure 3.4: The PV Panels Connection.

The total voltage (V_{PV}) = Number of PV parallel panels * voltage of the one panel (3.2)

V_{PV} = 15 * 36.1

V_{PV} = 541.5 V

The total Current (I_{PV}) = Number of PV series panels * current of the one panel (3.3)

I_{PV} = 15 * 8.32

I_{PV} = 124.8

The total power of PV = V_{PV} * I_{PV} = 67.5792 kW.

The PV system (V and I) and (P and V) characteristics of the selected panel (Talesun Solar TP672M-300) can be given as in Figure (3.5) for different temperatures (25 and 45) C^0

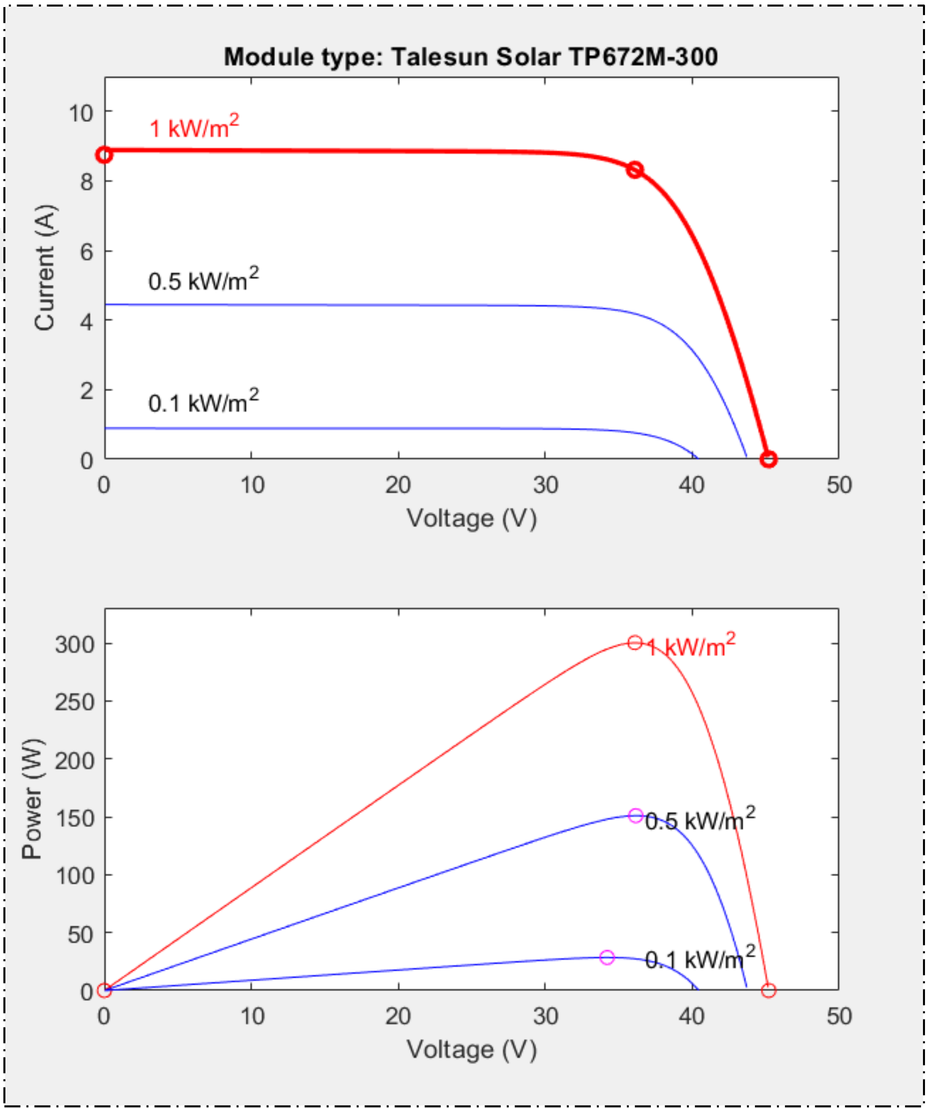

Figure 3.5: The PV system characteristics

3.3 DESIGN OF WIND TURBINE

Wind turbines are an evolution of the old windmills that continue to be prevalent in the globe's more rural areas. Their objective is to increase the generation of energy efficiency and reduce reliance on petroleum and coal. Wind turbines are work by harnessing the wind's kinetic energy that drives the turbine's blades and rotates a generator, turning the kinetic energy towards electrical energy that can be utilized by consumers. Wind turbines are revolving devices that may either be employed for grinding materials directly or to produce electricity using the kinetic energy of the wind. They supply us with clean, renewable energy for use in our residences and workplaces. Wind turbines are practical and contribute to an environmentally friendly world [81].

The proposed wind turbine that used in this work based on PMSG, this type of wind turbine is need for AC-DC and DC-AC power conversion devices for more power stability issues. In this work a three-phase uncontrolled rectifier with diode components are employed. To raise the DC voltage of the rectifier and to make it meet the DC bus system voltage a boost converter can be used and it should be controlled to get the MPPT. Perturbation and observation (P&O) MPPT method is employing here with PMSG wind turbine and DC-DC boost converter, Figure (3.6) shows the implementations of the proposed wind turbine by employing the MATLAB simulation with their control and conversion circuits.

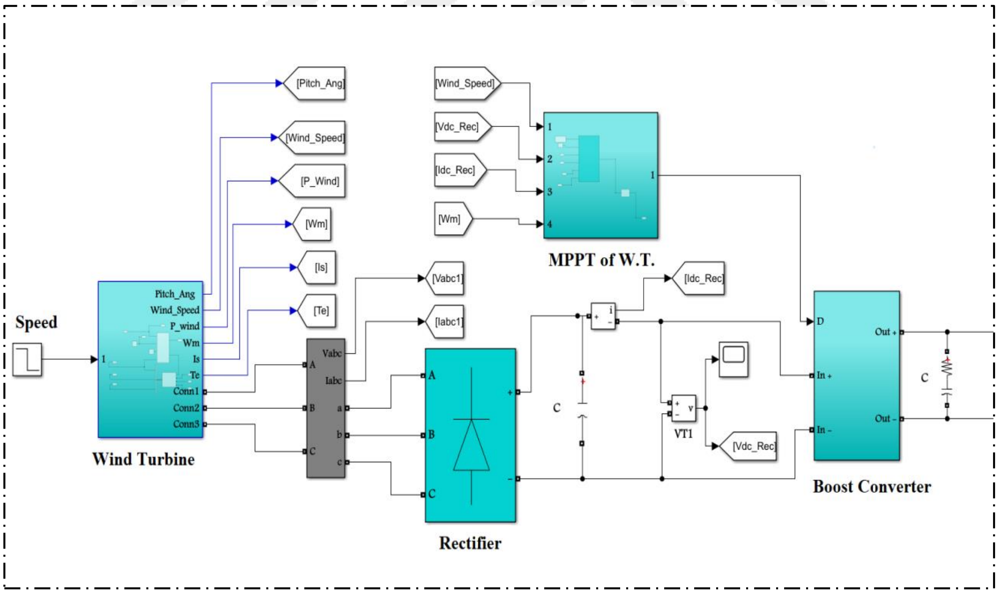

Figure 3.6: The PMSG Wind Turbine Simulations Employ the MATLAB.

The electrical parameters of the wind turbine based on PMSG it can be give as in Figure (3.7).

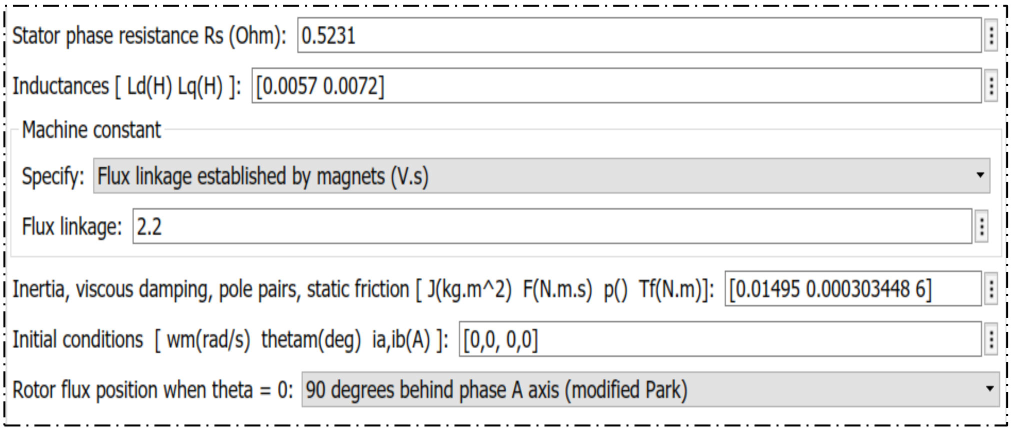

Figure 3.7: Parameters Of The PMSG

The mathematical modeling of the proposed wind turbine according on the equations (2.1), (2.2) and (2.3) is illustrated in Figure (3.8).

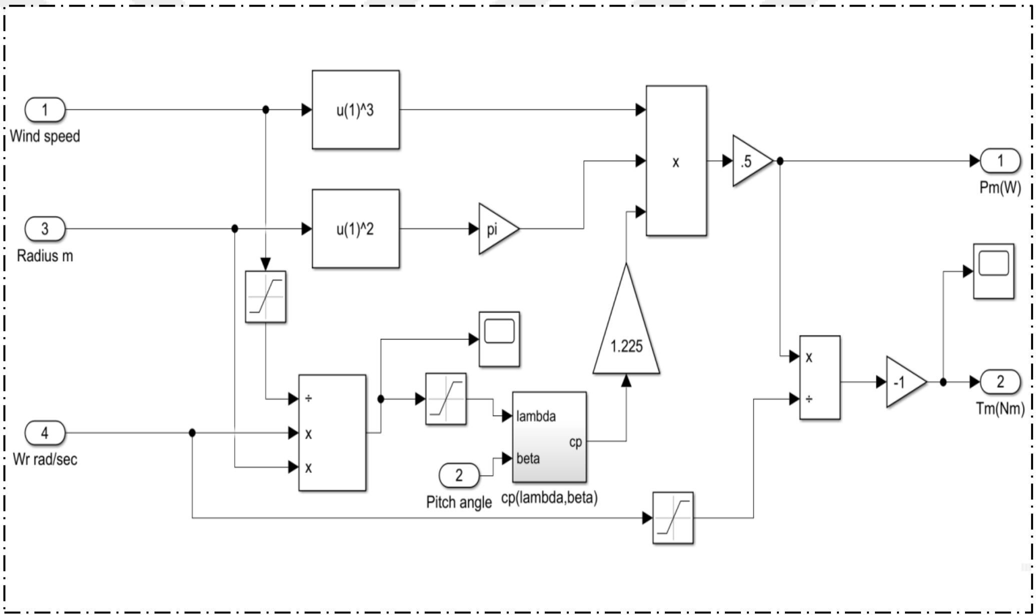

Figure 3.8: Mathematical Modeling of the Wind Turbine.

The equations of the power-coefficient and tip speed ration it can be computed using the equation below, Figure (3.9) shows the implementation of the equation (3.4) and (3.5):

$$Cp\ (\lambda,0)=0.5\ [116/\lambda-0.4\beta-5]\ e^{[21/\lambda]} \quad (3.4)$$

$$1/\lambda_i = 1/(\lambda+0.08\beta)-\ 0.035/(1+\beta^3) \quad (3.5)$$

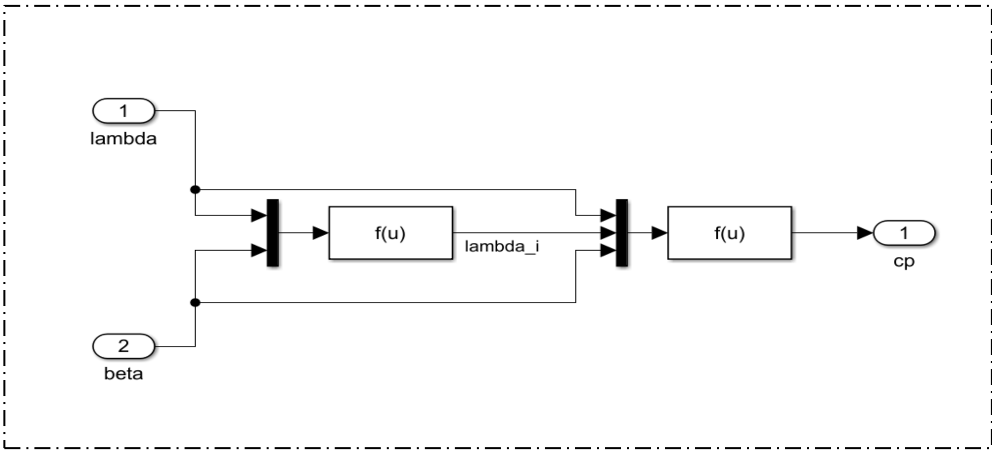

Figure 3.9: Cp and Λ Mathematical Equations In MATLAB.

3.4 RECTIFIER CIRCUIT

Rectifier circuits, which come in single-phase, three-phase, half-wave, regulated, and uncontrolled variations, are power electronic circuits that are employed for transforming the AC power (voltage and current) into DC-direct current. Six diodes are used for three-phase alternating current in the three-phase full-wave unregulated rectifier circuit, as illustrated in Figure (3.10). The major goal of this conversion is to manage the DC voltage and arrive at the highest power point. The rectifier circuit is employed to transform the AC power generated by the wind turbine into DC, and this DC power is then increased by utilizing the boost converter [82].

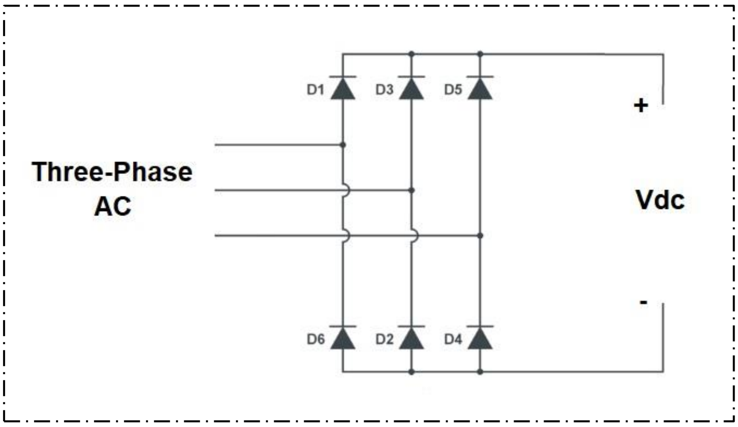

Figure 3.10: Three-Phase Uncontrolled Rectifier.

The DC output voltage is:

$$V_{dc} = \frac{3\sqrt{3}\, V_{peak}}{\pi} \tag{3.6}$$

and

$$V_{dc} = \frac{3\sqrt{3}\,V_{peak}}{\pi}\cos\alpha \qquad (3.7)$$

Where, Vdc Represent the DC-output voltage of the rectifier, Vpeak is the input peak voltage, and α –is the thyristor firing angle (for uncontrolled rectifier circuit the diodes have 0 firing angle, while for controlled rectifier circuit the firing angle is more than 0).

3.5 DC-DC BOOST CIRCUIT

Among the most popular converters employed to raise the PV photovoltaic array voltage to the appropriate DC bus voltage is the step-up converter, often known as the boost converter. The system's losses will be decreased when the voltage is raised. Figure (3.11) depicts the boost or step-up converter's circuit design. The inductor "L" is going to charge the power supply whenever the switch is turned "ON" and the diode is open circuit. The voltage at the input and the inductor voltage will be seen on the output side of the diode while it is conducting throughout the "OFF" switch. To reduce the ripple factor in the output voltage waveform, the capacitor "C" is used [83].

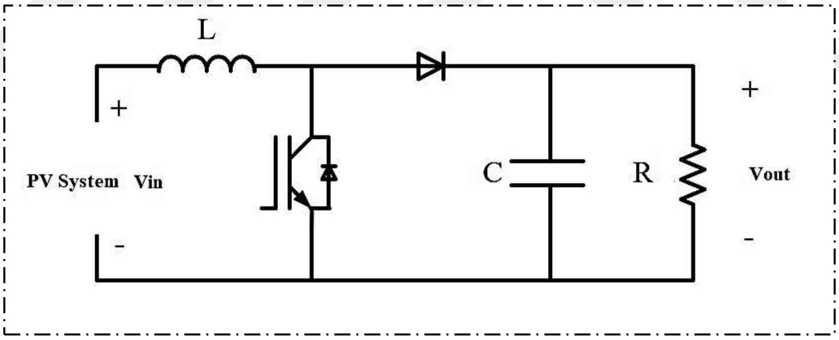

Figure 3.11: Circuit Diagram of Dc-Dc Boost or Step Up Converter.

The "Duty Cycle" (D) of the step up switching it can be given by:

$$D = 1 - \frac{V_{in}}{V_{out}} \qquad (3.8)$$

Calculations (3.9) and (3.10), accordingly, provide the step up inductor and outputting capacitor,

$$L_{min} = \frac{D\,(1-D)^2\,R}{2\,f} \qquad (3.9)$$

$$C = \frac{D}{R\left(\frac{\Delta V_o}{V_o}\right)f} \qquad (3.10)$$

Where $\left(\frac{\Delta V_o}{V_o}\right)$ outputs ripple voltage, "R" is output resistance, and "f" is the switching frequency [84]. The implementation of the DC-DC converter by employing MATLAB is shown in Figure (3.12).

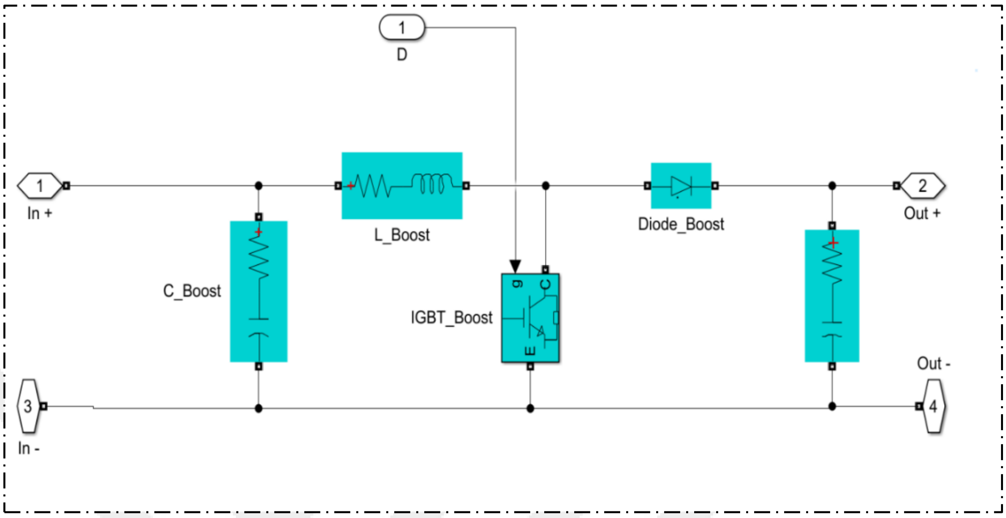

Figure 3.12: Circuit Diagram of Dc-Dc Boost Using Matlab Program.

For the boost of the PV system:

Vin = 541.5V, Vo = 800 V, then D is:

$$D = 1 - \frac{541.5}{800} = 0.323$$

R = V^2 / P = 800^2/67.5 k = 9.481 Ω

Let F = 4000 Hz, them:

$$L_{min} = \frac{0.323\ (1-0.323)^2 * 9.481}{2*4000} = 0.175 \text{ mH}$$

$$C = \frac{0.323}{9.841\ (20)*4000} = 0.41\ \mu\text{F}$$

For the boost of the wind turbine system:

Vin = 320V, Vo = 800 V, then D is:

$$D = 1 - \frac{320}{800} = 0.4$$

R = V^2 / P = 800^2/27.5 k = 23.27 Ω

Let F = 4000 Hz, them:

$$L_{min} = \frac{0.4\ (1-0.4)^2 * 23.27}{2*4000} = 0.418 \text{ mH}$$

$$C = \frac{0.4}{23.27\ (20)*4000} = 0.21\ \mu\text{F}$$

3.6 DC-DC BIDIRECTIONAL CIRCUIT OF BATTERY SYSTEM

A step-up DC/DC converter connects the photovoltaic (PV) system, which transforms PV energy towards DC electricity, with the DC bus. Nevertheless remains an MPP for each unique operating circumstance of a photovoltaic array because of the nonlinear properties of PV panels and the random variations of solar irradiation. In order to get the most power a PV array may produce, MPPT techniques are commonly used in PV systems. The suggested DC-DC bidirectional converter makes use of one of the most widely used techniques, the INC MPPT, which establishes the baseline voltage V at the MPPT that the photovoltaic system will follow to generate the most power under different operational circumstances (throughout different levels of irradiance and the ambient temperature). Battery-ESS is used with the PV and wind turbine system to store the energy when the generated power of the (PV+Pwind) greater than the load demand and to release the energy when the (PV+Pwind) less than the load power to maintain the system stability and reliability of the SG system.

Figure (3.13) shows the main electrical circuit of the bidirectional converter circuit. Figure (3.14) depicts the bidirectional converter's primary electrical arrangement. In this section, we will only talk about the structure of the bidirectional converter. Two toggle switches are going to be utilized: button (S2) for whenever power has to be sent to the power supply and button (S1) for use when the power is kept in the battery-ESS. The DC/DC converter controller mechanism is controlled by both switches S1 and S2 [85, 86]. The inside current loops control the battery's current in order to follow the given instruction, iLB*. View Figure (3.14). The external voltage loop controls the DC-link voltage and gives the internal loop (iLB*) its first input.

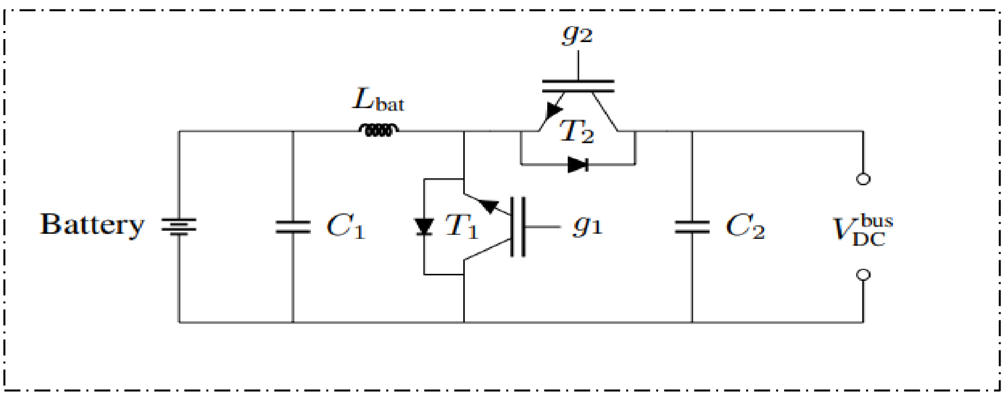

Figure 3.13: Circuit Diagram of DC-DC Bidirectional Converter.

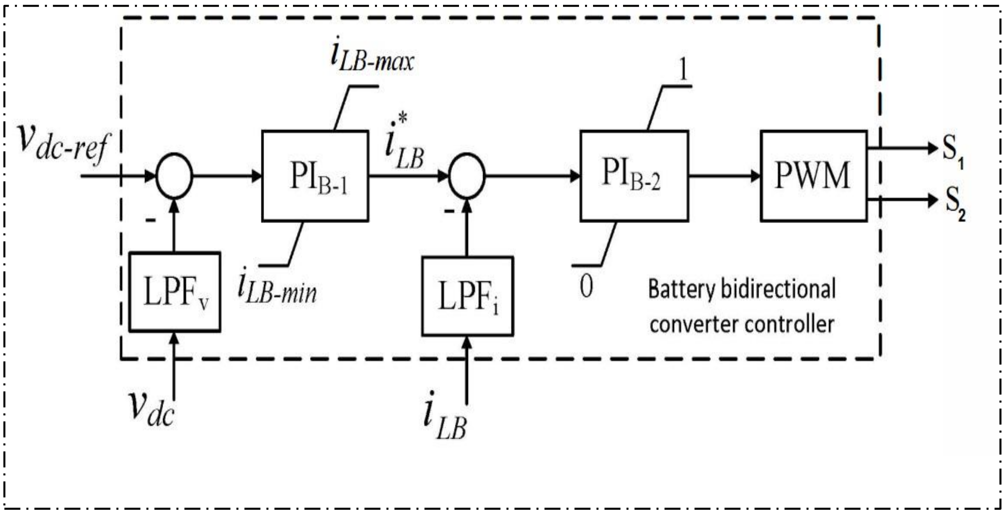

Figure 3.14: Control Circuit of DC-DC Bidirectional Converter.

The integration of the main circuit of the dc-dc bidirectional converter with their control that implemented by using the MATLAB program is shown in Figure (3.15).

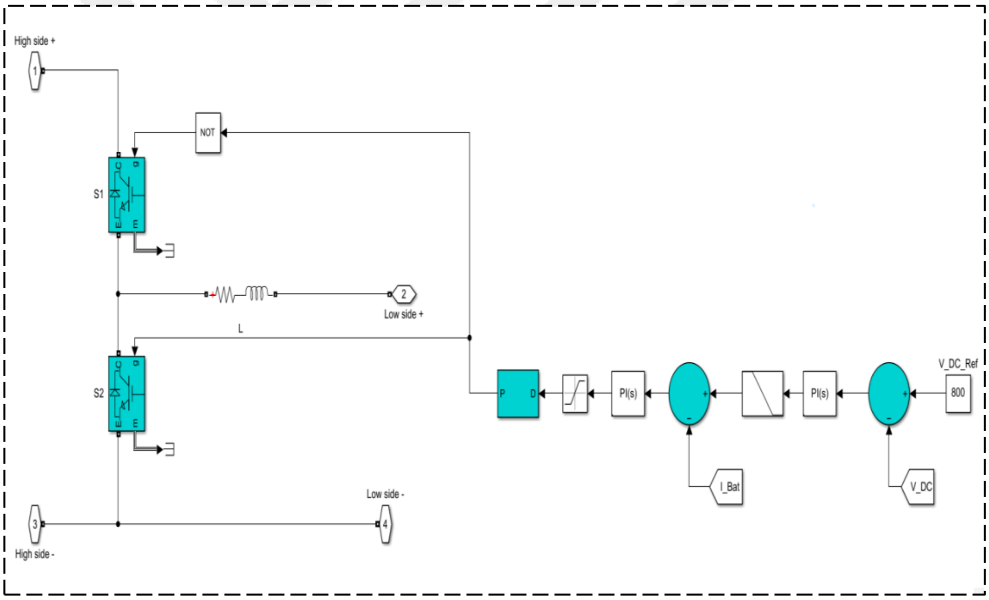

Figure 3.15: Main and Control Circuits of DC-DC Bidirectional Converter.

The Lithium-Ion battery cell is used in this work, the rated voltage is (400V) while the rated capacity is about (1000Ah). The State of Charge is (70%), while the detailed parameters of the discharging can be given as in Figure (3.16).

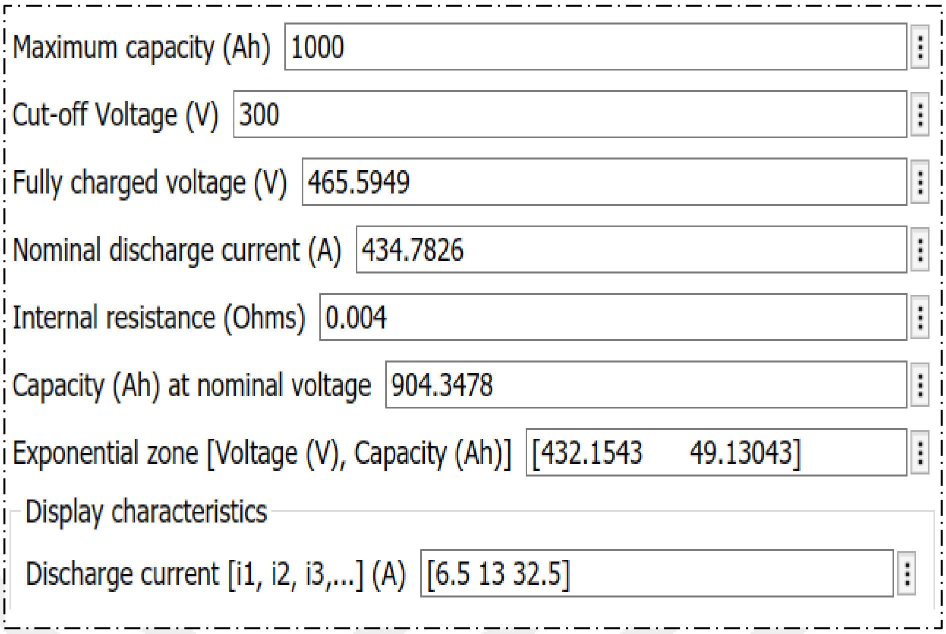

Figure 3.16: Discharge Parameters of the Suggested Battery System Using the MATLAB.

3.7 THE PROPOSED EMS

To deliver the proper power flow and satisfy load demands, the SG system requires an EMS approach. The primary objective of the power management technique is to enhance the SG system process. The major goal of a energy transfer strategy is to mantain supply and load in equilibrium. P-pv denotes power of the photovoltaic, P-wt power of the wind system, P-bat denotes power from batteries, P-grid denotes power from the electrical grid, and P-load denotes demand for consumption.

The equation (3.11) may be used to compute power balance:

$$P\text{-gen}=P\text{-load} \quad (3.11)$$

Power produced by the main sources:

$$P\text{-gen}=P\text{-pv} + P\text{-wt} \quad (3.12)$$

$$P\text{-load}=P\text{-ac} + P\text{-dc} \quad (3.13)$$

If (P-pv + P-wt)> P-load, the excess energy delivered to the battery.

If (P-pv + P-wt)< P-load, the required energy will imported from the battery.

The power grid will be used to import electricity if the P-bat is unavailable; otherwise, the grid will serve as a backup or standby because its management intends to lessen its reliance on conventional generation units and instead rely only on RES. Additionally, the outcomes of the power management strategy will be taken into account while performing various kinds of MPPTs.

3.8 DROOP CONTROL

An inverter that imitates the SG's control is known as a VSG. To achieve the ideal output characteristics, the inverter control needs to include SG capabilities and adjust the output of various parameters comparable to an SG. The output voltage and frequency of an SG are controlled and regulated, accordingly, by the excitation regulator and prime mover governor during ordinary operation. Although the excitation regulating system controls the generator's reactive power and output voltage, the generator control system has the capacity to control the generator's output frequency and mechanical power generation. The fundamental distinction among the VSG and SG is the absence of the need for mechanical or electro-hydraulic governors and excitation regulators. The excitation controller and governor of the generator are utilized to change the output characteristics of the inverter, and the voltage and power frequency adjustment units are added to the VSG [87].

The engine governor architecture serves as the model for the power-frequency (P-f) regulator. The governor is a device that regulates an SG's outputting frequency depending on the producing the unit's power-frequency parameters. The frequency and speed of the generating are related. The governor is a device that modifies the supplied power of the engine in order to regulate the velocity of SG. When the mechanical source of power, the power used by the burden, and the power required for armature induction are all the same, then the generator's output power and speed will remain constant [88]. The curve for the power-frequency characteristic is shown in Figure (3.17)(a). Curves are avoided in favor of straight lines to make the analysis simpler. The block daigram of the power-frequency droop control is shown in Figure (3.17)(b).

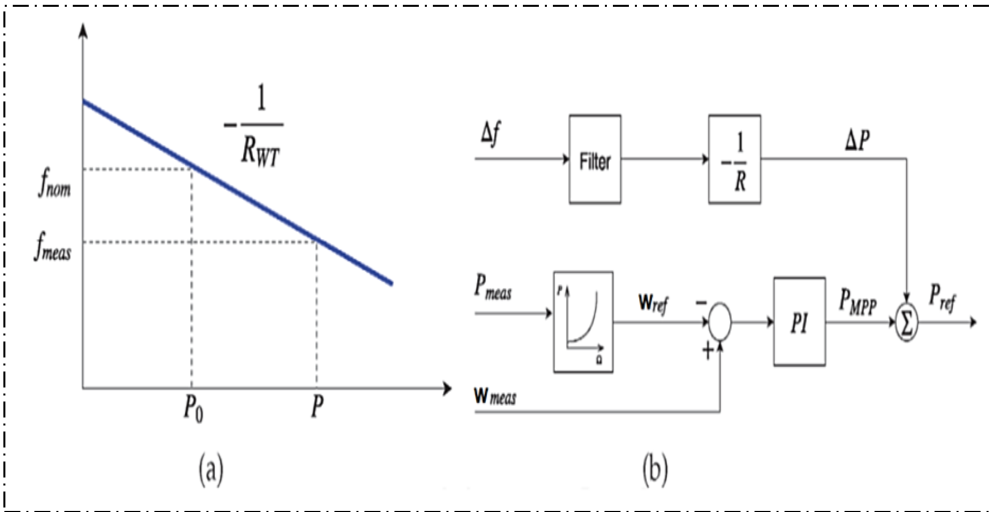

Figure 3.17: (A) (P-F) Droop Relationship Curve, (B) The Block Diagram of the (P-F) Droop Control.

The next formula may be used to find the gradient of the P-F features (m) for both the power and frequency quantities. [89]:

$$m = -\frac{f_{2-}\ f_1}{P_{2-}\ P_1} = -\frac{\Delta f}{\Delta P} \qquad (3.14)$$

Where the beginning and end frequencies fall, f1 and f2. P1 and P2 represent the final and beginning powers, respectively. The following equation's minus sign indicates that there is an inverse link between the change in frequency and the change in power.. The proposed inverter control (droop cintrol that used in this work is shown in Figure (3.18). The adjustment coefficient is kf and it represent the reciprocal of the slop of the frequency-power droop, hence the Kf = 1/m it and also can be called as static characteristic coefficient:

$$P2 – P1 = \Delta P = Kf\,(f2 – f1) \qquad (3.15)$$

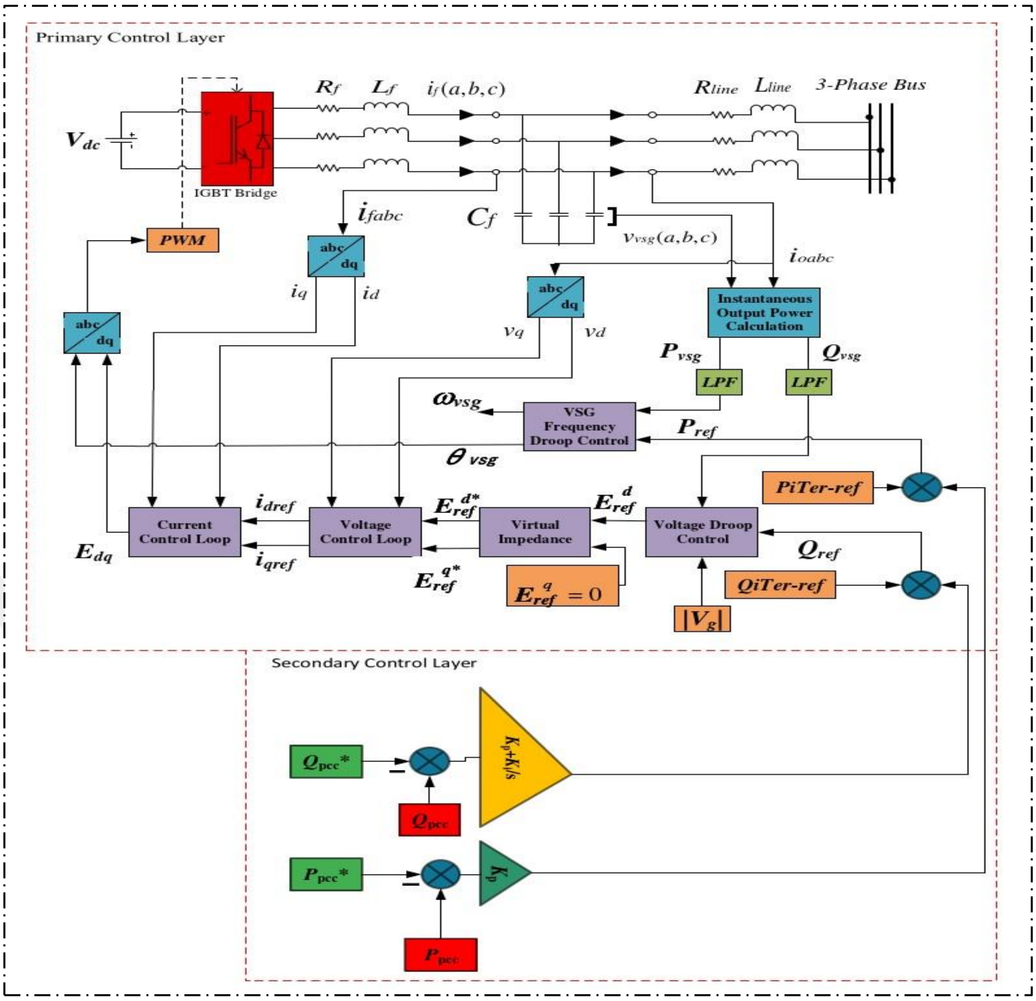

Figure 3.18: The Proposed Droop Control.

It is important to note that while the active power-frequency droop control is the main emphasis of this work, the reactive power-voltage droop management is also created in this study using the same methodology. When operating regularly, the power system must make certain that the voltage remains within the allowable range of fluctuation. Additionally, there needs to be an ongoing equilibrium among reactive power generated and reactive power used in the system for the power system voltage to stay constant. A great deal of the reactive power in the power system originates from SG. The excitation regulator controls its reactive power output and divides the system's reactive power between the parallel-operating generator sets to keep the reactive power balance in the system. Droop control is proposed in this study to enhance the frequency stability.

4. SIMULATION AND RESULTS

4.1 INTRODUCTION

The suggested system is illustrated in Figure (4.1), the system components are: (a) a wind turbine with conversion circuits (uncontrolled three-phase rectifier and DC-DC boost converter) the output power of the wind turbine is about (27.5) kW, (b) the PV system in this work consist from (15*15) panels farm with total output power about (67.5) kW, the DC-DC is important with the PV system to improve the efficiency. (c) The battery system is used in this work to supply the required power and store the excess power by using the bidirectional converter. Two types of loads are used in this work as shown in (d) and (e) which are DC and AC loads. The AC output of this system is achieved by employing the VSG three-phase inverter based on droop control.

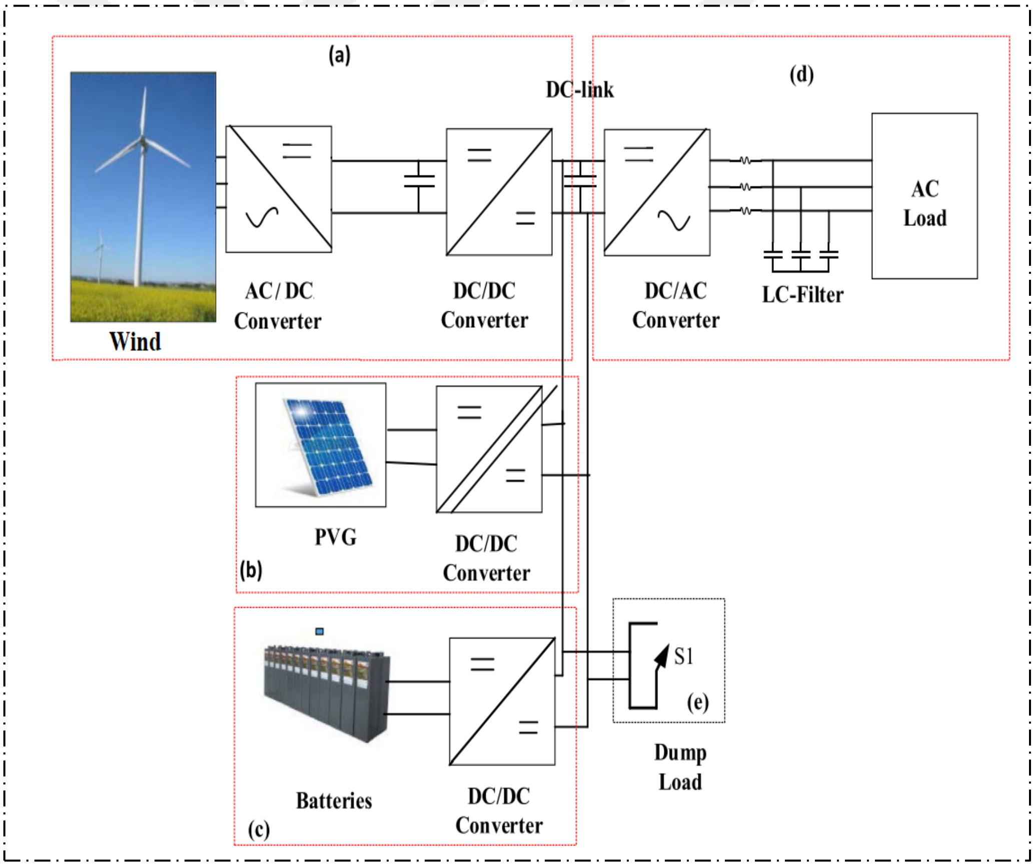

Figure 4.1: The Proposed System.

An LC filter is employed here to improve the output waveforms for both the voltage and current and reduce the total harmonic distortion. The employing of the proposed system by the MATLAB is illustrated in Figure (4.2).

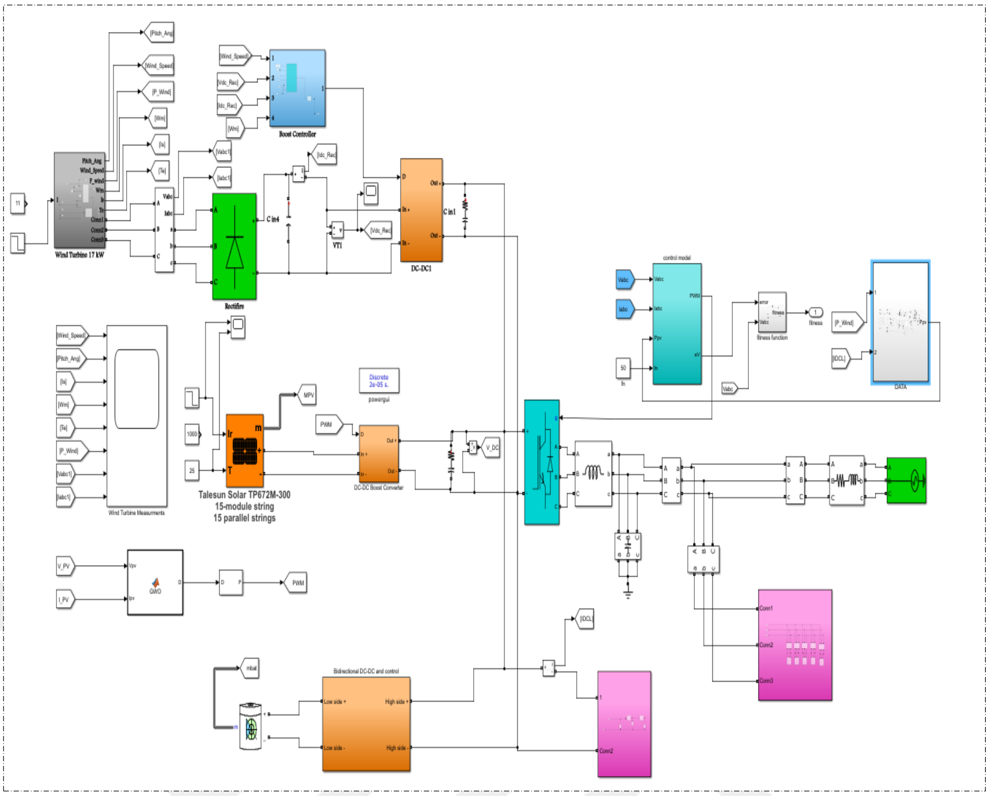

Figure 4.2: The Suggested System Employing the MATLAB Program.

Three types of controllers are utilized in this work: the first type is the PV MPPT to achieve the greatest output power of the PV system. The GWO and INC. MPPTs are used in this work, the GWO is an artificial intelligent method while the INC, method is a traditional method, and the comparison between the results is present in this work.

The second type of controller system is the bidirectional controller which is used for charge and discharge purposes also the EMS that proposed in this work is achieve by using the bidirectional controller.

The third and last one is the inverter control based on droop control which can give a high accuracy when used for off-grid purposes.

4.2 PV SYSTEM RESULTS

The panel type employed in this study is (Talesun Solar TP672M-300) from the MATLAB program library, with a power rating of approximately 300.352 W per panel. To calculate the number of PV panels that may be utilized to generate (67.5 kW), approximately (225) panels are employed. The output characteristics of the whole proposed PV system (I-V) and (P-V) during different temperature (25 and 45) C^o are shown in Figure (4.3).

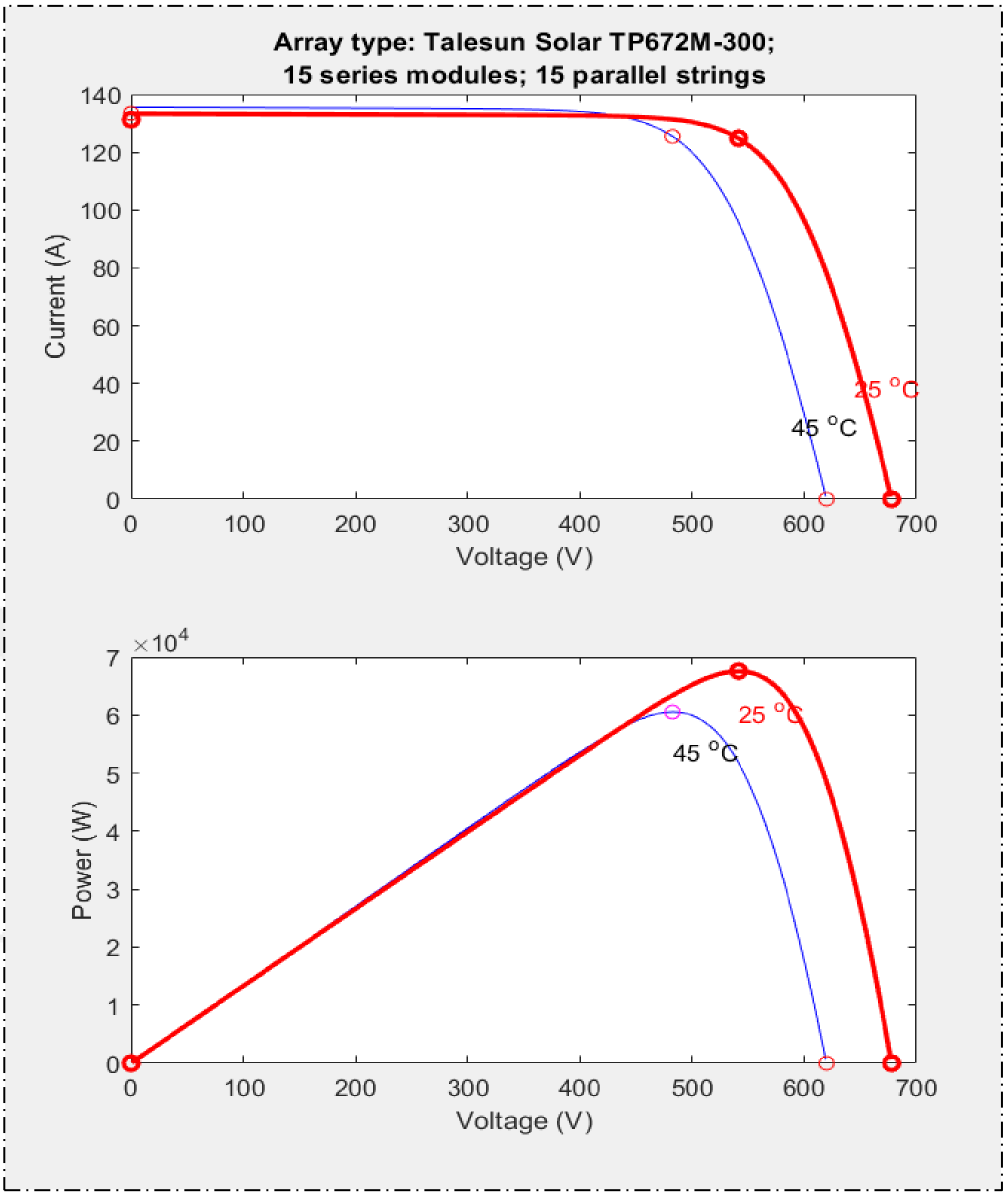

Figure 4.3: The Proposed (I-V) and (P-V) PV System.

The suggested inputs of the PV system, which are the irradiation and temperature, are shown as in the Figure (4.4) below. The irradiation is vary between the 850 and 1000 W/m2, at the 1000 W/m2 irradiation, the maximum output power of the PV system is achieved, while at the 850 w/m2 which is mean at 85% of the maximum power can be achieved. The temperature is suggested to be fixed at 25Co throughout the work time.

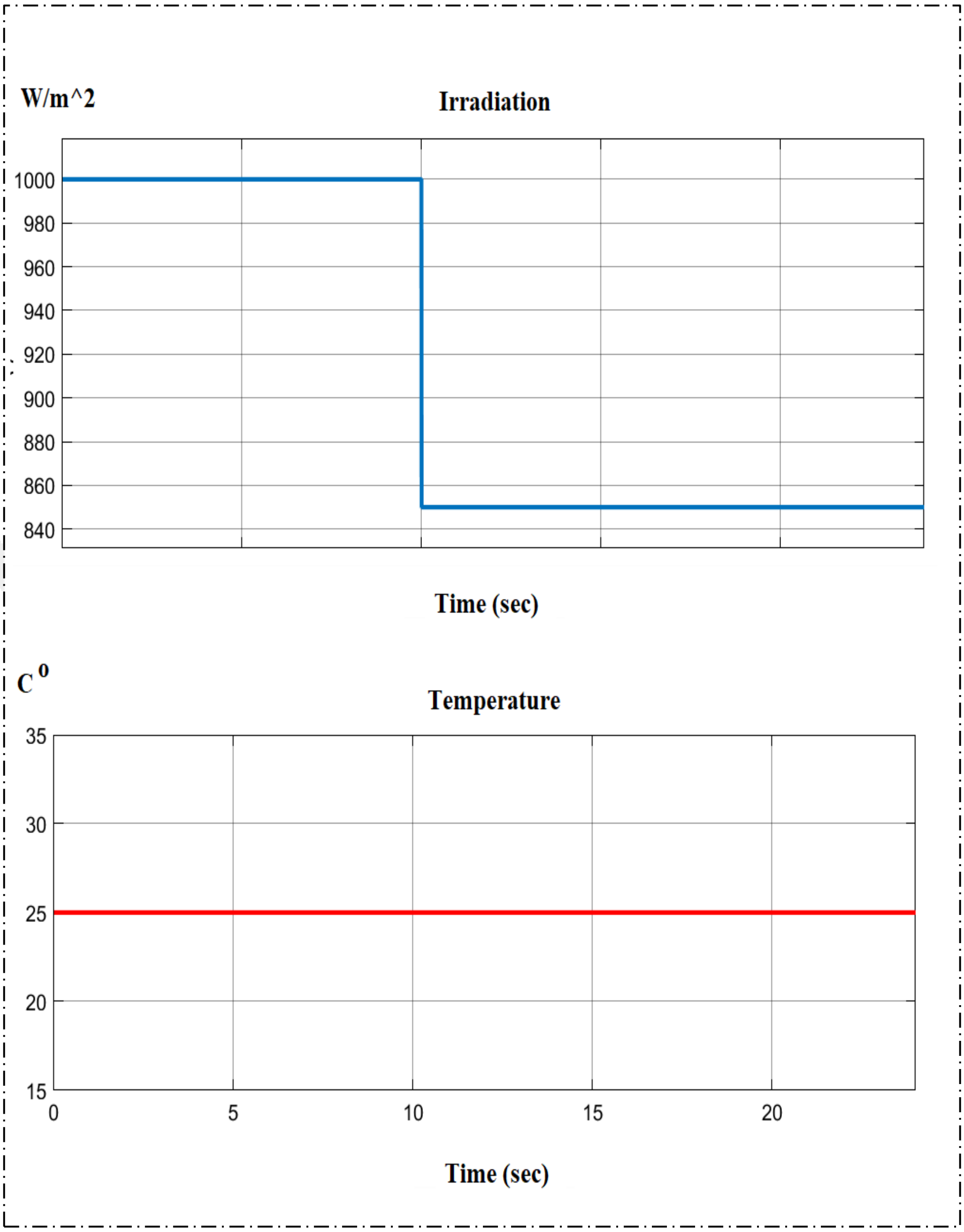

Figure 4.4: The Suggested PV Inputs (Irradiation and Temperature).

4.2.1 PV System Results with INC. MPPT

According to the equations (3.3) and (3.4) that was discussed in chapter-3 of this work, the PV system output voltage and the PV output current are shown in Figure (4.5). The voltage is fixed throughout the simulation time when the temperature is constant, while the current shape is identical to the proposed irradiation. By using the INC. method the voltage and current have a distortion and the efficiency of the output power is low.

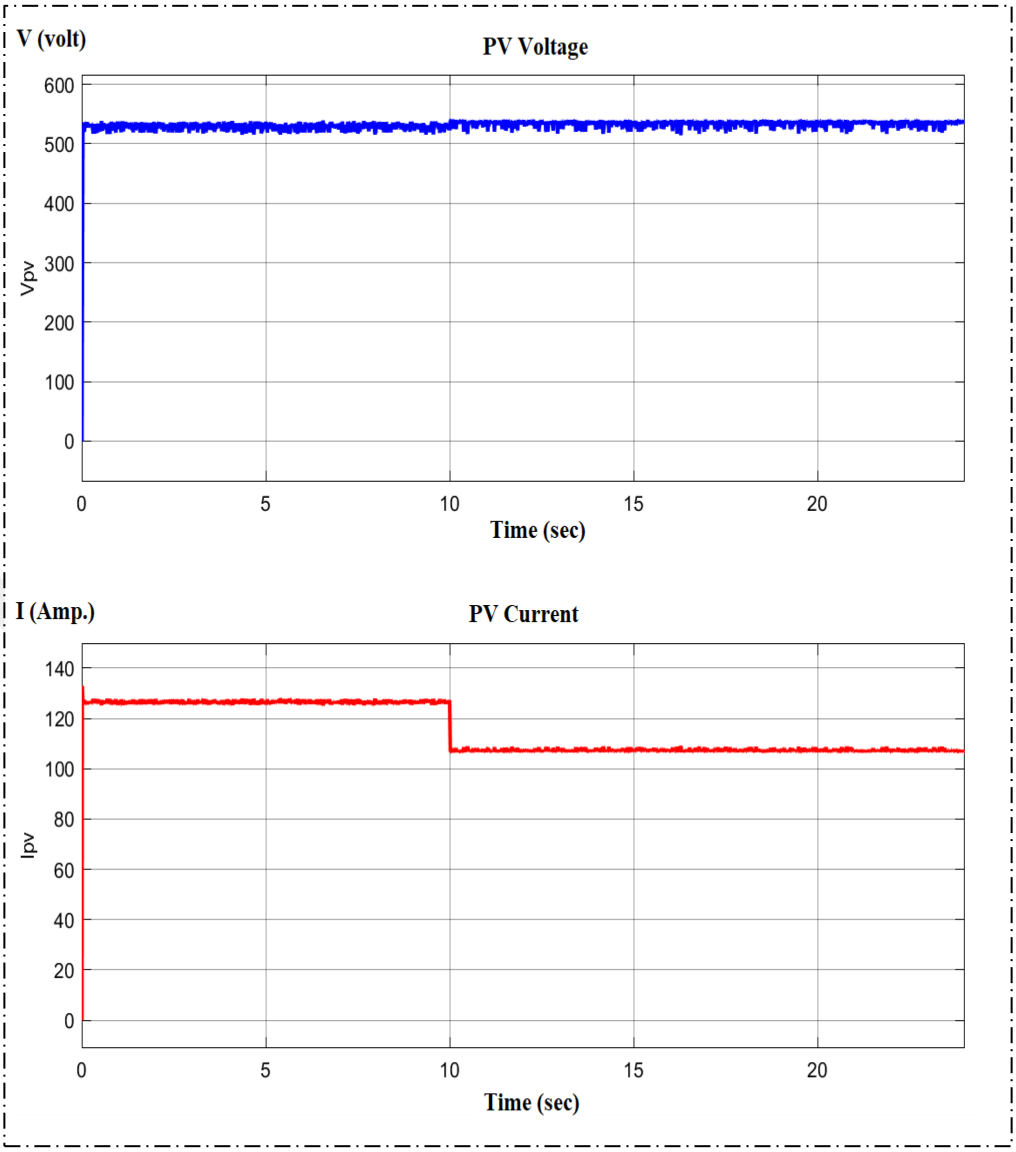

Figure 4.5: The Suggested PV Voltage and Current with INC. MPPT.

The output power of the PV system with INC. MPPT is shown in Figure (4.6), the output power achieve by using this type is (66.8) kW, the equation (4.1) is used to calaculate the output effeiciency of the INC. converter.

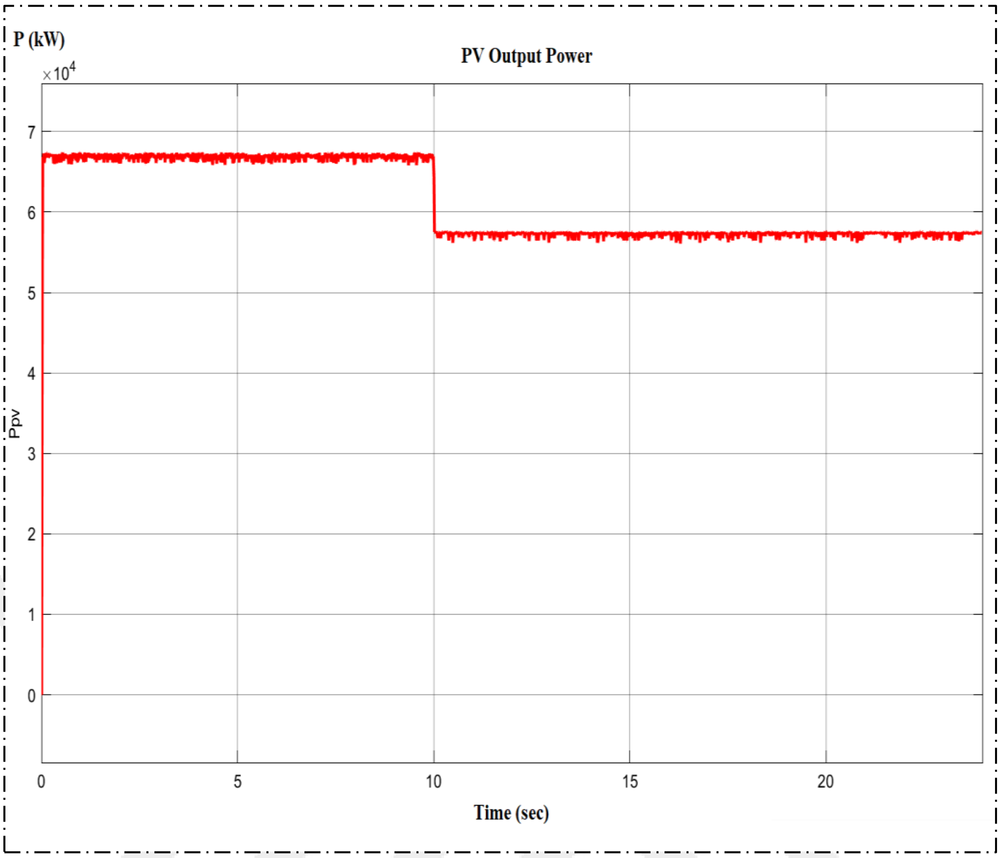

Figure 4.6: The Suggested Power with INC. MPPT.

The effeciency is:

$$\eta_{Inc.} = \frac{Actual\ Maximum\ outpout\ Power}{Maximum\ rated\ power} *100\% \tag{4.1}$$

$$\eta_{Inc.} = \frac{66.8\ kW}{67.5\ Kw} *100\%$$

$$\eta_{Inc.} = 98.9.\%$$

4.2.2 PV System Results with GWO MPPT

By using the same procedure, the PV system output voltage and the PV output current using the GWO MPPT are shown in Figure (4.7). By using the GWO method the voltage and current have a less distortion and the high efficiency of the output power.

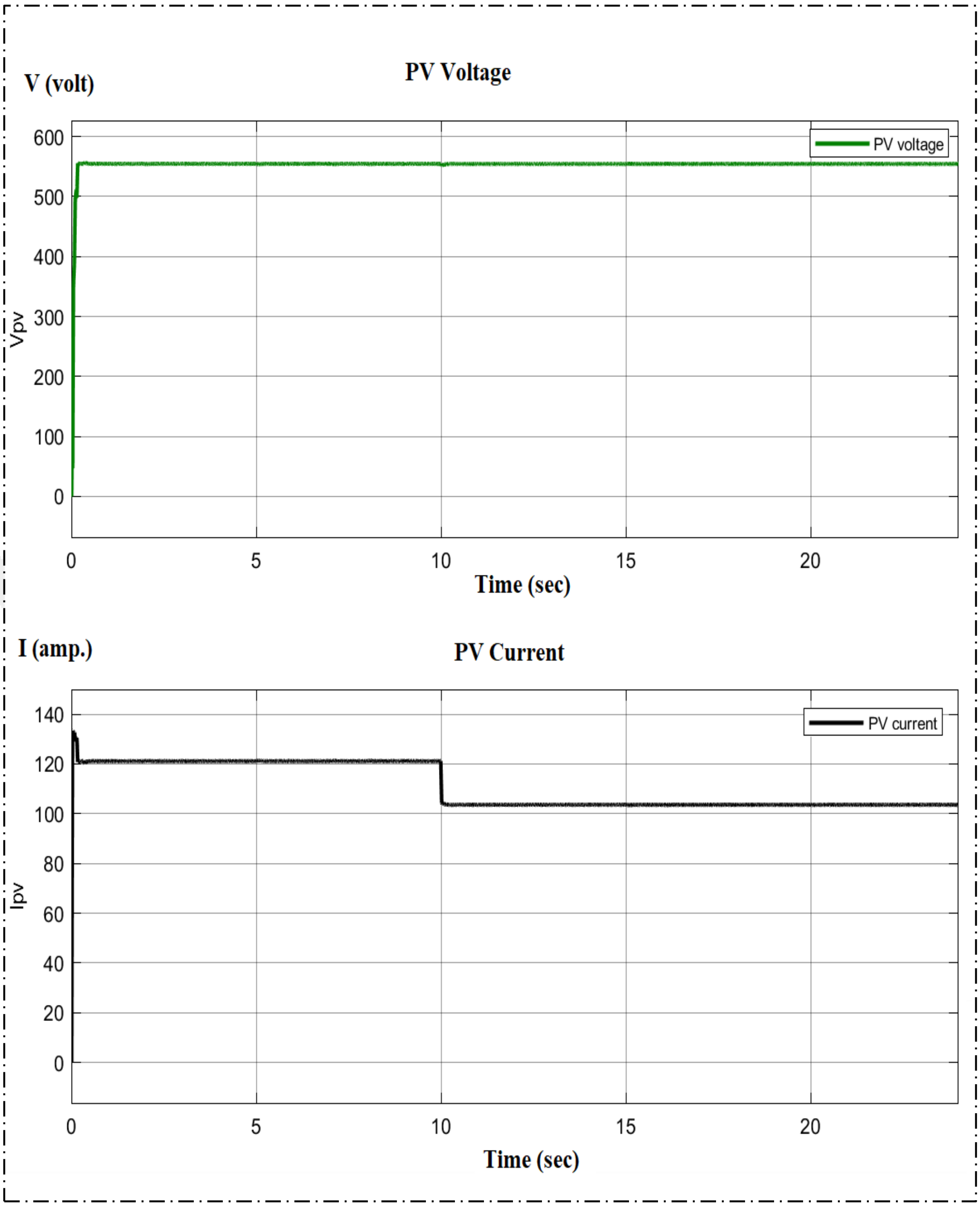

Figure 4.7: The Suggested PV Voltage and Current with GWO MPPT.

The output power of the PV system with GWO MPPT is illsutrated in Figure (4.8), the output power achieve by using this type is (67.18) kW, the equation (4.2) is used to calaculate the output effeiciency of the GWO converter.

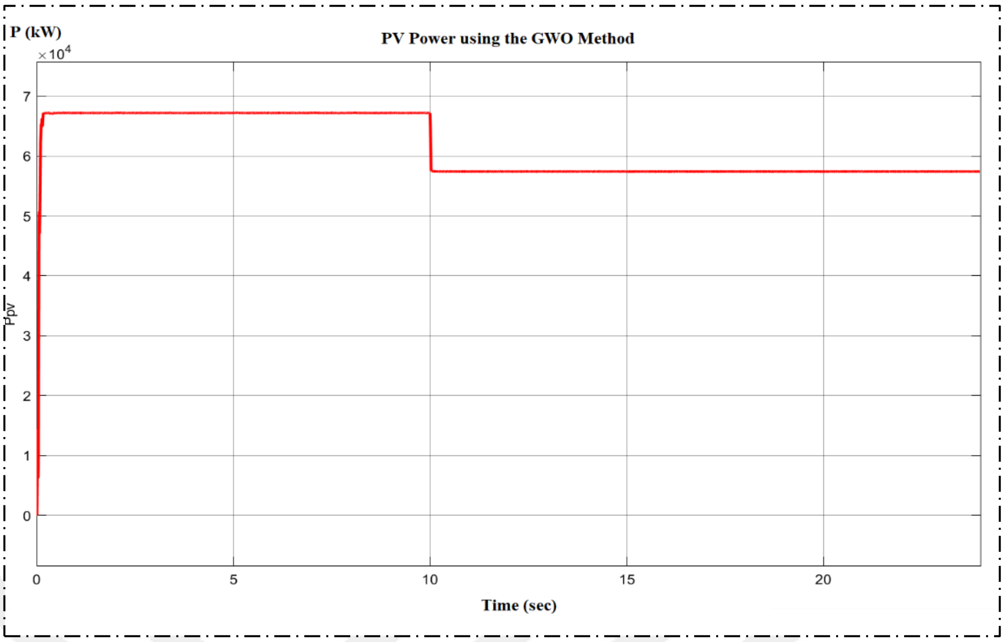

Figure 4.8: The Suggested Power with GWO MPPT.

The effeciency is:

$$\eta_{GWO} = \frac{Actual\ Maximum\ outpout\ Power}{Maximum\ rated\ power} *100\% \tag{4.2}$$

$$\eta_{Inc.} = \frac{67.18\ kW}{67.5\ Kw} *100\%$$

$$\eta_{Inc.} = 99.52.\%$$

The Table (4.1) below shows the comparison between the two proposed MPPTs that used in this work.

Table 4.1: MPPT Comparison.

Type of MPPT	Designed output power (KW)	Actual output power (KW)	Efficiency (100%)
INC.	67.5	66.8	98.9
GWO		67.18	99.52

4.3 WIND TURBINE RESULTS

By using the P&O MPPT the wind turbine can be achieved the maximum output power. The output results of the proposed wind turbine based on PMSG is shown in Figure (4.9). At the 11 m/s speed which is represent the rated speed of the wind turbine and (27.5) kW power can be achieved.

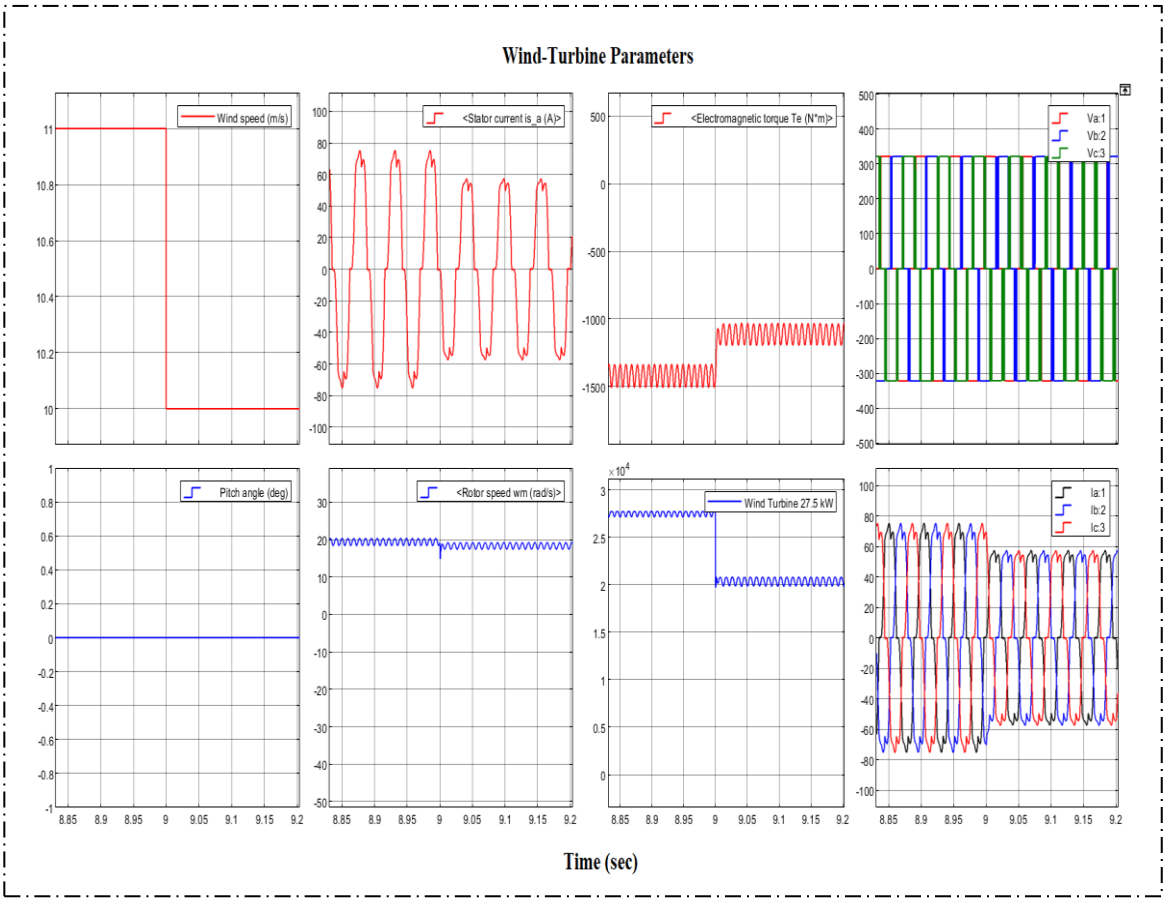

Figure 4.9: The Outputs of the PMSG Wind Turbine.

The wind speed, output power, output current, output voltage, turbine speed, pitch angle, turbine output torque are shown in Figure (4.9), in case of the wind speed is reduced the most of the measured above are changed, here in this case the speed is changed from (11 m/s) to (10 m/s).

Figure (4.10) depicts the measured the tip speed ratio and the power coefficient of the suggested PMSG wind turbine employing MATLAB software. According to the design of wind turbine that explained in the section (3.3) in chapter three of this thesis, the MPPT is achieved

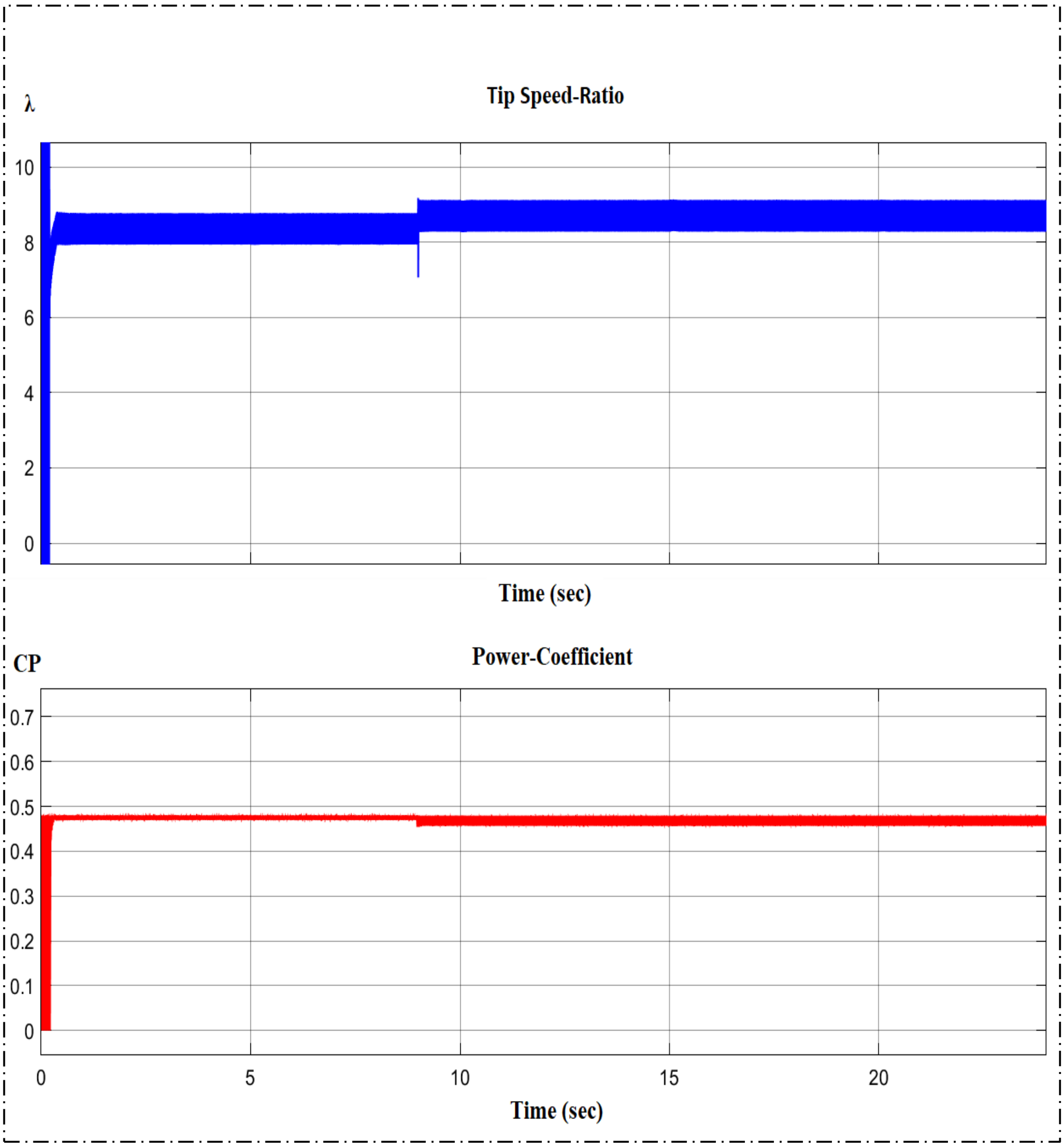

Figure 4.10: The Tip Speed Ratio and the Power Coefficient.

The uncontrolled rectifier (diode rectifier) output voltage that connected at the output terminals of the PMSG explained in Figure (4.11) and its fixed throughout the period of simuation to keep the voltage constant during the changing the wind speed.

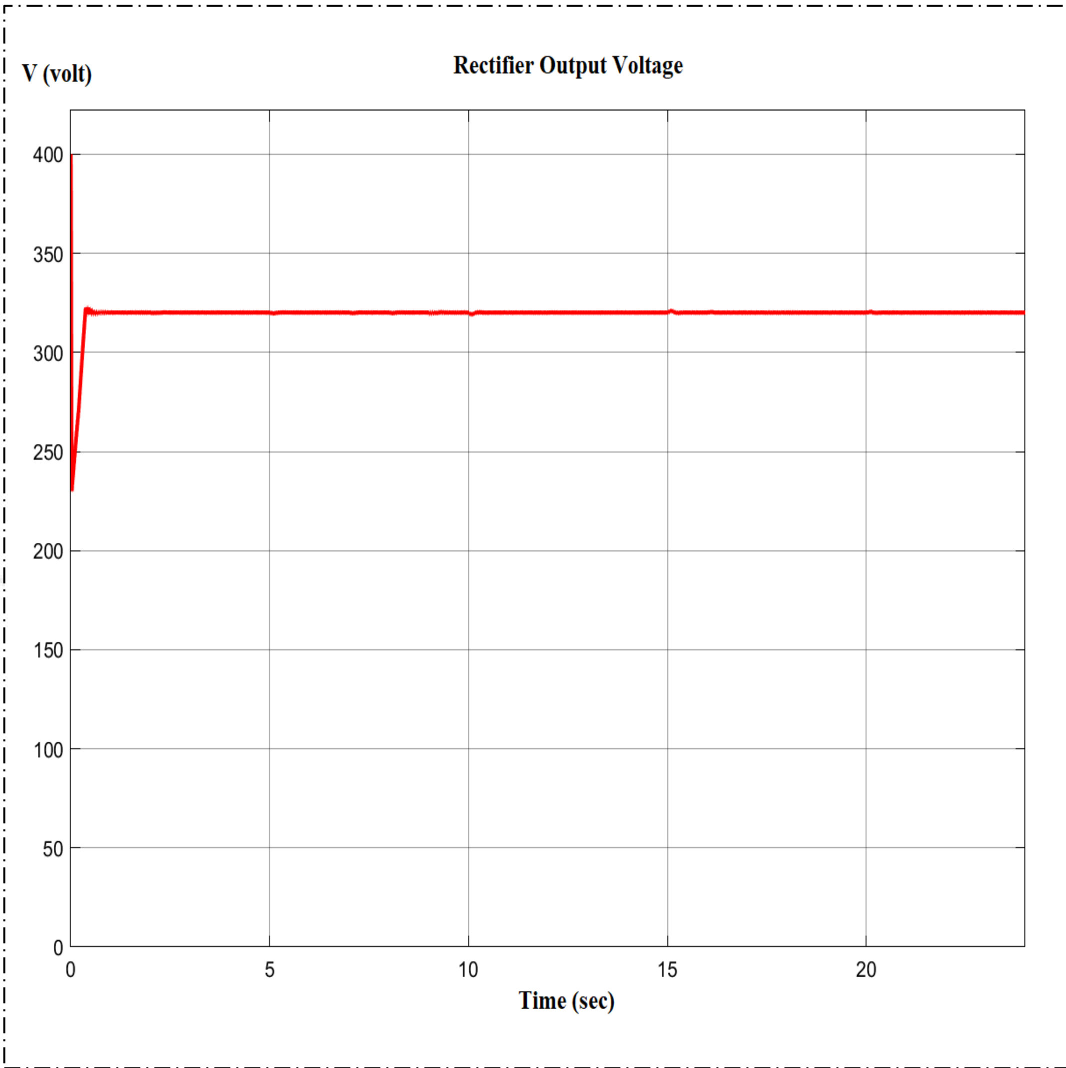

Figure 4.11: The Output Voltage of the Rectifier

4.4 BOOST CONVERTER RESULTS

The boost converter is connected to the output of the PV system and wind turbine system to increase the voltage level from the system's voltage (541.5V and 320V to 800V), the output of the boost converter must be the same. Figure (4.12) shows the output voltage of the boost converter and its constant during the simulation time period.

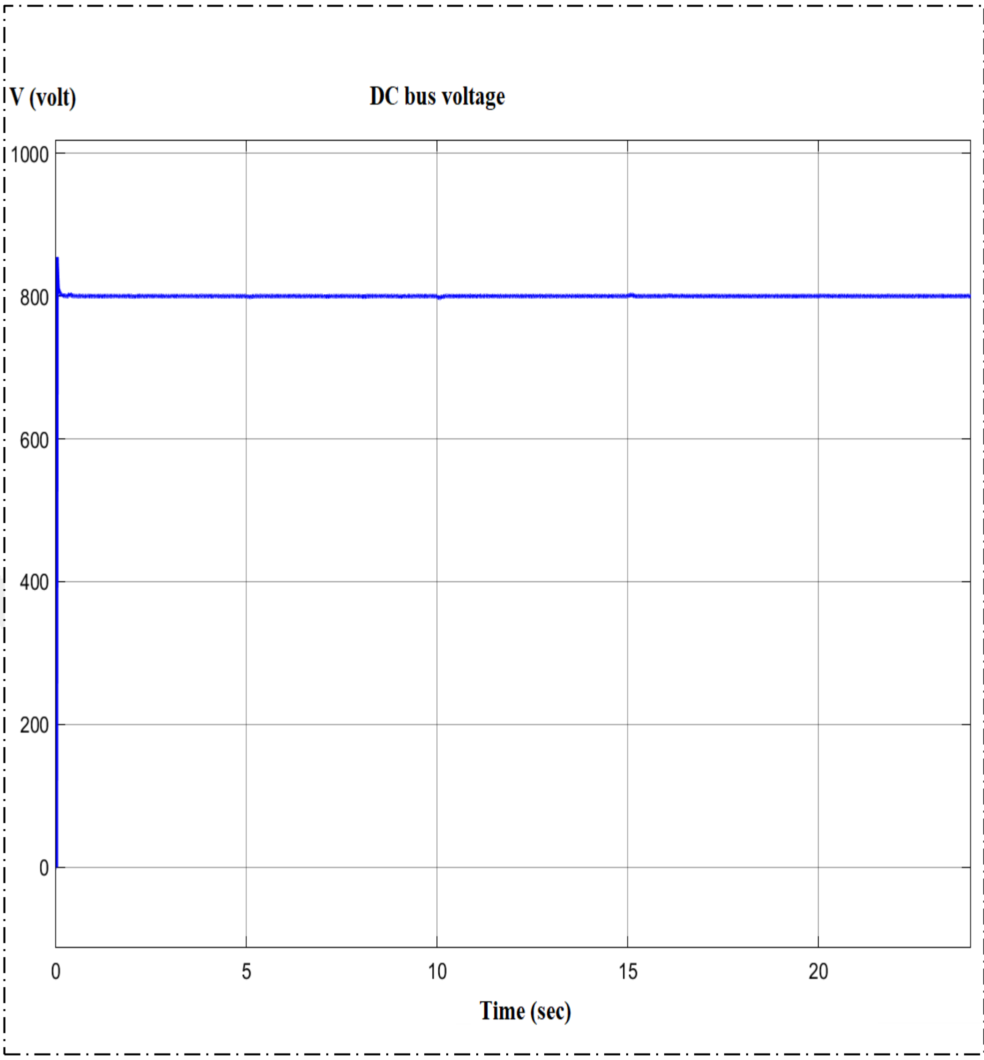

Figure 4.12: The Output Voltage of the Boost Converter.

4.5 INVERTER CONVERTER IMPLEMENTATION

The proposed droop control of the VSG inverter is present in Figure (3.18) as in chapter three of this thesis. The droop control can be explained as in the flowing three stages, the first stage that used to measure the active power and reactive power from the output of the LC filter. The Vd and Vq (direct and quadratic axis) can calculated in this stage. The first stage of the converter is shown in Figure (4.13). In the next stage which the second ones the comparison between the set values and the measured (P, Q, V, and F) is implemented as droop control between them as shown in Figure (4.14).

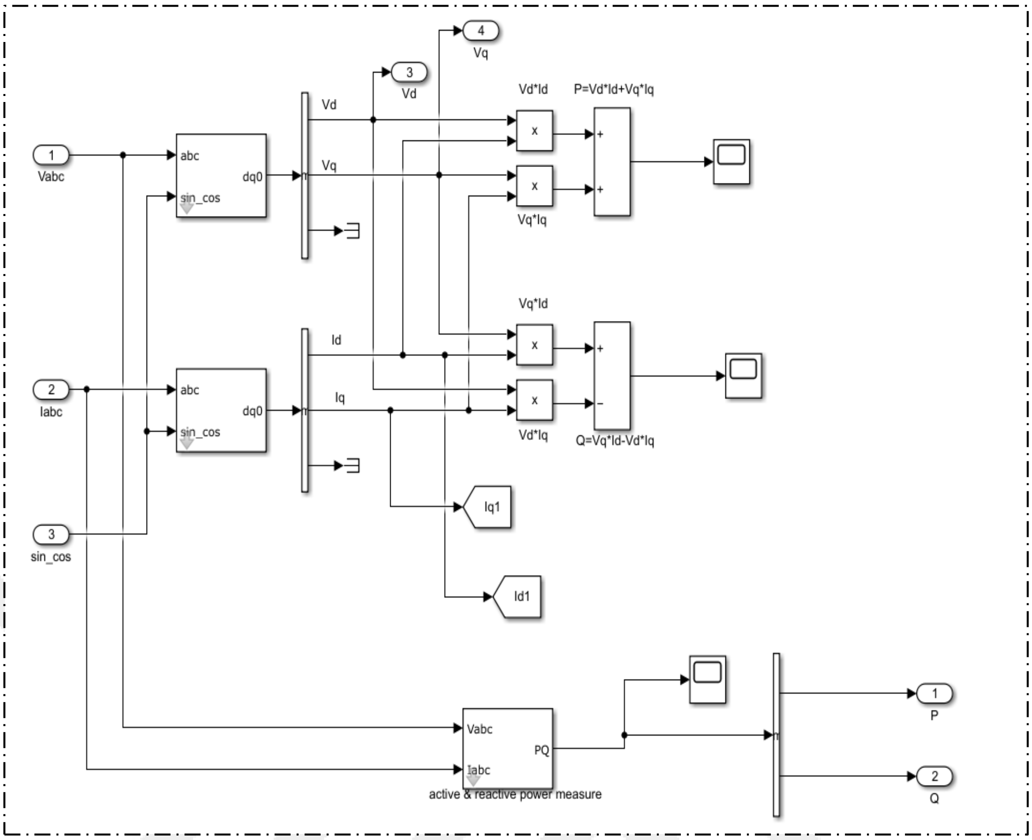

Figure 4.13: First Stage Inverter Control.

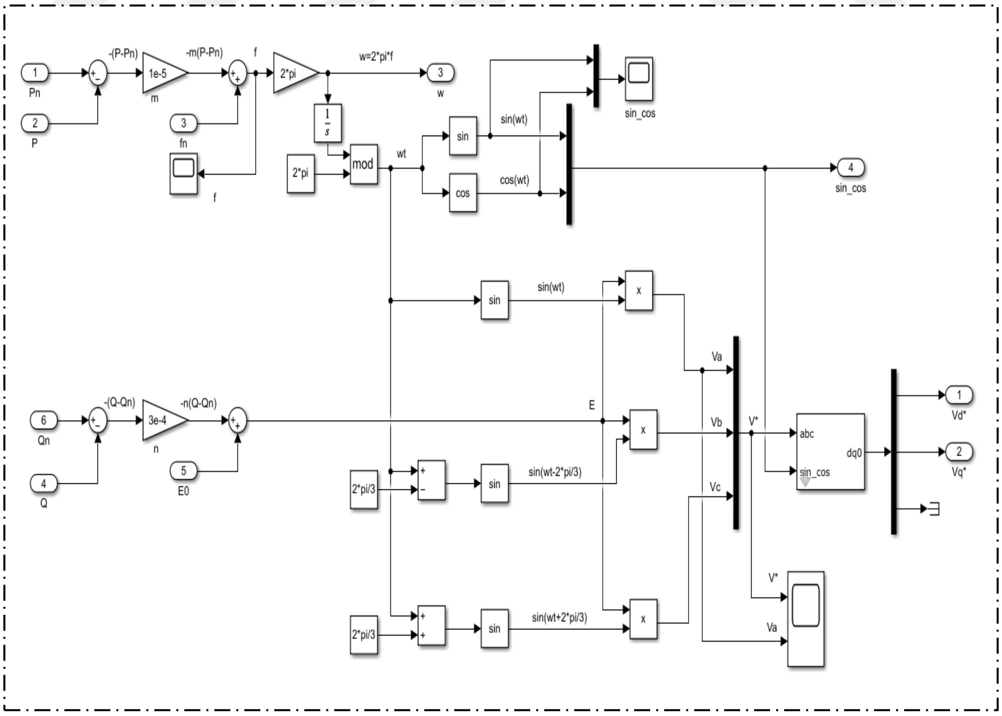

Figure 4.14: Second Stage Inverter Control.

The main purpose of the third stage of the proposed droop control is to convert the measured Vd and Vq signals to six pulses that applied to inverter switch based on the PWM methodology, the implementation of the third stage by using the MATLAB program is shown in Figure (4.15).

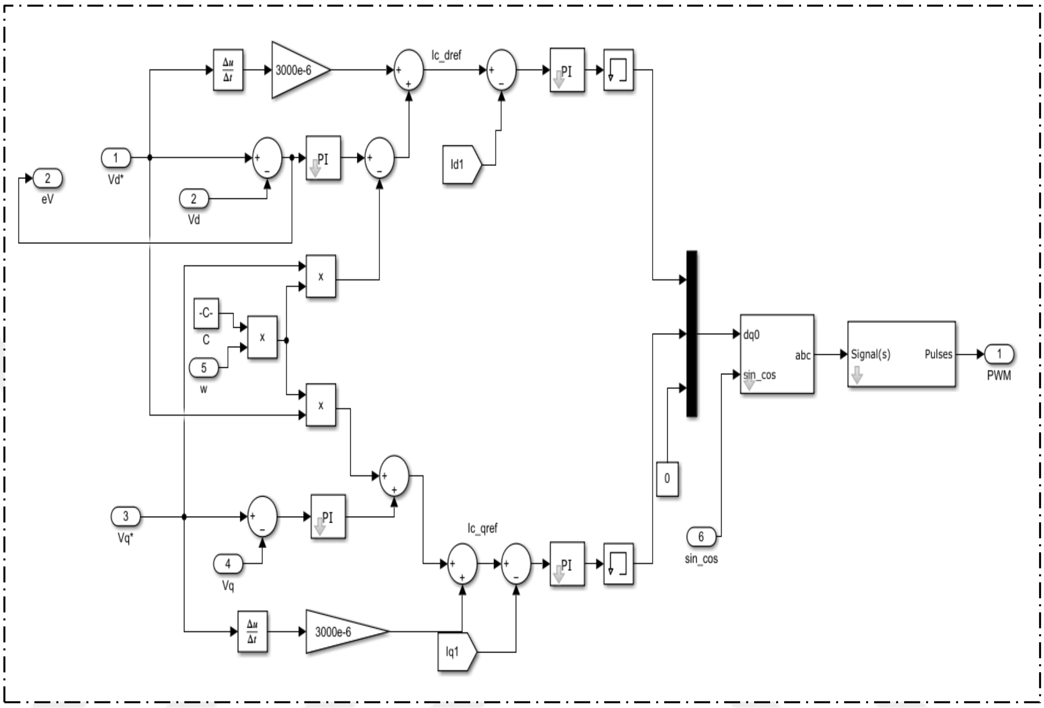

Figure 4.15: Third Stage Inverter Control.

With the increased use of RES, the stability of the on-grid MG has grown into a key concern. However, when the grid load varies, the on-grid and off-grid inverters cannot operate efficiently using solely the typical control. Furthermore, the imbalanced factor of voltage/current at the common coupling point may greatly rise. The capacity to correct for grid unbalance should be implemented to enable the steady functioning of an on-grid system under grid disturbances. This paper proposes an enhanced voltage-type grid-connected control approach to address the previously mentioned problem. This type of the inverter control will reduce frequency and voltage variations under different operating conditions, in addition the THD of the output voltage and current waveforms are within the standard values of the IEEE 519-2014 standard for low voltage (for the less than 1kV system the THD should be less than 5%). Figure (4.16) shows the THD of the output voltage and current while the Figure (4.17) shows the output frequency of the system.

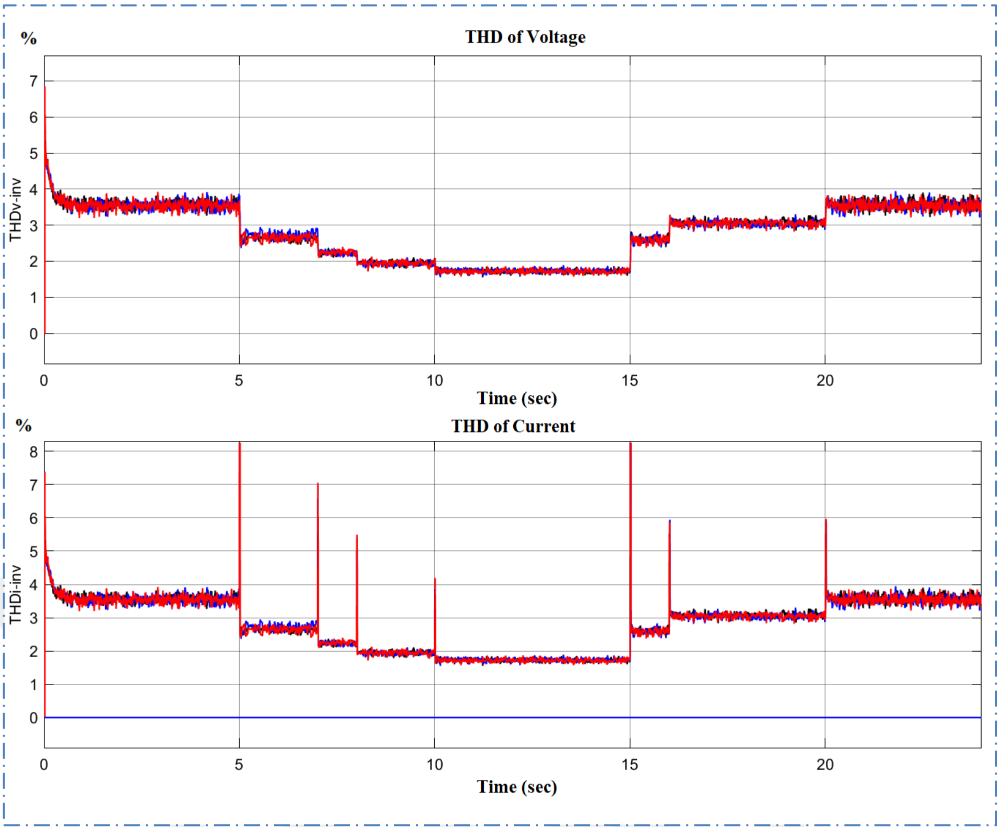

Figure 4.16: THD of the Voltage and Current Waveform.

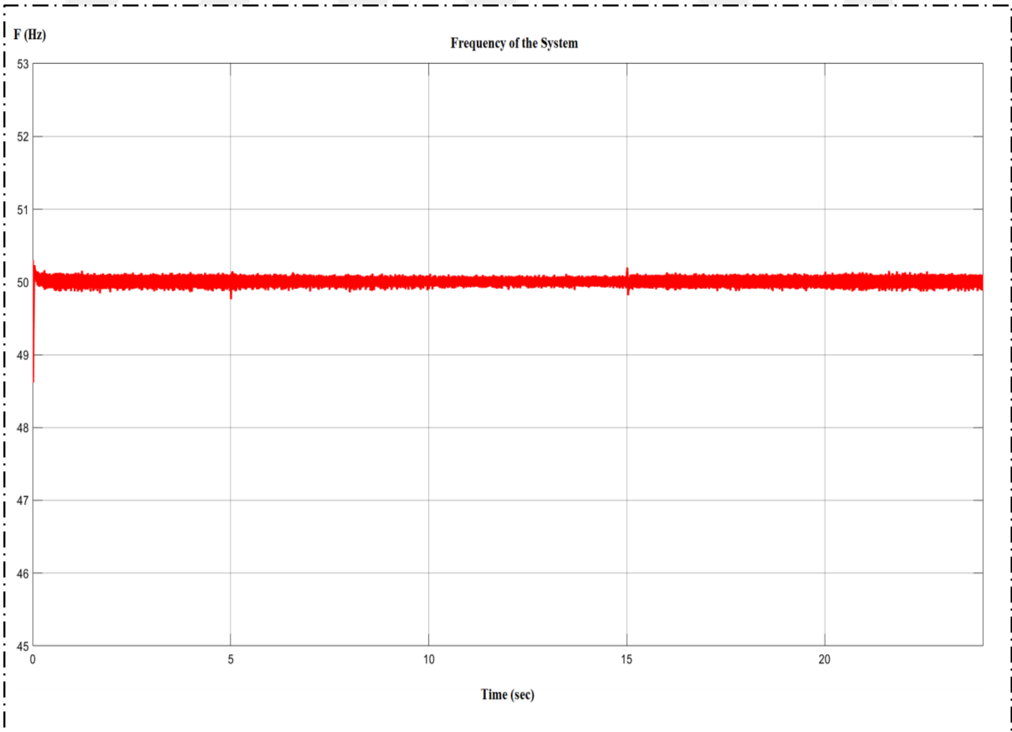

Figure 4.17: System Frequency.

4.6 BATTERY SYSTEM RESULTS

Battery devices transform chemical power into electricity. Typically, these systems are connected to a DC-DC that can be utilized all over both charging and discharging procedures. The way the battery was powered up and drained depended on changes in DC bus voltage and battery current. Figure (4.18) depicts the input/output parameters (voltage, current) of the battery system, while the power, and state of charge (SOC)) for the proposed load and RES generation are explained in the Figures (4.19) and (4.20).

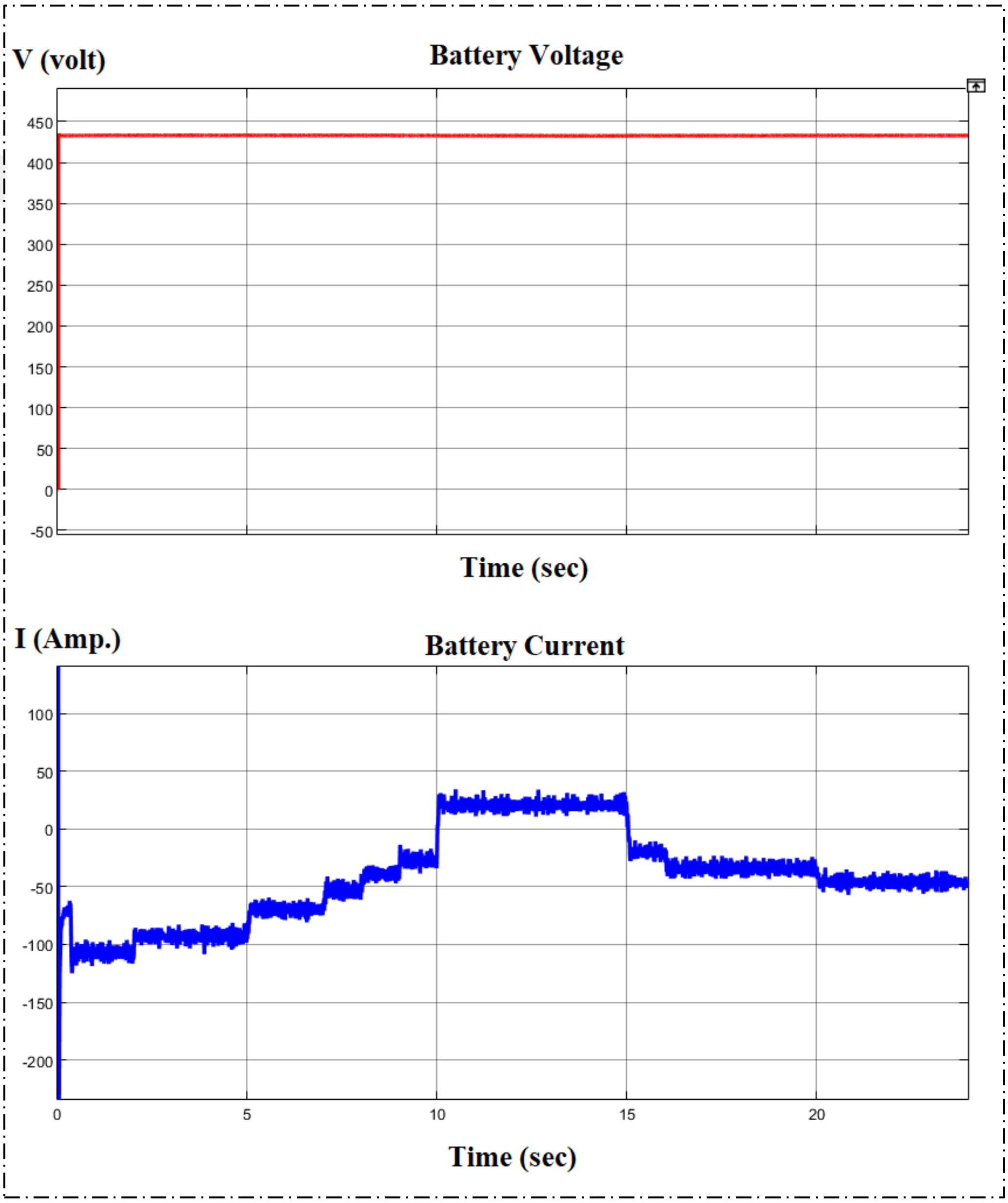

Figure 4.18: Voltage and Current of the Battery System.

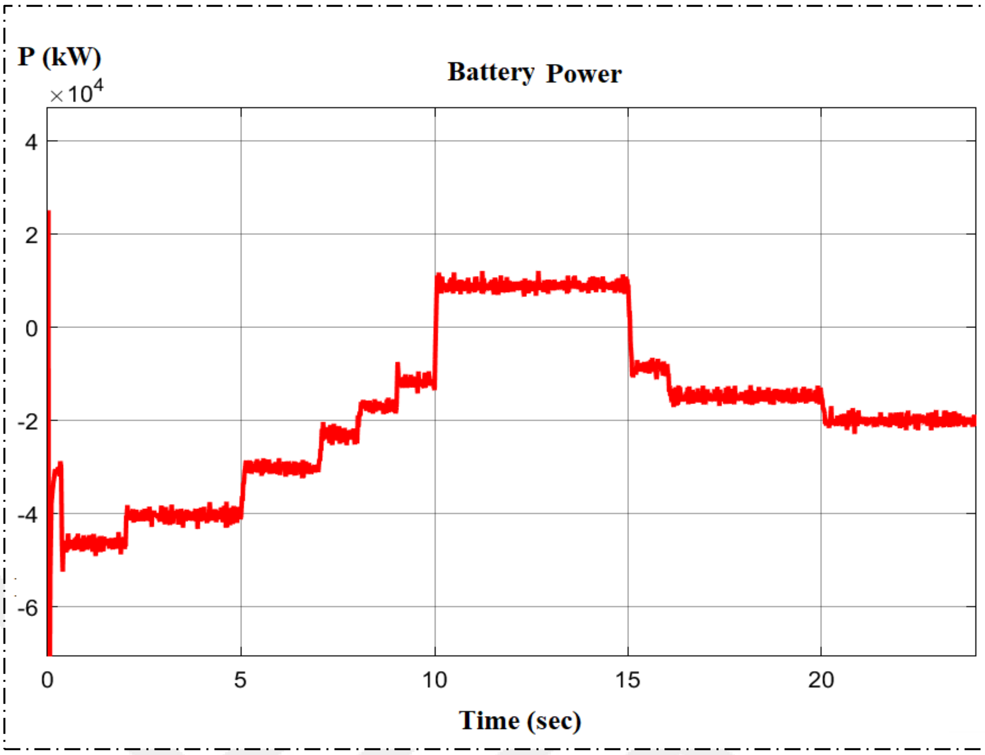

Figure 4.19: Power of the Battery System.

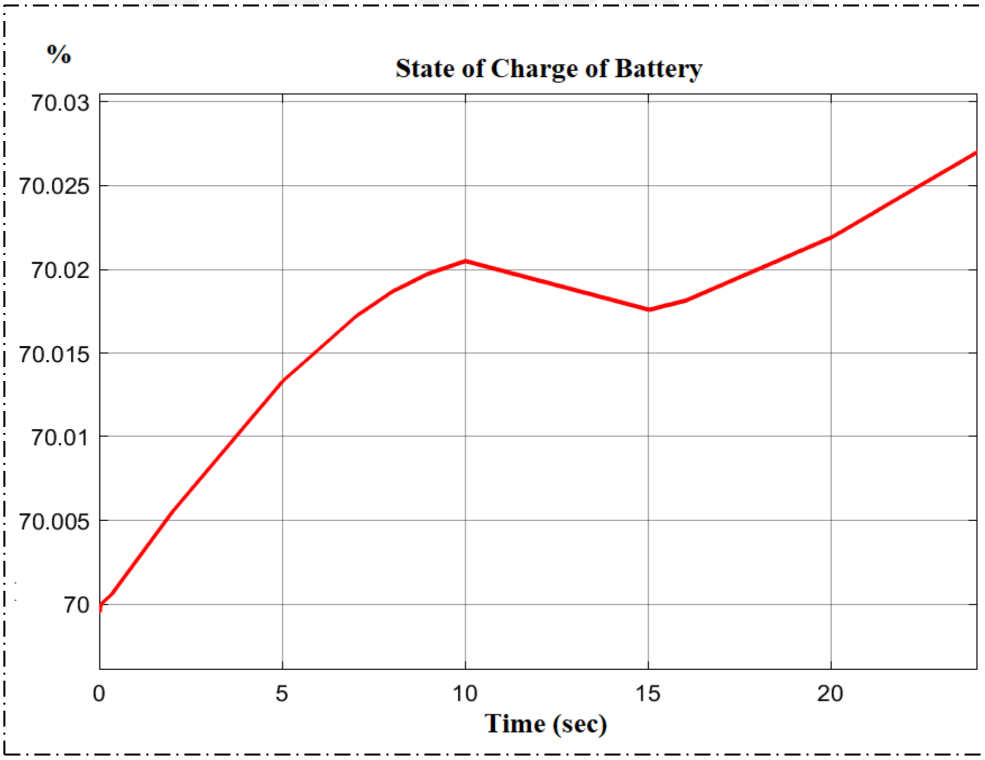

Figure 4.20: S.O.C of the Battery System.

4.7 THE PROPOSED LOADS

Two types of loads are proposed in this work, which are DC and AC. The DC load is connected to the DC bus system and it has three values, a switch is used in this type to connect the resistive load and to increase the DC load. The configuration of the DC load of the proposed load is shown in Figure (4.21 – a). On another hand, the AC three phase load is connected to at the inverter output and after the LC filter. The AC load is consisting of five loads that connected to the grid via three-phase circuit breakers. These circuit breakers can be controlled by applying the IoT technology to connect or disconnect the loads in case of the shortage in the generation side or exceeding of the generation. The three-phase AC loads with circuit breakers are shown in Figure (4.21-b).

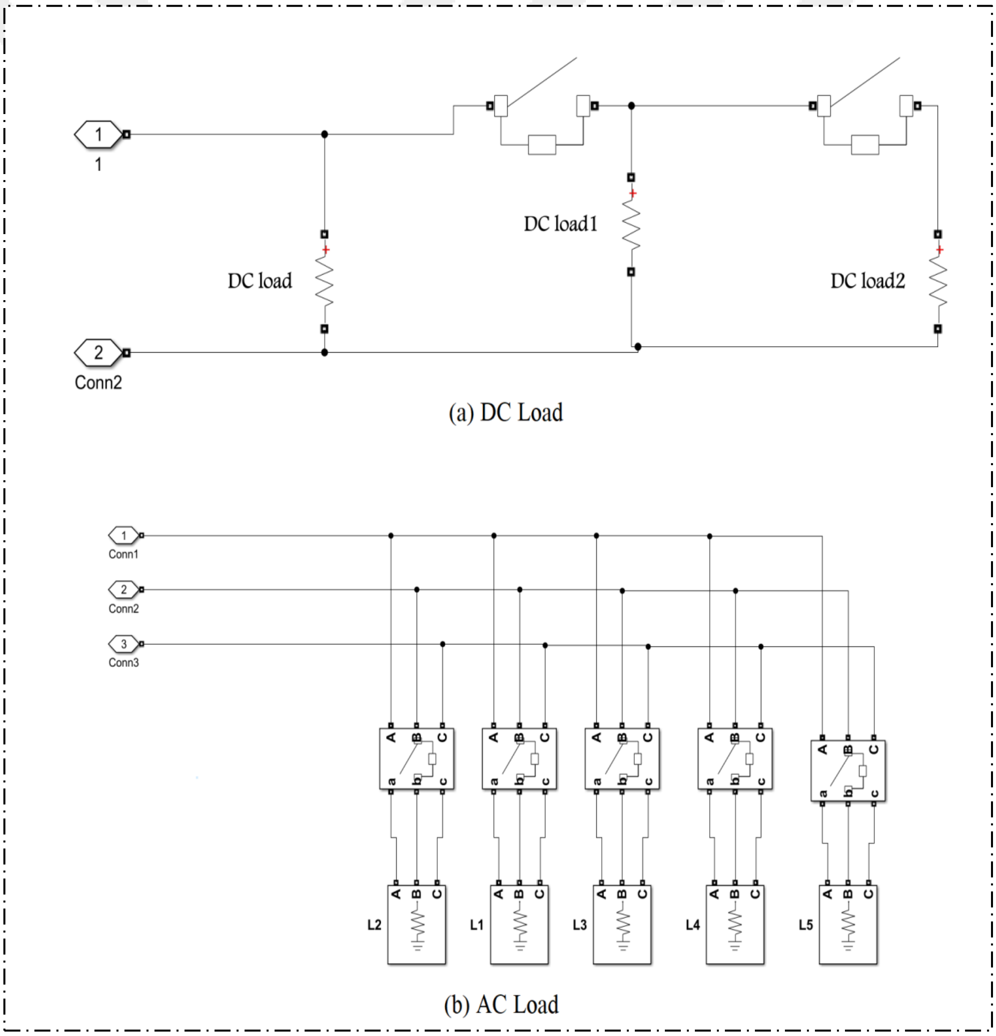

Figure 4.21: (A) DC and (B) AC Load Circuits.

The DC and AC three-phase load profiles that applied in this work are shown as in Figure (4.22).

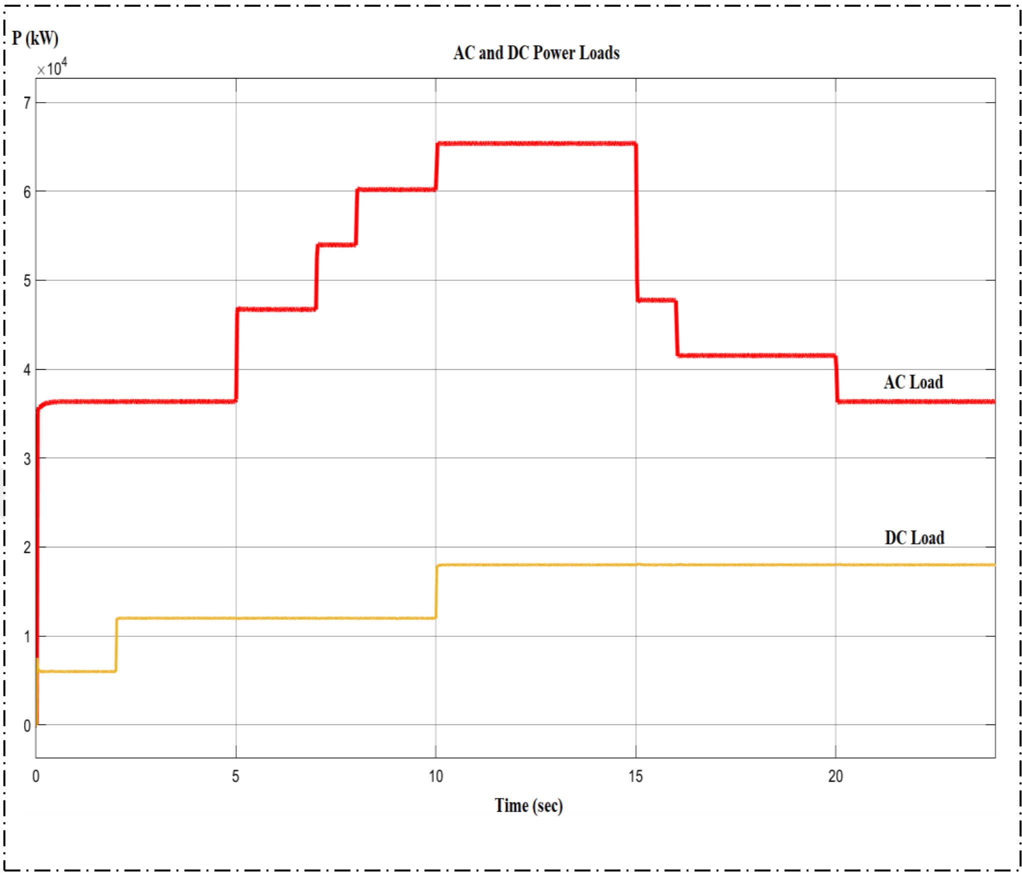

Figure 4.22: DC and AC Load Profile.

4.8 THE PROPOSED EMS

The SG system requires an EMS method to produce the necessary energy transfer and meet demands. EMS technique's major goal is to enhance the SG system process. A power management strategy's main purpose is to maintain supply and demand in balance. P-pv represents power generated by a photovoltaic system, P-wt power generated by a wind turbine, P-bat power generated by batteries, P-grid power generated by the electrical grid, and P-load power consumed.

The load balances for the two case of MPPT controller (INC. and GWO) are shown in Figures (4.23) and (4.24) respectively. The oscillation at the PV system is directly effected on the battery system waveform as explained in Figure (4.23).

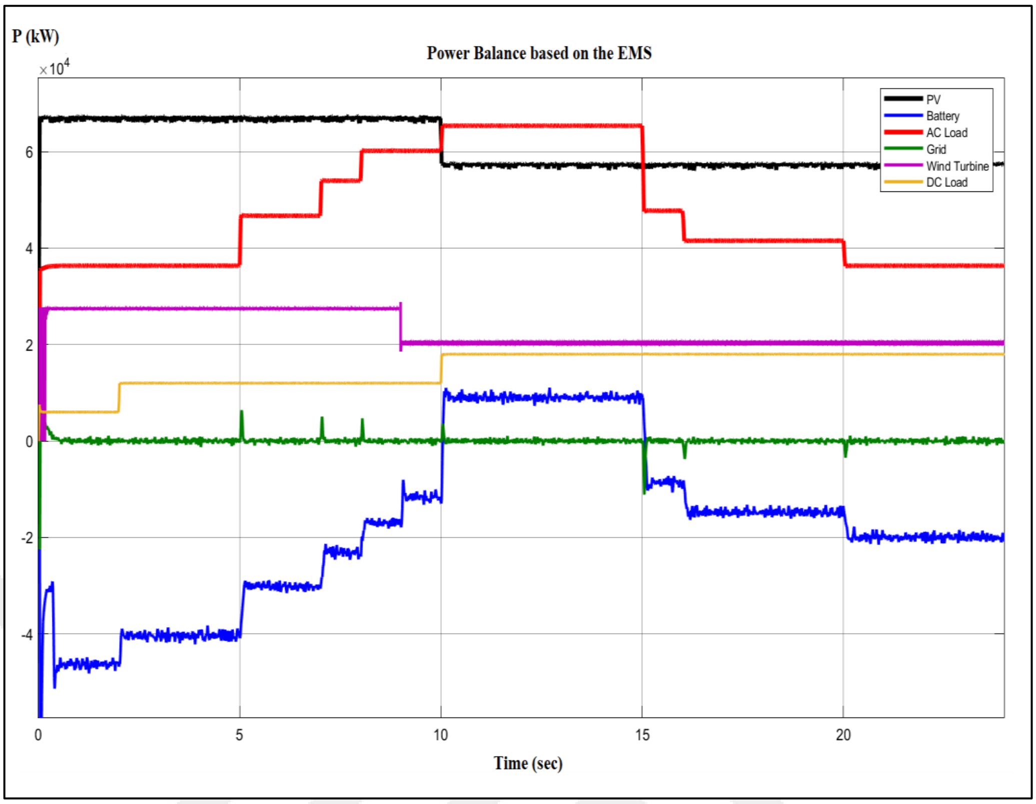

Figure 4.23: Power Balance with INC. MPPT.

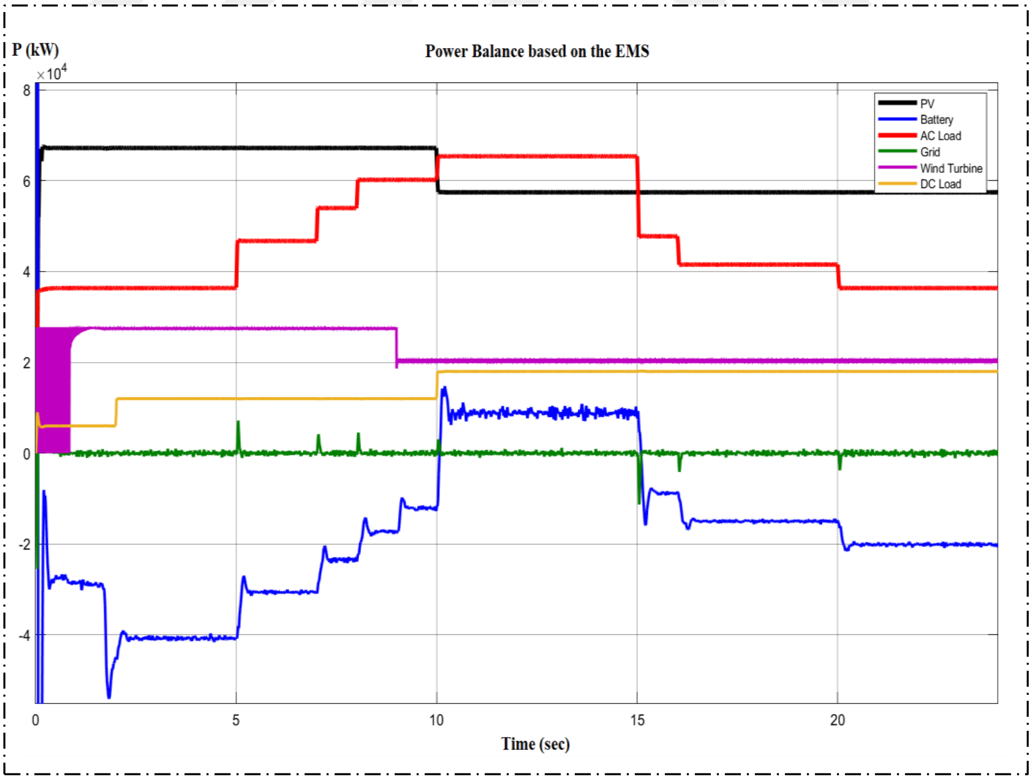

Figure 4.24: Power Balance with GWO MPPT.

4.9 AC VOLTAGE AND CURRENT WAVEFORMS

The three-phase load voltage and current waveforms are shown in Figure (4.25), the voltage is kept to be constant while the current are identical to the proposed load power.

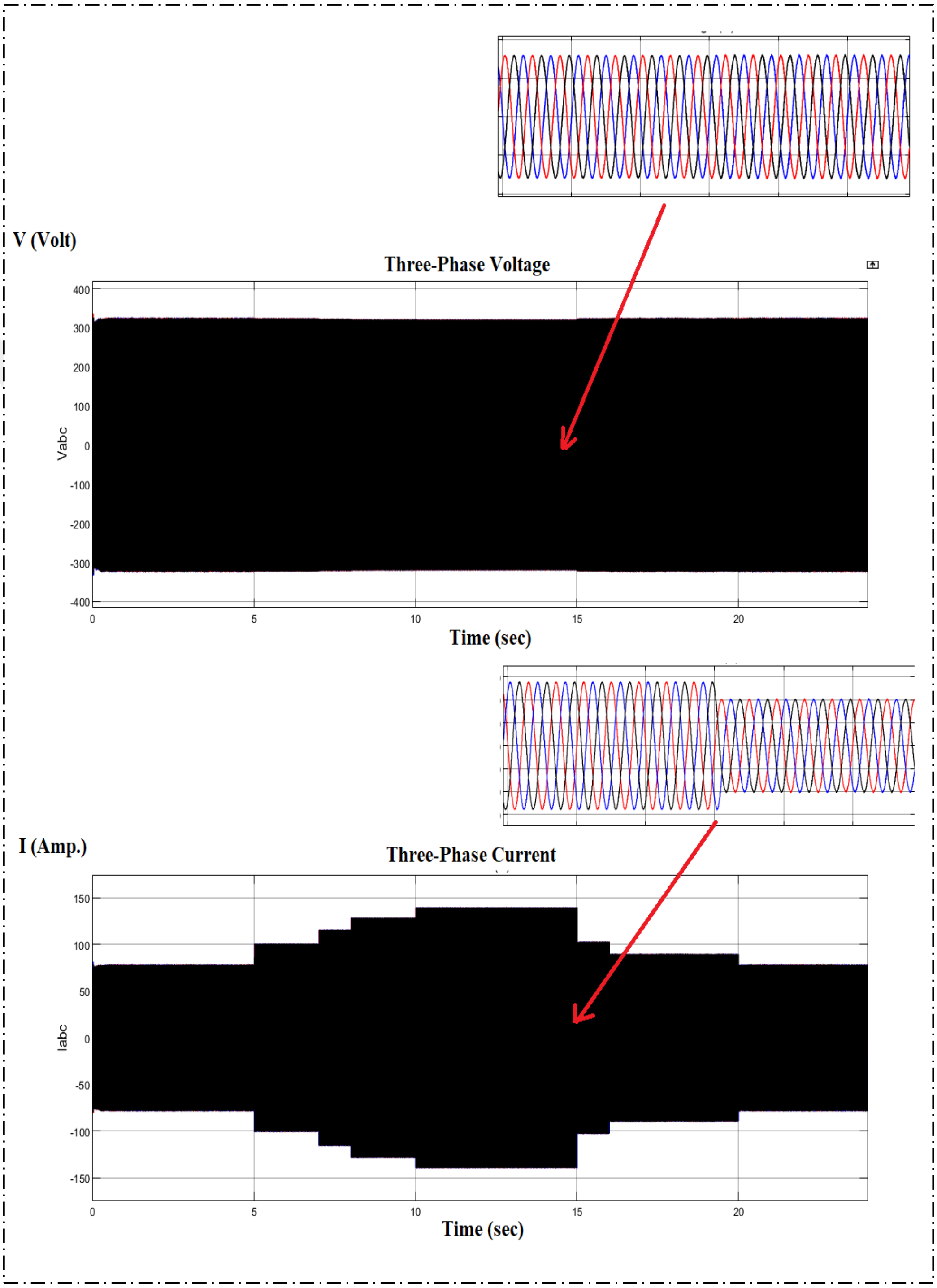

Figure 4.25: Three-Phase Voltage and Current Waveforms.

5. CONCLUSIONS

5.1 CONCLUSIONS

The distribution and transmission grids are upgraded to improve the effectiveness, security, economic status, and dependability of the electrical system. The SG improves the distribution and transmission grids by utilizing information, communication, and control technology. Smart metering, improved network operation and administration, rapid fault detection, and self-healing features enabled by grid automation may all be used to turn the conventional electricity grid into the SG.

SG is a combined set of technology and infrastructure for communication, data storage, and control that interacts with organizational procedures and automation throughout the entire power industry, covering the production of electricity, transmission, distribution, and consumption. There are various sorts of technologies, including microgrids and Nano-grids, which are meant to function in small community areas, but the SG is a large-scale power supply infrastructure and is built to work on big community power supply technology. A small-scale power system with the ability to regulate is called a microgrid. It may therefore function autonomously and be cut off from the wider network.

The suggested SG has several RESs with ESS and loads at varying ecological input resources. It is challenging to provide enough power flow and management control in SG among various resources and demands, even with this important control. Researchers in this field have used control algorithms in many of their prior attempts, but these algorithms have significant drawbacks as contrasted with independent SG. Determining energy management control techniques for the suggested circuit employing RES that operates at MPPT (both PV and wind turbine) is the aim of this study. The proposed system includes a wind turbine with converting systems (an unregulated three-phase rectifier and a DC-DC boost converter). The wind turbine's output power is approximately (27.5) kW, and the overall output power of the photovoltaic system used in this work is approximately (67.5) kW. The DC-DC boost converter is crucial to the PV system's effectiveness. In this procedure, the bidirectional converter stores extra power generated by the battery system while supplying the necessary electricity. This study uses both DC and AC loads, which are two different types of loads. This system uses a three-phase VSG inverter based on droop control to provide AC power.

To maximize the output power of the PV system, the first category of controller used in this study is the PV MPPT. This work uses the GWO and INC MPPTs; the GWO is an artificially intelligent approach, whereas the INC method is a conventional way, and this work compares the outcomes. By using the GWO method the voltage and current have a less distortion and the high efficiency of the output power as compared with INC MPPT method. The bidirectional controller utilized for both charge and discharge purposes, is the second category of regulator system. The EMS suggested in this work is accomplished by utilizing the bidirectional controller. The inverter control based on droop control, which may provide great precision when utilized for off-grid reasons, is the third and final option. The study suggests two different kinds of loads: DC and AC. Purely resistive DC loads are linked to the DC bus. The AC three-phase load, on the other hand, is attached to the inverter output after the LC filter. Five loads make up the AC load, and they are each linked to the grid by a three-phase circuit breaker. In the event of a generation shortfall or generation overshoot, these circuit breakers may be managed by utilizing IoT technology to connect or disconnect the loads.

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