Dynamic Power Management and Control of PV-Wind-BES Based Microgrid System

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DECLARATION

I hereby, certify that this manuscript, entitled “Dynamic Power Management and Control of a PV-Wind-BES Based Microgrid System”, is my own work with the exception of appropriately cited and quoted material.

In addition, I certify that it has not been used in whole or in part to apply for any other degree or certificate at Nazarbayev University or any other local, national, or international organization.

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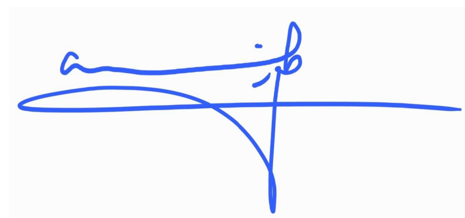

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Abstract

This study discusses the design and modeling of a microgrid system that is comprised of wind turbines, solar panels, and battery energy storage units (BESU). The purpose of the proposed system is to offer a consistent and dependable supply of power by integrating renewable energy sources with BES units in order to overcome the intermittent nature of these sources of energy. Continuity of power supply to vital loads is ensured by the microgrid's ability to function in either grid-connected or island mode, depending on the situation. The findings of the simulation indicate that the suggested system has the potential to achieve high levels of efficiency and reliability while simultaneously lowering carbon emissions and cutting down on energy expenses. In addition, the control strategy for the system is developed utilizing a hierarchical structure, which ensures the most efficient functioning of the photovoltaic, wind, and battery energy storage units. In order to increase the power quality, stability, and efficiency of this microgrid system, it is managed and regulated using an improved power management (IPM) algorithm. The efficiency of the proposed system is examined under a wide variety of scenarios, including the unpredictability of the weather patterns and the erratic nature of the electrical grid. According to the findings of the research, the PV-wind-BES-based microgrid system has the potential to be a workable option for off-grid and isolated locations that demand a dependable and environmentally friendly source of power.

Acknowledgements

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Abbreviations

BESU	Battery energy storage unit
BESS	Battery energy storage system
MG	Microgrid
RES	Renewable energy source
IPM	Improved power management
DC	Direct current
AC	Alternative current
MPPT	Maximum power point tracking
P&O	Perturb and observation
InC	Incremental conductance
PMS	Power management scheme
PBT	Power balance theory
IRPT	Instantaneous reactive power theory
CSD	Current synchronous detection
ISC	Instantaneous symmetrical component
DERs	Distributed energy resources
HAWTs	Horizontal-axis wind turbines
VAWTs	Vertical-axis wind turbines
DR	Demand response
PLL	Phase-locked loop
SES	Solar energy system
PWM	Pulse-width modulation
IGBT	insulated-gate bipolar transistor
VI	Voltage current
ESR	Equivalent series resistance
PMSG	Permanent magnet synchronous generator
RL	Residential load
PI	Proportional Integral
PCC	Point of common coupling
VSC	Voltage Source Converter
LD	Load Demand
UG	Utility Grid
THD	Total harmonic distortion
FFT	Fast Fourier Transform

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Chapter 1st - Introduction to Renewable Energy and Microgrid System

1.1 Introduction

Today's world cannot function without a reliable and cost-effective supply of power. Given that almost every aspect of contemporary life is dependent on constant access to power, the generation of energy has always played a crucial role. Moreover, how to generate power without negatively impacting the planet's ecosystem is now a major concern in light of the challenges posed by climate change and global warming. In light of the fact that the use of fossil fuels and the production of electricity using traditional energy sources such coal, gas, oil, and radioactive materials, are steadily raising the planet's temperature. To minimize carbon output, we should switch to renewable energy sources as our primary source of electricity for households and businesses [1].

A microgrid system is a small electrical network that functions either alone or in conjunction with other renewable energy sources (RES). The ideal way for a business, family, or small industrial with a modest power demand to meet their own power demands is via the usage of a microgrid system. Microgrid systems provide reliable, cost-effective, and sustainable electricity. In addition, it makes the local power grid more stable and efficient [2]. In other words, microgrid systems are the ideal choice for lowering energy costs, and in addition, you can even sell the electricity you create to the utility grid. With conventional resources like coal, oil, and radioactive materials running out soon and the requirement for energy production growing daily, a microgrid system may help maintain consistent energy output. When a microgrid is deployed, energy generation is referred to by several terms, including embedded, district, distributed, dispersed, and decentralized. At times of peak demand, microgrids are typically utilized to supplement the main power grid or provide backup power. Typically, they rely on clean energy like wind and solar. Reducing the utility system's susceptibility to localized disasters may be possible with the help of a microgrid plan that employs surrounding wind or solar resources to offer redundancy for key services. [3].

The purpose of this suggested system is to produce electricity from two renewable sources, such as solar and wind, and employ of a BESS for further consumption of electricity when the production is not available. In other words, solar can only produce electricity when the sun's irradiation is accessible, and wind turbines can only generate power when there is enough wind flow. This system has issues due to the unpredictability of the weather, which creates a gap for energy production. Numerous studies on microgrid systems have been conducted, and numerous papers have been written in this field. Despite this, there are still many challenges and opportunities for advancement in the power management and control scheme of PV, wind, and BESS during the "on-grid" and "off-grid" modes, taking into account the fluctuation in PV and wind power availability, etc.

1.2 Objectives

The suggested system is based on the production of electricity from renewable resources, with solar power acting as the major source, wind acting as the secondary source, and batteries acting as the backup power source. A combination of solar and wind energy may provide enough electricity throughout the day for a company, a home, and commercial buildings. The system may be configured to produce electricity from solar energy and wind energy while the sun is shining and to charge the batteries for use when the power is out. On the other hand, it can be designed to function in both "on-grid" and "off-grid" settings to improve power management synchronization when PV, wind, and utility grid are unknown, which is the main factor to focus on.

This thesis effort will present an enhanced power management and synchronization strategy to raise the microgrid's efficiency and dependability. Under underload and overload conditions, these configurations make the system dependable and simple. In other words, when there is high generation during an underload state, the produced power must be injected into the utility grid, and when there is high production during an overload condition, the system draws electricity from the grid. We create the system to draw electricity from the utility grid to meet customer demand since weather conditions are unpredictable when power output is down. The suggested system will be evaluated under different utility grid and microgrid operating conditions.

The following is an outline of the primary goals that this thesis work aims to accomplish:

1. To design and develop new/modified synchronization techniques for PV-Wind-BESS based microgrid system to work with utility grid during ‘grid-connected’ mode and ‘off-grid’ mode of operations without any power interruptions.

2. Design and development of a new/modified power management scheme for PV-Wind-BESS based microgrid system to enhance the communication between these sources of microgrid for optimal utilization of generated power.
3. MATLAB Simulink environment is used for the *in-silico* design of the power management and control techniques.
4. The power management and control schemes devised during this research shall be validated on a lab-based test rig, which is being developed under the Collaborative Research Project (CRP) at the Nazarbayev University. However, the scope of this thesis work does not include the development of the test rig, which is being carried out by other researchers in the CRP project.

1.3 Methodology

The proposed system consists of solar, wind, BESS, inverter, controller and etc. To raise the PV output voltage, a DC-DC boost converter is used to link the solar panels, which are then connected to a DC bus bar. A boost converter is required when a device's properties degrade as a result of faulty or unreliable voltage sources. To convert the alternating current (AC) electricity generated by the wind turbine into direct current, a rectifier is linked to the PMSG generator, this is afterwards linked to a boost converter connected to the DC bus bar. Maximum power point tracker of the solar arrays and wind turbine is set to track the MPP for a better and efficient power generation. There are different types of MPPT techniques in order to track the MPP of PV and wind, during different hours of the day such, Perturb and Observation (P&O) control technique, Incremental Conductance (InC) control technique and, fuzzy logic control technique. However, the incremental conductance maximum power point tracking (MPPT) approach is used for this suggested system in order to monitor the maximum power that is available from PV and wind [4].

The size of the batteries will be determined based on the power needs. The BESS is linked to a bi-directional DC-DC converter, connected to the DC bus bar. A three-phase voltage converter is being developed and is set to convert the DC supply of the DC bus bar to AC for use in home appliances and grid synchronization. A power management scheme (PMS) is developed to make the system reliable and to reduce the power losses. Grid synchronization of the system is one of its key factor that makes the system reliable. Synchronization of the system can be done through various methods such as instantaneous reactive power theory (IRPT), instantaneous symmetrical component theory (ISC), power balanced theory (PB) and, current synchronous detection theory (CSD). However, for this proposed system power balanced theory based algorithm is used to synchronize the power inverter to the grid easily and to avoid power delay to the load. The proposed system is tested in-silico under various condition of utility grid and microgrid mode of operation using MATLAB Simulation platform[5].

1.4 Thesis Structure

The structures of the MSc thesis are explained as the following chapters; in chapter 2^{nd}, A comprehensive literature survey on solar cells topology, wind turbine topologies, microgrid operation and energy management is covered. The chapter 3^{rd}, overall configuration of microgrid, control topology of microgrid system, design of boost converter, MPPT algorithm, battery energy storage model, grid synchronization and power management system is covered. The chapter 4^{th} describes the applications of the proposed system. The chapter 5^{th} describes results and findings. Finally, the conclusion of the proposed model is described in chapter 6^{th}.

Chapter 2nd - Literature Review

A number of research papers can be found in the literature on microgrid systems especially on PV-Wind-BES based microgrid systems. In this thesis work, a comprehensive literature survey have been conducted based on microgrid control operations, energy management system (EMS), microgrid standards, economics of microgrids and microgrid protection. The contribution on synchronizing the PV with the utility grid under the solar irradiation condition, dynamic load, and nonlinear load circumstances is a major area of interest[6]. More so, by addressing these concerns, we may learn how to improve power quality. The idea of the literature study is based on an awareness of the most up-to-date, updated and sophisticated control topologies for synchronizing solar and wind systems with the utility grid, which is necessary for resolving the aforementioned problems. It is essential to take into account that the selection of these control approaches must be made in accordance with the control topologies that are applicable to the system and equipment specifications[7].

2.1 Background

A microgrid is a localized, small-scale system for producing and distributing energy that may run either independently or in cooperation with the main power grid. Often, microgrids are built to provide electricity to a particular region, such a university campus, a military installation, or a rural hamlet. Microgrids often consist of a range of distributed energy resources (DERs), including backup natural gas or diesel generators, wind turbines, solar panels, and battery storage devices[8]. A centralized control system that coordinates the flow of power to satisfy the needs of the regional grid is linked to these resources . The capacity of microgrids to function independently of the larger power grid is one of its main advantages. This implies that they can keep supplying electricity to their neighborhood despite blackouts or other interruptions to the wider system. This may be especially useful in places that are vulnerable to natural catastrophes, such as those affected by hurricanes or wildfires, as well as in distant locations where the grid infrastructure is faulty or nonexistent. The flexibility of microgrids to include renewable energy sources, such as solar and wind power, is another benefit. In the long run, this may help lower the local community's carbon impact and provide more consistent, predictable energy prices. In general, microgrid systems are gaining popularity as a method to supply local communities with dependable, sustainable electricity while simultaneously lowering reliance on the broader power grid and fostering more energy independence[9].

2.2 Topology of Solar Photovoltaic Cells

Depending on the intended use and electrical properties, solar photovoltaic (PV) cells can be coupled in a variety of combinations or topologies. In a series connection, the positive terminal of one photovoltaic cell is connected to the negative terminal of the cell that comes after it, which joins numerous PV cells end to end. By doing this, the PV array's overall voltage output is increased while maintaining its single cell-level current output[10]. The positive and negative terminals of several PV cells are all linked to a common positive bus and a common negative bus, respectively, in a parallel connection. By doing this, the PV array's overall current output is increased while maintaining its single cell-level voltage output. A certain voltage and current output may be obtained by combining series and parallel connections [11].

The total current output, for instance, may be increased by connecting many strings of PV cells in parallel, and the total voltage output, for each string, can be increased by connecting several strings of PV cells in series. A diode or other device is linked in parallel with each PV cell in a shunt connection to stop reverse current flow, which may happen when a PV cell is shaded or has a lower voltage output than the cells around it[12]. To stop a shaded or damaged cell from lowering the output of the whole PV array, a bypass link is employed. The faulty or shaded cell is linked in parallel with a bypass diode, which enables the current to flow around the cell rather than through it. The intended output voltage and current, as well as other elements like shading, temperature, and module efficiency, all influence the selection of the PV cell architecture[13].

2.3 Wind Turbine Topology

Topology in the context of wind energy refers to the many categories of wind energy systems and their constituent parts. Horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs) are the two primary types of wind turbines that are used in wind energy systems. HAWT blades revolve on a horizontal axis and feature a horizontal rotor shaft[14]. A blade root joins the rotor hub to the rotor blades, which are commonly constructed of carbon fiber or fiberglass[15]. The gearbox is then attached to the rotor hub, causing it to rotate at a higher speed than the generator, or from low to high speed. After that, the generator turns the rotor's mechanical energy into electrical energy[16].

Blades in VAWTs revolve around a vertical axis and are attached to a vertical rotor shaft. Drag-type or lift-type turbines are also possible. Curved blades are seen on drag-type turbines whereas flat blades are found on lift-type turbines. While less prevalent than HAWTs, VAWTs offer certain benefits over HAWTs, including the ability to function in choppy winds and ease of maintenance [17].

2.4 Microgrid Operation

A microgrid system is a compact electrical grid that may run alone or in cooperation with a bigger grid. It primarily comprises of DERs, or distributed energy resources, built into a local distribution network[18]. Examples of DERs include solar panels, wind turbines, and energy storage devices. The day-ahead stage establishes the MG's power routing and energy sharing after the economic functioning of the MG has been optimized. The performance of MG systems without storage is severely hampered by intermittent generation and rapid load demand variations. In order to assure a consistent and efficient supply of electricity, operating a microgrid system entails managing distributed energy resources, balancing energy demand and supply, and preserving grid stability[19]. The operation of a microgrid system involves several key components, which have been tracked from different literatures. In [20] a central management system that oversees and controls the power flow between various DERs and the local distribution network operates a microgrid system. The author in [21] used balancing energy supply and demand; the energy management system is in charge of ensuring that the microgrid operates as efficiently as possible. In order to guarantee that there is enough energy to fulfill demand, this involves controlling the production of renewable energy sources and storage systems. In reference [22], electricity is produced and stored by DERs such solar panels, wind turbines, and energy storage devices. In order to provide an effective and dependable power supply, the microgrid system coordinates the functioning of numerous DERs. In [23], the load management system keeps track of and manages the energy consumption of various microgrid-connected equipment and appliances. This entails controlling use patterns and allocating loads according to their criticality. In [24], Microgrid systems have the option of being linked to a larger power grid or functioning independently. In an energy system that is linked to a larger grid, the microgrid may trade electricity with the bigger grid in order to maintain a healthy balance between energy supply and demand. A comprehensive literature survey on microgrid control operation is illustrated in **Table .2.4**.

Table .2.1 Microgrid control operation

Year	Control Type	Brief description	Reference
2023	Centralized	This method employs a central controller to handle the microgrid system, which includes managing energy storage systems, managing DERs and loads, and coordinating power flows. To achieve precise and dependable control, this method needs a high-speed communication network and sophisticated control algorithms.	[25]
2023	Decentralized	Decentralized control spreads the control task across several microgrid system elements, including distinct DERs, storage systems, and loads. Decentralized control can increase system resilience by reducing reliance on a centralized controller.	[25]
2023	Hierarchical Control	Combining centralized and dispersed control strategies creates hierarchical control. The hierarchical structure has numerous levels, each of which is in charge of a certain function of the microgrid system.	[26]
2022	Predictive control	To improve control choices, predictive control makes predictions about future system behavior using mathematical models. This method anticipates changes in load or generation in the future and modifies system operation accordingly to save costs or increase efficiency.	[27]
2022	Master-Slave mode	Microgrids typically employ this control method while operating in islanding mode.	[28]

2.5 Energy Management Topology

The purpose of this research is to give a thorough examination and analysis of a variety of energy management strategies that can be applied to a variety of microgrid systems. Topics covered in this review and analysis include the objectives, constraints, and techniques of each strategy, as well as optimization methods and simulation tools. In addition to this, it analyzes the problems that now exist and offers ideas for the research that should be done in the future [29]. To ensure dependable and efficient operation, lower energy costs, and cut greenhouse gas emissions, microgrid systems must practice effective energy management.

Using a wide range of renewable energy sources including solar, wind, and hydropower, in addition to energy storage technologies, in order to store surplus energy for use at a later time, it is possible to maximize the energy production of a microgrid system. To balance energy supply and demand in a microgrid system, effective load control is essential [30]. This may be accomplished by utilizing intelligent control systems to regulate energy use and turn off unnecessary loads during times of high demand. Batteries are one example of a technology that can be used both to supply energy and to store energy at times of high demand and store it for use during periods of low demand when demand is lower. This can reduce energy expenditures and increase the microgrid system's dependability.

At times of peak demand, energy consumption can be decreased via demand response tactics. This can be done by offering incentives to consumers to get them to use less energy during certain times. It is possible to combine microgrid systems with the main grid to increase energy security and lower energy expenses. This study looks at the techno-economic effects of renewable energy, electricity prices, and grid involvement. Offering a demand-response (DR) model that optimizes the advantages of energy merchants, in this instance microgrid consumers, is the main objective.

In order to determine the ideal incentive value, a thorough optimization process is started. A revolutionary intelligence algorithm is then applied to reduce the total cost of a microgrid system and examine the results both with and without a DR program. Fuel expenses, fined pollution fees, operation and maintenance costs, depreciation costs, etc. are all cost considerations [9]. This can be accomplished by controlling energy flow between the microgrid and the main grid with sophisticated control technologies. Generally, the success of microgrid systems depends on efficient energy management. Microgrid systems may be improved to offer a dependable and efficient energy supply while minimizing energy costs and lowering greenhouse gas emissions by utilizing a combination of renewable energy sources, energy storage systems, and smart control systems.

2.6 Microgrid Protection

The protection of microgrid system is another challenge of this paper. This article, surveys several research papers regarding protection of microgrid systems from natural disasters, cyber-attacks, and physical attacks as illustrated in **Table .2.**

Table .2.2 **Protection measures of Microgrid systems**

Year	Protection type	Specifications	Reference
2022	Physical security	Only authorized people should be able to enter the secure facility where the microgrid equipment is kept. To safeguard the microgrid, physical security measures like locks, fences, and security cameras should be put in place.	[31]
2019	Cybersecurity	Cyberattacks against microgrids may result in the loss of data or an interruption of the power supply. To defend against such assaults, a strong cybersecurity program that uses firewalls, encryption, and frequent software upgrades should be put in place.	[32]
2022	Redundancy	Microgrids may be built with redundant parts, which can guarantee that the system will function even if one part fails. They might include backup power supplies, storage devices, and control systems.	[33]
2020,2021	Monitoring and maintenance	The microgrid may be regularly maintained and monitored to find possible concerns before they become serious ones. Regular component testing, power quality monitoring, and system performance are examples of this.	[34], [35]
2023	Master-Slave mode	Microgrids typically employ this control method while operating in islanding mode.	[36]

2.7 Grid synchronization of PV-Wind-BESS

The primary obstacle that has to be overcome is the synchronization of the proposed system with the grid to look in the literature and find out the best-suited synchronization technique for the microgrid system to avoid power generation losses during power dominant mode. The synchronization of microgrid systems with the main power grid is one of their fundamental difficulties. A grid utility synchronization approach is used to guarantee that the microgrid is running concurrently with the main grid[37]. With the help of control algorithms and communication protocols, the microgrid can maintain a consistent frequency and voltage level using this technique. A microgrid is a compact power system that may run separately from the larger grid or be linked to it. In isolated locations or as backup power systems for vital facilities like hospitals, data centers, and military sites, microgrids are frequently employed. Photovoltaic (PV) panels and wind turbines are examples of renewable energy sources that may be included into microgrids to assist minimize the need for fossil fuels and greenhouse gas emissions. Due to their erratic nature and the requirement to synchronize their power output with the grid, renewable energy sources can be difficult to integrate into microgrids. This research review focuses on the grid synchronization of a microgrid system powered by PV, wind, and battery energy storage (BES).

To guarantee that the microgrid can safely and reliably deliver electricity to the grid or receive power from the grid, synchronization is required. Controlling the output voltage, phase, and frequency of the microgrid allows for synchronization[38]. The grid synchronization of microgrids has been suggested using a number of ways. The phase-locked loop (PLL) approach is one of the most used methods. The PLL approach creates a reference signal that is used to regulate the output of the microgrid by using a feedback loop to detect the phase and frequency of the AC grid. Although the PLL method is straightforward and efficient, it might not be appropriate for microgrids with high-frequency variations[39]. Droop control is an additional method for synchronizing a grid. Based on the difference between the voltages of the microgrid and the grid, the droop control approach modifies the microgrid's output. Although the droop control method is straightforward and efficient, precise synchronization may not be achieved. Another method for grid synchronization is the vector control approach[40]. The vector control[10] approach modifies the microgrid's output to maintain synchronization by measuring the phase and amplitude of the grid voltage. Though more complicated than the droop control technique, the vector control technique can offer better synchronization.

Renewable energy is used to produce electricity through the PV and wind turbines, with backup power and power output balancing assistance from the BES. Compared to a single renewable energy source, the combination of PV panels with wind turbines can offer a more steady and dependable power supply. The grid synchronization method must be carefully considered when integrating solar and wind power into a microgrid. The characteristics of the renewable energy sources and the load determine the best grid synchronization strategy. In order to maintain synchronization with the grid and accommodate the intermittent nature of renewable energy sources, the synchronization approach must be able to handle these factors. For microgrid systems, a number of grid utility synchronization techniques are available, such as:

2.7.1 Phase-Locked Loop (PLL)

This method is often used in AC power systems to match the frequency and phase of a power source's output voltage with that of the grid. The PLL method compares the phase and frequency of the two signals using a feedback loop, and then modifies the output signal to match the grid[41].

2.7.2 Synchro-Phasor Measurement

This method uses synchronized phasor measurements to keep track of the power system's condition. Synchro-phasor measurements are gathered from many systemic locations and are coordinated using a shared time standard. This makes it possible to monitor the system in real-time and makes it easier to find errors or disruptions[41].

2.7.3 Grid-Tied Inverters

The output of a grid-tied inverter is synchronized with the grid, making it a frequent component of renewable energy systems. To keep the output in sync with the grid's frequency and phase, the inverter employs a control algorithm[42].

2.7.4 Power Balance Theory (PBT)

The power produced by a microgrid system must match the power used by the loads within the microgrid. This is done via a process called power balance synchronization. This is a crucial part of running a microgrid because it keeps the system stable and keeps the components from being overloaded or under loaded. While using the power balance synchronization approach, electricity produced by the microgrid is measured and compared to power used by the loads. The system will alter the power output in accordance with any imbalance between the two to keep everything in balance. The author in [43] proposed a vector control strategy for a PV-wind-BES based microgrid system. The active and reactive power of the microgrid are managed using a decoupled control method via the vector control technique. The technique successfully maintained grid synchronization during testing using a simulation model. For this proposed system power balance theory, based control algorithm is utilized for synchronization of PV wind and battery[44].

2.7.5 Drop Control

In microgrid systems, droop management is a method for preserving power balance. To guarantee that the power provided by the microgrid matches the power used by the loads, the droop control algorithm modifies the microgrid's output in response to variations in frequency and voltage[45].

2.8 Battery Energy Storage Topology

Depending on their intended use and performance requirements, battery energy storage systems can be set up in a variety of topologies. In[43] the author proposed a battery energy storage system without a grid connection is used. A battery bank, a charge controller, and an inverter are often included to convert the battery's DC electricity to AC power for use by the loads. In isolated areas where dependable or accessible access to the grid is not possible, this topology is frequently employed. The authors in [46] uses a grid-connected battery energy storage system to store excess grid energy during periods of low demand or low prices and subsequently release that energy during periods of high demand or high prices. A bidirectional inverter, a battery bank, and a control system to regulate energy flow between the battery, loads, and the grid are often included. In [47] this topology, a grid-connected battery energy storage system is used to supply backup power in the event of a grid outage. It generally consists of a battery bank, a bidirectional inverter, and a transfer switch to connect the loads to the battery during an outage and disconnect them from the grid.

In order to offer a dependable and sustainable supply of energy, this architecture integrates a battery energy storage system with renewable energy sources, such as solar or wind power. It generally consists of a battery bank, a charge controller, an inverter, and a source of renewable energy, as well as a control system to regulate the energy flow between the various parts[48]. In [49] a battery energy storage system is combined with a number of energy sources, including the grid, diesel generators, and renewable energy sources, to create a self-sufficient energy system that can function without the grid. A microgrid controller is often used to govern the flow of energy between the various components, along with a battery bank, a number of energy sources, a control system, and other components.

Chapter 3rd - Control topology of PV-Wind-BES Based Microgrid System

The suggested model's overall system setup, together with its design parameters and the recommended control mechanisms, are presented in chapter 3. The suggested topology, designing process, and proposals are first described. The recommended control methods' impact is understood.

3.1 System Configuration

A complete Architecture of Microgrid system with its boost converter and control algorithm is illustrated in Figure 3.1. This system configuration is consist of PV panels, wind turbine and BESS. The microgrid's DC component is built using renewable energy sources (such as PV and wind) and battery energy storage systems (BESS), while the AC component of the converter is built with residential loads and the utility grid. In DC portion, the PV system is provided with a DC-DC boost converter to step up the input voltage of the PV power and then linked with the DC bus bar. The PMSG generator is coupled with the rectifier so that the wind power may be converted from AC to DC, which is then linked with the DC-DC boost converter connected with the DC bus bar. The BESS is equipped with a bidirectional buck-boost converter, and this converter is coupled to the DC bus bar. In AC portion of the system, the DC bus bar is connected with a 3-phase rectifier to convert the DC generated power from the renewable sources to AC for utilization in home appliances and power sharing. The suggested system's control approach was developed using an algorithm based on power balanced theory (PBT) [4].

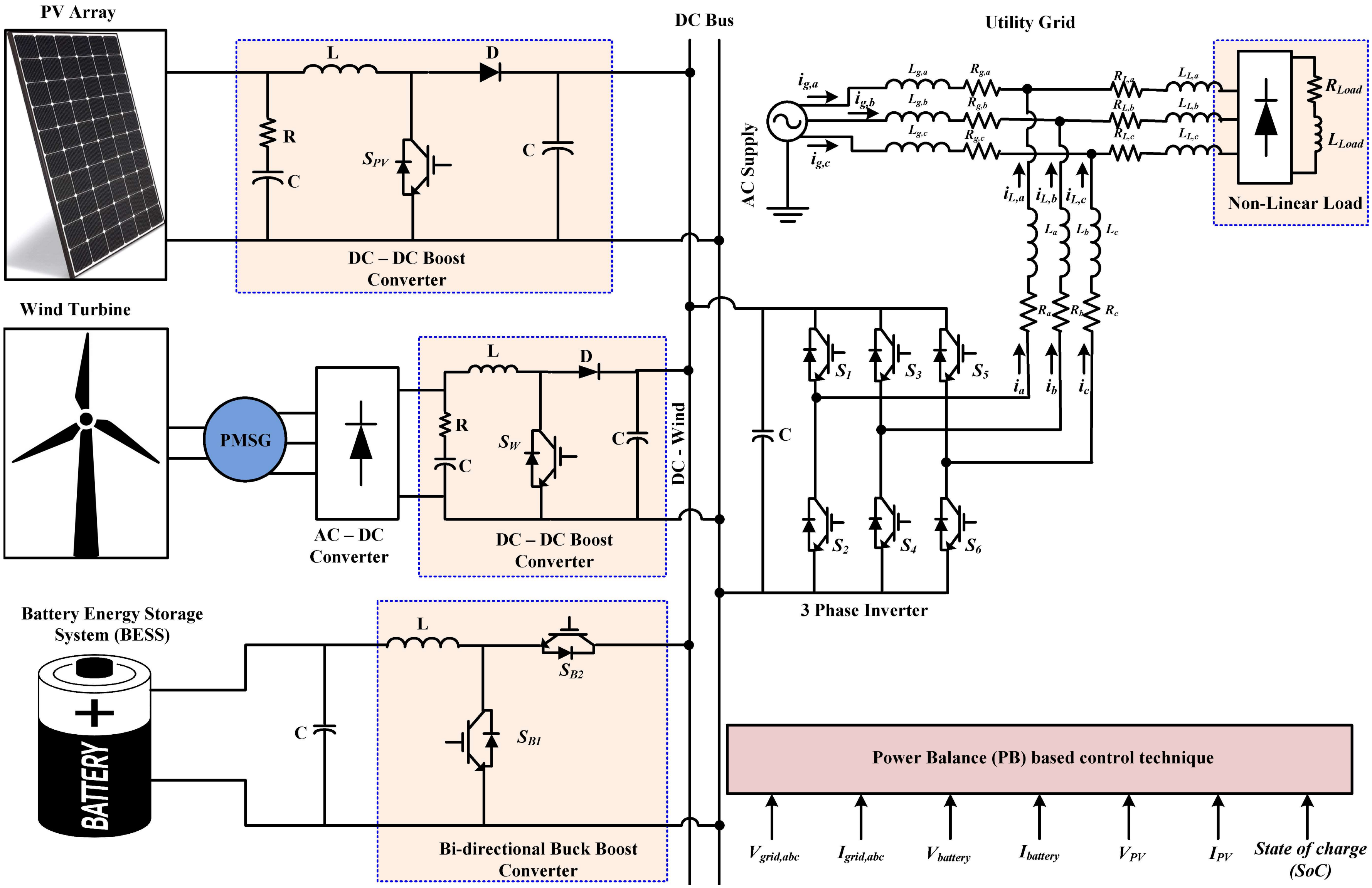


Figure .3.1 schematic diagram of MG with its boost converter and control operation[4].

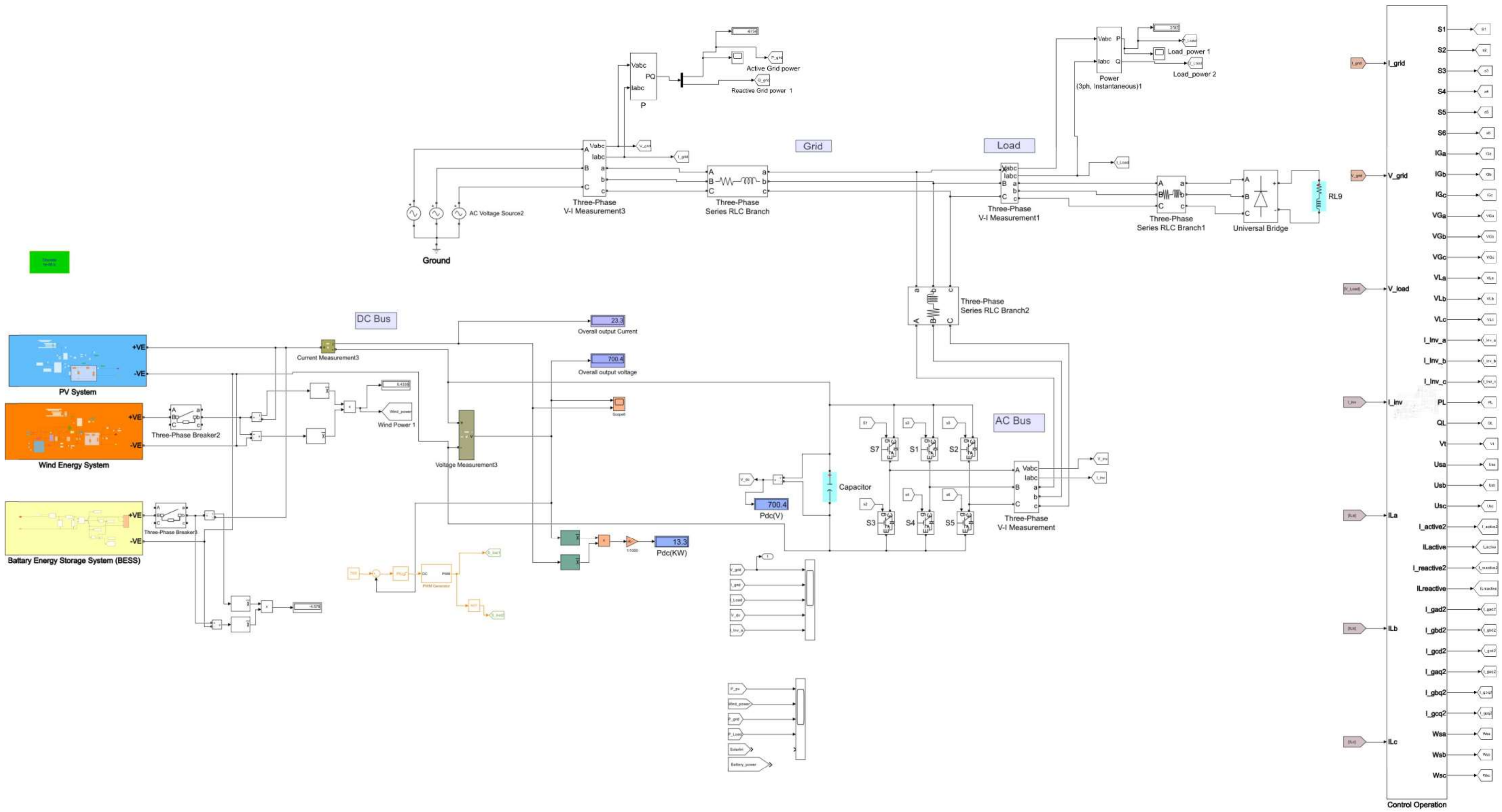


Figure .3.2 simulation configuration of the proposed model

3.1.1 10kW Solar Energy System

Today, power has become a vital necessity of human life and the energy management has always been day-to-day critical aspect of researchers and power engineers. Nowadays demand for renewable energy is rising rapidly as the conventional resource like oil, gas and radioactive materials are going to be finished in upcoming centuries and/or decades. A solar energy system is a collection of tools that uses solar energy to generate heat, electricity, or other types of energy. The sun's rays are directly converted into electricity using a photovoltaic solar energy system composed of semiconductor materials like silicon. The power produced by these panels, which are often put on the roof or in a sunny spot, may be utilized right away or stored in batteries for later use[50].

A 10KW solar energy is the best replacement for a house hold or a small commercial shop to supply their power demand. As explained, the proposed is divided into four subsystems such as solar, wind, BESS and control strategy subsystems. The solar energy system (SES) is consist of solar panels, boost converter and MPPT. The necessity for a boost converter arises from the need to prevent characteristics from deteriorating owing to inappropriate voltage supplies or unreliable voltage sources, in other hand a boost converter makes the system reliable to integrate with utility grid easily and reduces power sharing losses. The proposed DC-DC boost converter, boosts the input voltage to 700V for better power supply and battery charging. The proposed system is provided with the MPPT control scheme to track the MPP of the PV during the different hours of the day and solar insulation changes. For this proposed system Incremental Conductance (InC) MPPT, control scheme is used. Simulation model of the PV system, VI characteristic waveform and the PV with its boost converter and MPPT are illustrated in below Figure 3.3, 3.4 and Figure 3.5 respectively.

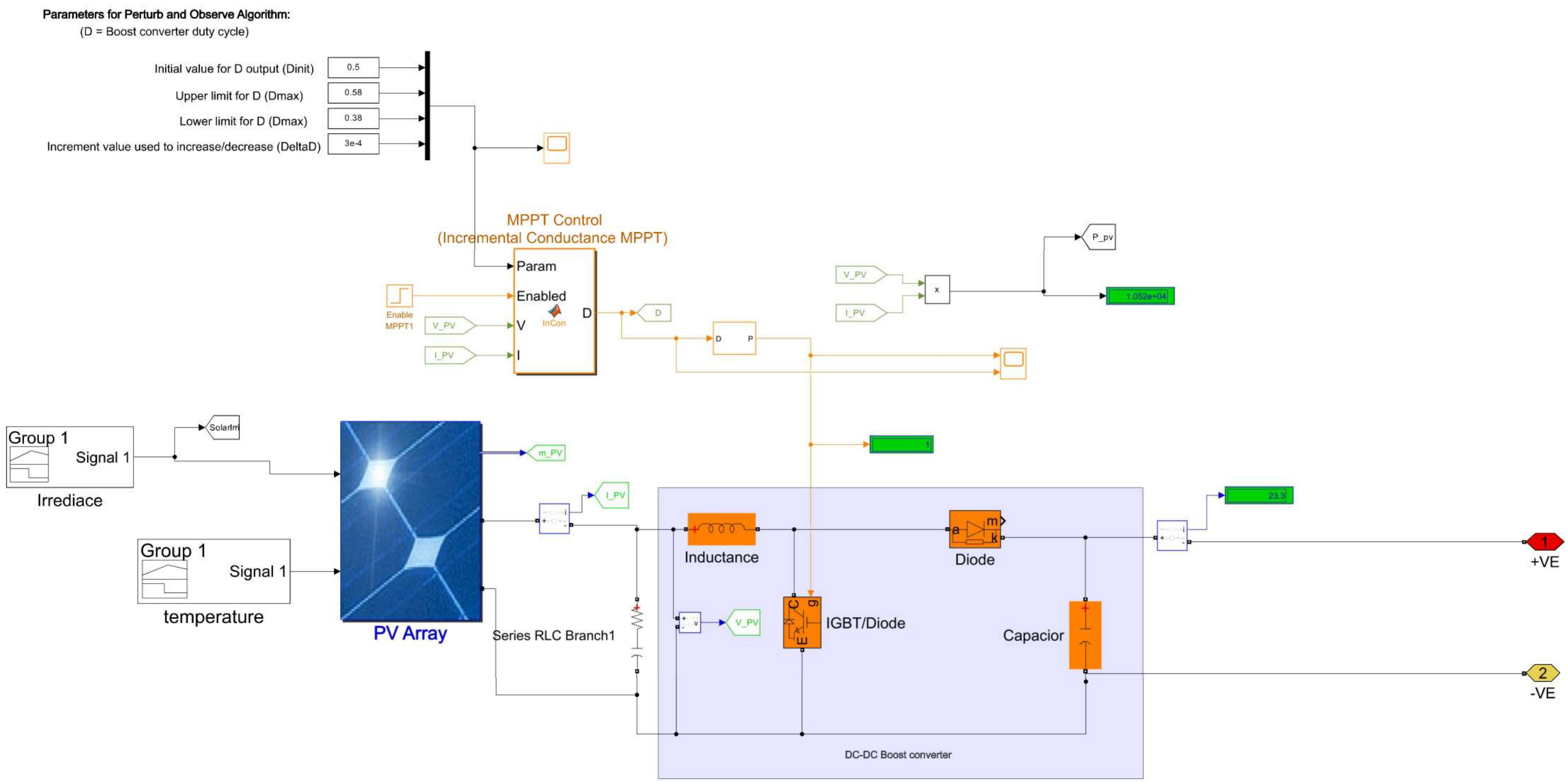


Figure 3.3-simulation model of the PV system

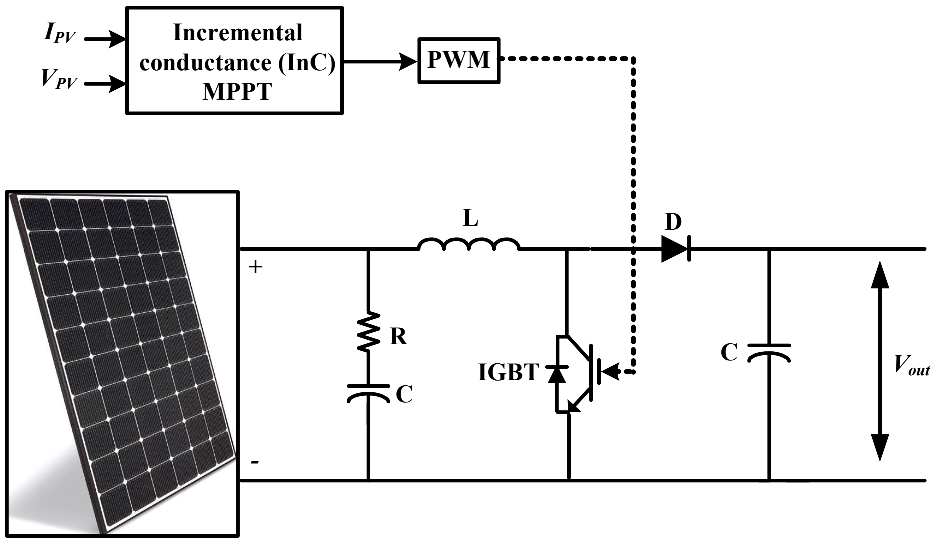


Figure .3.4 solar arrays with their boost converter and MPPT algorithm[4]

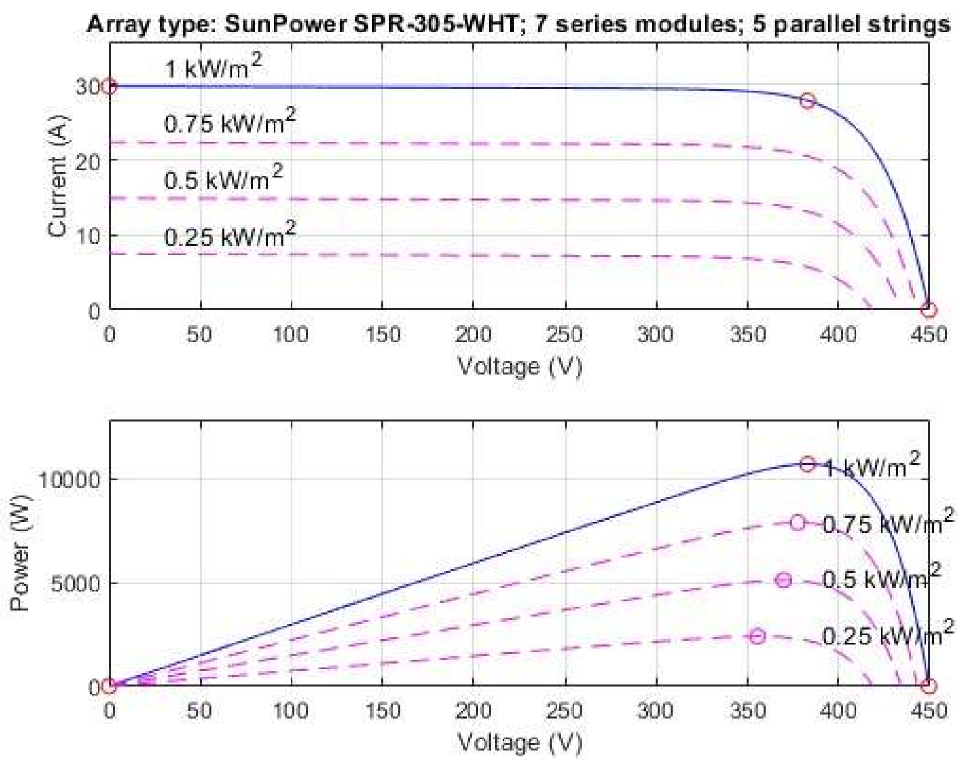


Figure .3.5 VI characteristic waveform and MPP plot of the PV system

Voltage and current (VI) characteristic waveform graph show the specification of the PV system in which the PV arrays are arranged in seven series modules and five parallel strings generating 10kW of PV power.

3.1.1.1 Development of a DC-to-DC Boost Converter

A lower DC voltage is transformed into a greater DC voltage using an electrical circuit known as a DC-DC boost converter. The input voltage is changed into a different output voltage via high frequency switching, which is a form of switching power supply. Inductor, diode, output capacitor, switch, input voltage source, and inductor make up the boost converter. Usually, a pulse-width modulation (PWM) signal governs a MOSFET or an IGBT, which serve as the switch. The inductor absorbs energy from the input voltage while the switch is closed, storing it for release when the switch is opened, raising the output voltage. While the switch is open, the diode serves as a conduit for the inductor current, and the output capacitor filters the output voltage to provide a continuous DC output. By altering the PWM signal's duty cycle, which controls the switch, the boost converter's output voltage can be changed. An output voltage that is greater will be produced with a higher duty cycle, while one that is lower will be produced with a lower duty cycle. Figure .3.6 presents the schematic representation of a DC-to-DC boost converter.

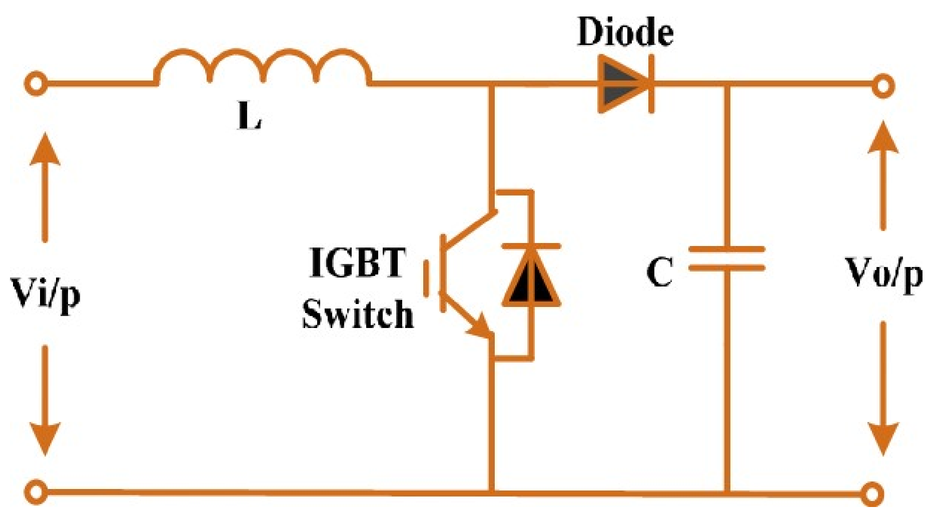


Figure .3.6 illustration of the circuitry for a DC-DC boost converter

A DC-to-DC boost converter acts as a step up transformer, which step up the input voltage for better use of the power and power sharing of the generated electricity. The calculation's formulas[51] for capacitance, inductance and resistance for the DC-DC boost converter are given as follows:

Duty cycle:

$$D = 1 - \frac{V_{in}}{V_{out}} \tag{3.1}$$

Capacitor:

$$C = \frac{I_{out}*D}{f_s*\Delta V_{out}} \tag{3.2}$$

Where, $\Delta_{V_{out}}$= Equivalent series resistance (ESR)*$\left(\frac{I_{out}}{1-D}\right) + \frac{\Delta_{I_L}}{2}$

ESR range is between 0.01 to 0.1 Ω

$$\Delta_{I_L} = 0.2 \text{ to } 0.4 * I_{out} * (V_{out}/V_{in}) \tag{3.3}$$

Switching frequency (Fs) has been taken as 15 KHz

Inductance:

$$L = \frac{V_{in}\,(V_{out}\text{-}V_{in}}{\Delta_{I_L} * f_s * V_{out}} \tag{3.4}$$

Resistor:

$$R = V^2/P \tag{3.5}$$

Overall, the values obtained after the calculation are as the following:

- Power = 10Kw
- Input Voltage = 382.9 V
- Output Voltage = 700 V
- Input Current (I_{in}) = 26.11 A
- Output Current (I_{out}) = 14.28 A
- Duty cycle *(D) = 0.45s*
- Capacitor: (C)= 0.15m F
- Fs = 15000 Hz
- Inductance (L) = 2.213 *mH*
- Resistor (R) = 49Ω

3.1.2 Wind Turbine Construction

To convert the mechanical energy of the wind into usable electrical energy, a PMSG generator is used as a wind turbine. This electrical PMSG is powered by mechanical energy, shown in (3.6). $Z_P - \gamma$ is used to classify wind turbines, where, γ represents the tip speed ratio as shown in (3.7).

$$P = \frac{1}{2}\rho A Z_P V^3 \tag{3.6}$$

$$\gamma = \frac{\omega_m R}{V} \tag{3.7}$$

Where ρ is the air density, the symbols A,Z_P and V represent the area of the blades, the power efficiency, and the air speed (velocity), respectively. The InC Algorithm is used to identify the increase in wind velocity[52]. The idea behind integrating wind and PV into a single energy system is to take use of the two technologies' complementary strengths: PV can produce electricity throughout the day, while wind can do so whenever wind flow is present. When photovoltaic (PV) systems are not working, wind energy systems may step in to meet energy needs, and vice versa. Wind turbines are especially effective during the colder months, when solar irradiation is low. The suggested system is optimized for 5 kilowatts (kW) of wind energy, and it employs a PMSG generator as its wind turbine. The PMSG's alternating current (AC) is transformed into direct current (DC) by means of a rectifier coupled to a boost converter. MPPT is a control technology built into the system that monitors the wind and adjusts the generator output accordingly. Figures 3.7 and 3.8 depict the design simulation of a wind turbine and its boost converter.

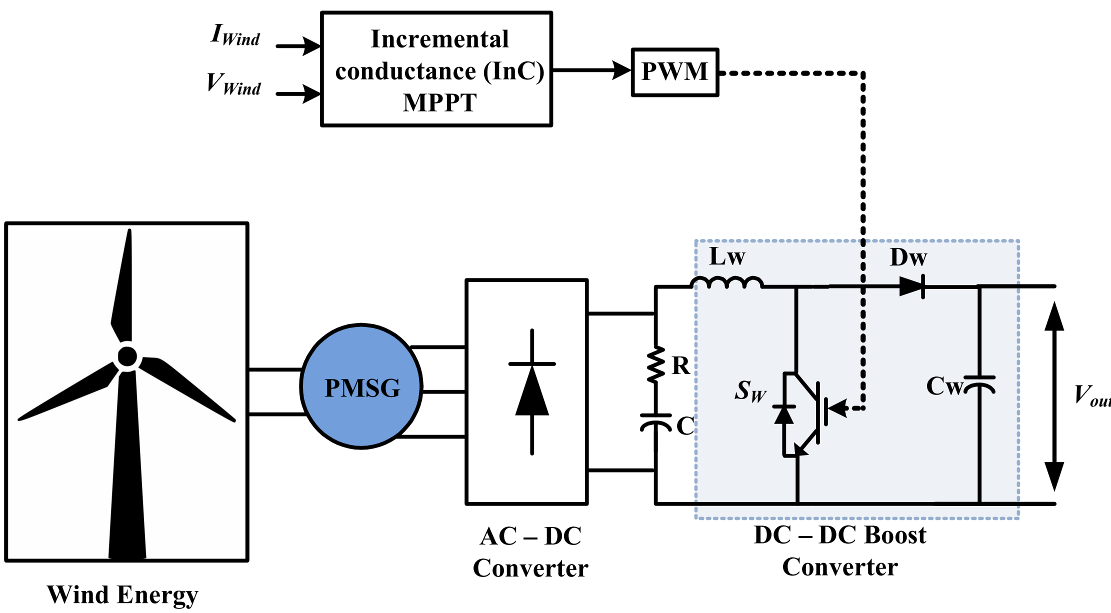


Figure .3.7 schematic architecture of wind turbine (PMSG) with its MPPT control algorithm[4]

The Wind PMSG generator is designed with a three phase rectifier and a boost converter to increase the input voltage till we reach the target voltage of 700V. The values for capacitance, inductance and resistance for DC-DC boost converter is obtain from the formula's explain in section 3.1.1.1 and the values obtained after the calculation is shown below respectively.

- Capacitor = 2.65e-7
- Resistor = 98
- Inductor = 4.73e-3
- Duty cycle = 0.3

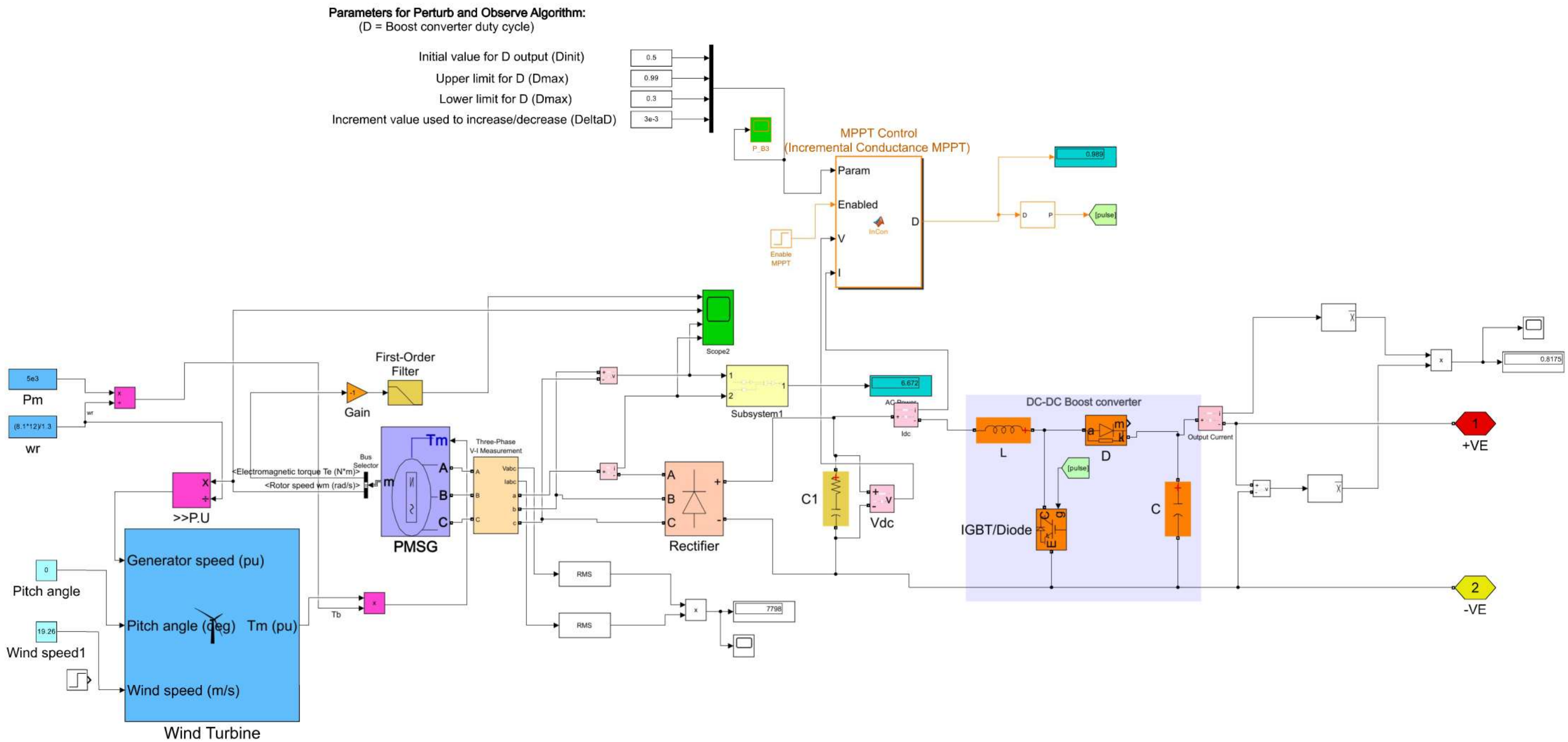


Figure .3.8 simulation model of wind turbine

3.1.3 MPPT Technique for Solar and Wind Energies system

Setting a control approach to monitor the highest power throughout various hours of the day is essential for the smooth operation and full utilization of the PV and Wind system. This system uses the Incremental Conductance (InC) control mechanism; however, there are other methods of MPPT as well [53]. This MPPT method will follow the hours of peak solar irradiation, and the optimal wind speed flow, for the wind system. The P-V curve's slope is calculated using an incremental conductance method, and the MPP is monitored by identifying the curve's peak. When it comes to maximizing energy production from photovoltaic (PV) panels, the InC MPPT method is widely used. The principle behind the InC MPPT method is the fact that the maximum power point (MPP) on a PV system's power-voltage (*P-V*) curve changes depending on the level of solar irradiation and the ambient temperature. In order to estimate the MPP, the incremental conductance (*dI/dV*) is used in conjunction with continuous measurements of the instantaneous voltage and current from the PV panel. The InC MPPT method determines the direction of change in the PV panel's operating voltage by comparing the InC (*dI/dV*) of the panel to a reference value. No more changes are needed to get the PV panel to operate at the MPP if the incremental conductance is the same as the reference value. Nevertheless, the operating voltage of the PV panel is changed if the InC is more than or less than the reference value in order to approach the MPP. InC MPPT is advantageous because it can quickly and precisely locate the MPP, regardless of how the irradiance and temperature are fluctuating. In addition, it is easy to install and does not need familiarity with the specifications of PV panels. In some circumstances, however, such as when there is partial shade or several MPPs, its performance may suffer. The incremental conductance MPPT flow chart is shown in Figure 3.9.

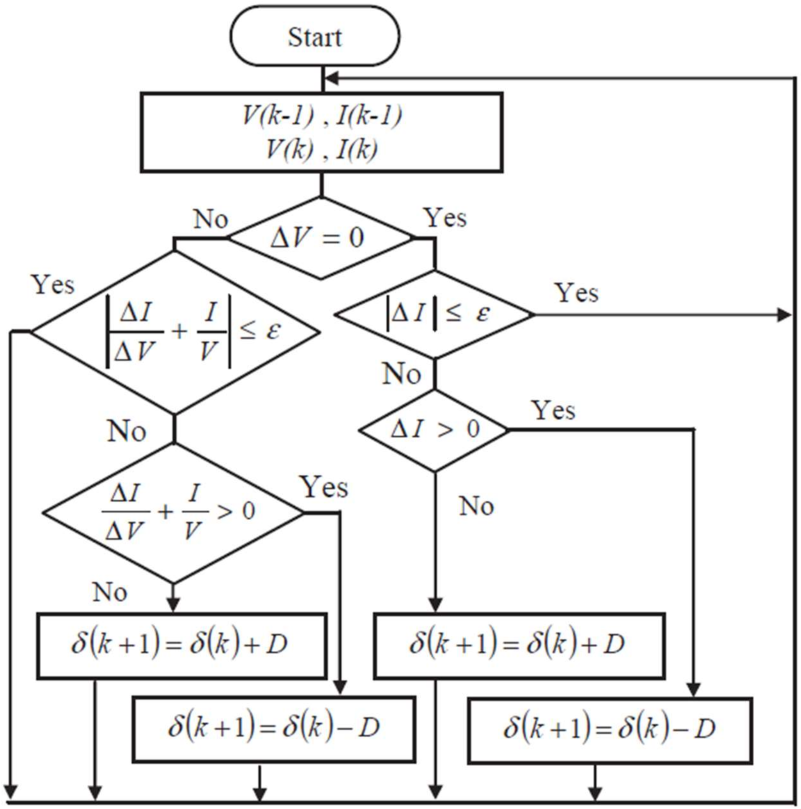


Figure .3.9 incremental conductance MPPT flow chart

3.1.4 Battery Energy Storage System (BESS)

The capacity to store and discharge energy as required makes battery energy storage devices an attractive option for microgrids. Microgrids may benefit from battery energy storage systems because they can provide backup power during grid failures, lower peak demand charges, and improve overall stability and dependability. The residential load (RL) and renewable energy source (RES) output of electricity must be determined in order to compute the BES reference power; from the reference power, the reference current (I) may be derived. The PI-based controller adjusts the duty cycle depending on the amount of current inaccuracy. The BESS is intended as a 3kW backup power source for use in times of emergency[53]. When alternative energy sources like solar and wind power, as well as the power grid, are unavailable, a buck-boost converter is included into the BESS to make the most of the power stored in the batteries. Figure .3.10 depicts the overall layout of the BES system.

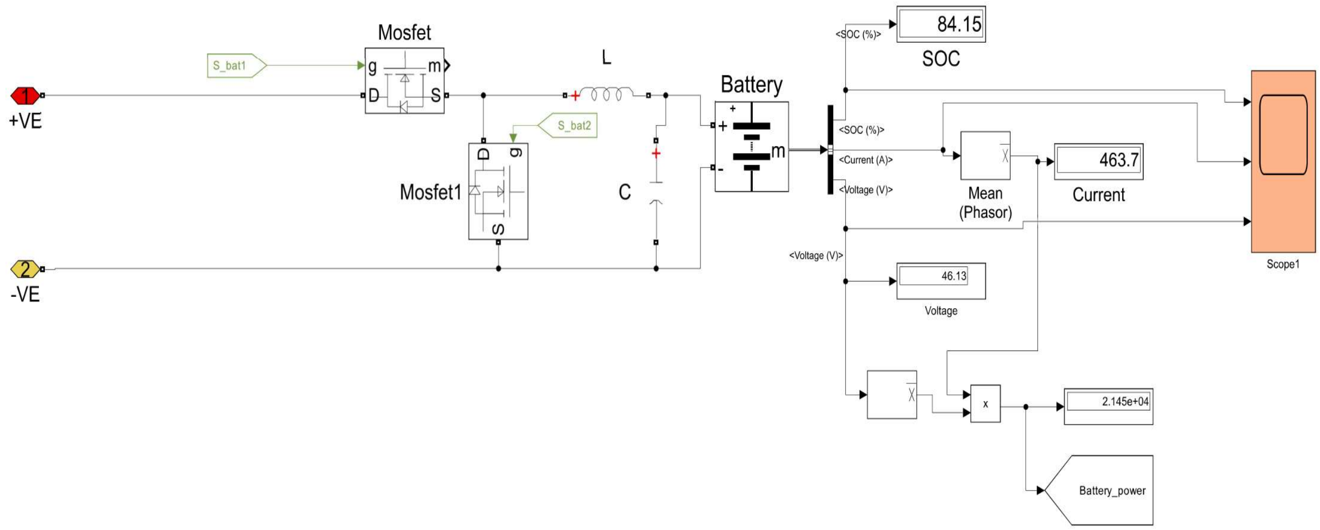


Figure .3.10 battery energy storage system

3.1.5 Grid Synchronization of Microgrid

The creation of templates provides the framework for implementing the control technique. The templates are formed, and then classed, according on the phase orientation that they have with the grid voltage. The ability to regulate both active and reactive power is made possible by the creation of in-phase templates and quadrature templates. The templates are responsible for managing the power compensation and synchronizing the grid's frequency with the converter within the context of this control algorithm [54]. A comprehensive control algorithm using power balanced based theory is illustrated in Figures. 3.11 and 3.12 respectively.

A. Creation of phase unit templates

This sample's phase orientation is perfectly synchronized with the voltage of the grid. The extent of the templates has been standardized, and its value is equivalent to unity. The in-phase unit templates are created with the help of (3.8) and (3.9).

$$U_{sa} = \frac{V_{sa}}{V_t},\ U_{sb} = \frac{V_{sb}}{V_t},\ U_{sc} = \frac{V_{sc}}{V_t} \tag{3.8}$$

$$V_t = \sqrt{\frac{2}{3}}\left(\sqrt{v_{sa}^2 + v_{sb}^2 + v_{sc}^2}\right) \tag{3.9}$$

Where V_t denotes the amplitude of the three-phase voltage at the point of common coupling (PCC). In order to synchronize the frequency of the grid and maintain active power regulation within the system, the in-phase templates are used. In order to do active power control, the direct axis multiplier of the currents is used to scale the unit templates.

B. Creation of templates for quadrature units

The phase orientation of this particular kind of unit template is 90 degrees perpendicular to the phase orientation of the in-phase unit template. This indicates that the phase is in quadrature with the grid voltage. The quadrature unit templates are responsible for controlling the reactive power compensation that is generated by the in-phase unit templates. The templates for the quadrature units are produced as

$$\frac{u_c - u_b}{\sqrt{3}} = w_a \tag{3.10}$$

$$\frac{u_a}{\sqrt{2}} + \frac{u_b - u_c}{\sqrt{6}} = w_b \tag{3.11}$$

$$\frac{u_b - u_c}{\sqrt{6}} - \frac{u_a}{\sqrt{2}} = w_c \tag{3.12}$$

The units for w_a, w_b, w_c are voltage (V)

C. Active and reactive power components

It is possible to make an estimate of the current component of active and reactive power by utilizing the (3.13) and (3.14), and thus the active power and reactive power can be computed using (3.15) and (3.16), respectively. The active and reactive power may also be calculated using equation (3.19), although doing so involves converting from three to two phases, or from *abc* to $\alpha\beta$.

$$i_{LP} = \frac{2}{3}\frac{P_L}{V_t} \tag{3.13}$$

$$q_{LP} = \frac{2}{3}\frac{Q_L}{V_t} \tag{3.14}$$

$$P_L = V_{t,a} * I_{L,a} + V_{t,b} * I_{L,b} + V_{t,c} * I_{L,c} \tag{3.15}$$

$$Q_L = \left(V_{t,a} - V_{t,b}\right) * I_{L,a} + \left(V_{t,b} - V_{t,c}\right) * I_{L,b} + \left(V_{t,c} - V_{t,a}\right) * I_{L,c} \tag{3.16}$$

Using Equations (3.17) and (3.18), we use Clark's transformation matrix to convert the load current and PCC voltage from the original coordinate system of *abc* to the target coordinate system of $\alpha\beta$. Both active and reactive power may be determined by (3.19). It is necessary to ascertain the active and reactive power levels before moving on to the determination of the active and reactive current components (3.22). One-half of the current's active and reactive components are located along the a-axis, while the remaining half of the current is located along the b-axis. Converting the current components from (3.20) and (3.21) into a matrix form yields (3.22).

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{3.17}$$

$$\begin{bmatrix} v_{L\alpha} \\ v_{L\beta} \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{t,a} \\ V_{t,b} \\ V_{t,c} \end{bmatrix} \tag{3.18}$$

$$\begin{bmatrix} P_L \\ Q_L \end{bmatrix} = \begin{bmatrix} v_{L\alpha} & v_{L\beta} \\ -v_{L\beta} & v_{L\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \tag{3.19}$$

$$i_{Lp} = \frac{v_{L\alpha}}{v_{L\alpha}^2 + v_{L\beta}^2} P_L + \frac{v_{L\beta}}{v_{L\alpha}^2 + v_{L\beta}^2} P_L \tag{3.20}$$

$$i_{Lq} = \frac{v_{L\beta}}{v_{L\alpha}^2 + v_{L\beta}^2} Q_L + \frac{-v_{L\alpha}}{v_{L\alpha}^2 + v_{L\beta}^2} Q_L \tag{3.21}$$

$$\begin{bmatrix} i_{Lp} \\ i_{Lq} \end{bmatrix} = \frac{1}{v_{L\alpha}^2 + v_{L\beta}^2} \begin{bmatrix} v_{L\alpha} & v_{L\beta} \\ v_{L\beta} & -v_{L\alpha} \end{bmatrix} \begin{bmatrix} P_L \\ Q_L \end{bmatrix} \tag{3.22}$$

The units for $(i_{L\beta,}\ i_{L\alpha})$ are ampere (*A*), the units for $(v_{L\alpha}, v_{L\beta})$ are voltage (*V*), and the units for P_L, and Q_L are kW and kVAR respectively. In addition, the units for i_{Lp}, and i_{Lq} are amperes (*A*).

D. Current specification for active power regulation and unity power factor operation

the active power current necessary to feed VSC losses (i_{loss}) and maintain the DC bus voltage at the reference level as well as the direct axis load current are both taken into account by the control algorithm for grid-connected systems operating in unity power factor mode (3.23). With active power transmission, the dedicated dc voltage PI controller keeps the dc bus voltage at the set point and compensates for VSC losses.

$$i_{LP}^* = i_P + i_{d,loss} \tag{3.23}$$

The dynamic power sources that make up the reference grid currents are included in (3.24)

$$i_{Lq}^* = i_q + i_{q,Vt} \tag{3.24}$$

E. Current reference for zero voltage regulation

While the component of the quadrature current is denoted by (i_q), and the component of the direct current is denoted by (i_d). A PI controller is used in order to achieve voltage regulation at the PCC point. When the power factor is one, the (i_q) is zero. When there is no voltage regulation, it is determined by comparing the result to the input of the PI controller and the primary factor contributing to the reactive power coming from the load. The current that serves as a reference, expressed in terms of q components is given in (3.25).

$$i_q^* = i_q - i_{q,Vt} \tag{3.25}$$

Currents in the reference grid, together with their respective reactive power components, are given in (3.26).

$$I_{sqa}^* = i_{Lq}^* * w_{sa}, I_{sqb}^* = i_{Lq}^* * w_{sb}, I_{sqc}^* = i_{Lq}^* * w_{sc} \tag{3.26}$$

F. References to the grid

The reference for grid current can be established by bringing together the references that were created for active and reactive power regulation. In accordance with the fundamental principles underlying the control grid current, it is expected that this current will follow the reference current that is produced by the load's active and reactive current components.

$$I_{sa}^*=I_{spa}^*+I_{sqa}^*, I_{sb}^*=I_{spb}^*+I_{sqb}^*, I_{sc}^*=I_{spc}^*+I_{sqc}^* \tag{3.27}$$

Controlling the output current of the converter requires the use of a hysteresis current controller. The reference current that is created is compared with the current that is being supplied by the grid, and the result of this comparison is what will cause the current that is being supplied by the converter to stay within the zone that has been determined upon by the hysteresis current controller.

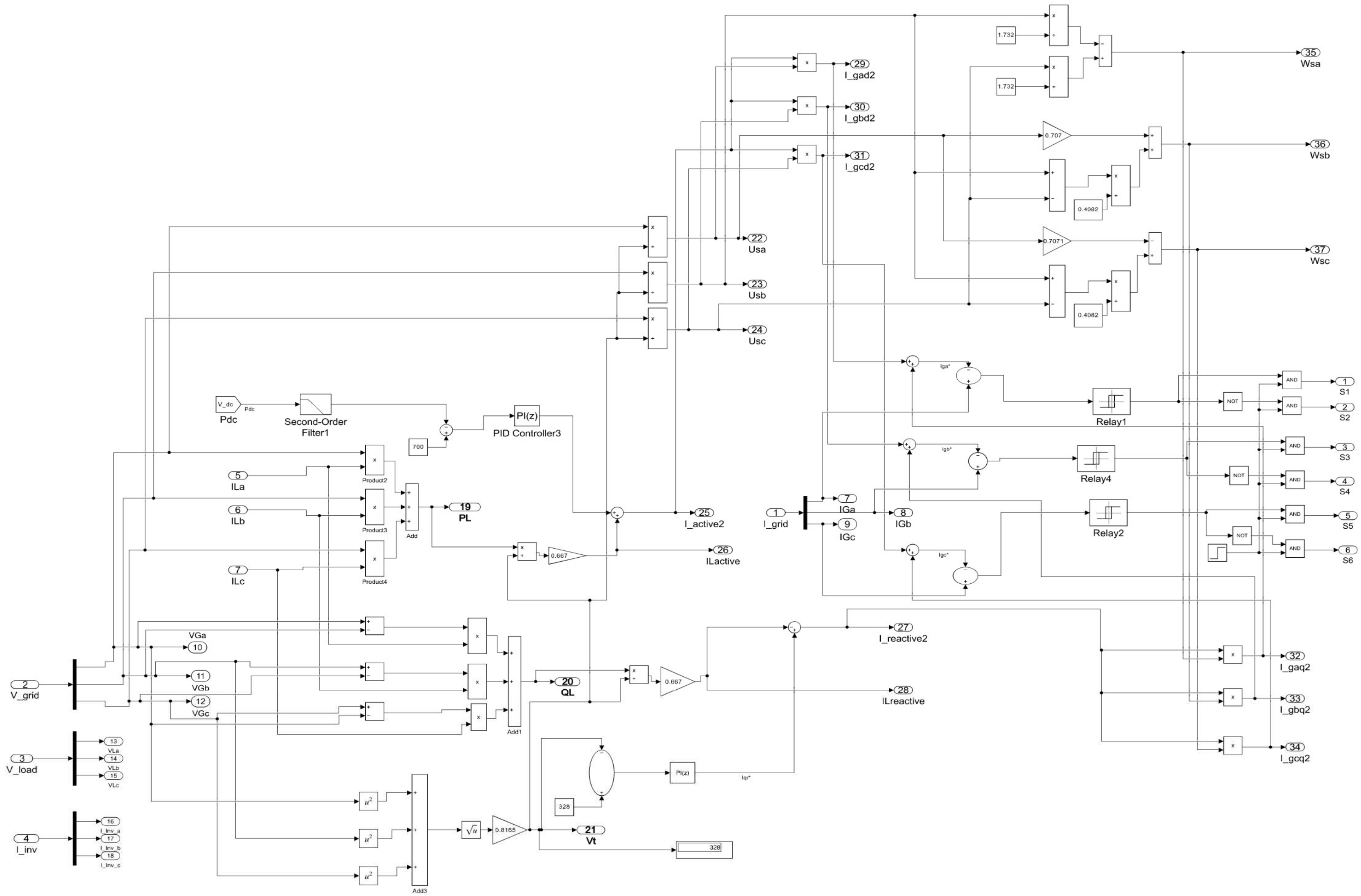


Figure 3.11 control operation of the microgrid system using Simulink environment.

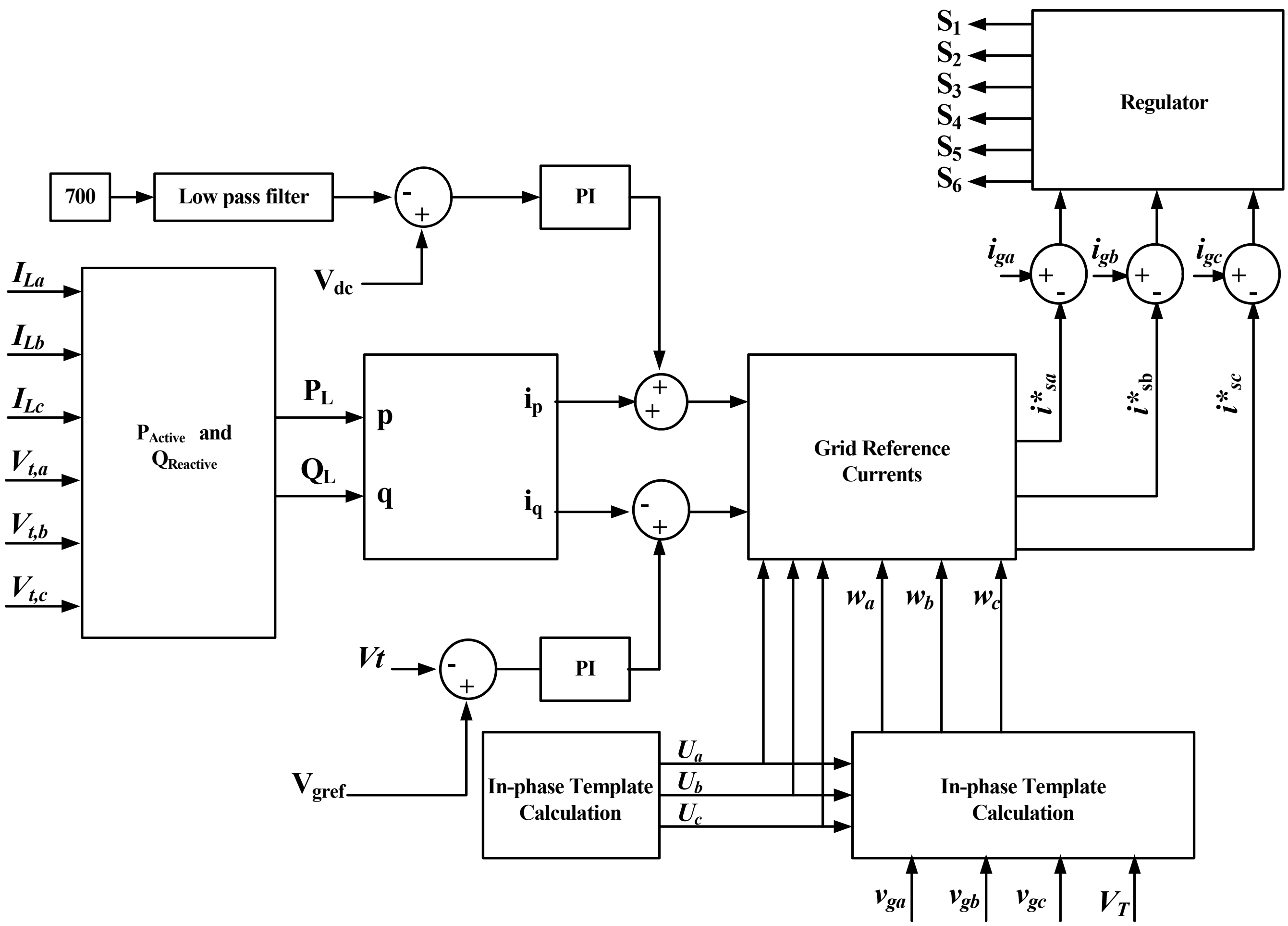


Figure 3.12. Control algorithm based on the power balance (PB) theory.

3.1.6 Power Management Scheme

Microgrids can function in either grid-connected or islanded mode, depending on the situation. Solar, wind, and biomass power plants are all examples of renewable energy sources that can be used alongside conventional fossil fuel plants. In order to keep a microgrid running smoothly and efficiently, its power supply must be carefully managed. Microgrids may use a variety of power management strategies; selecting one requires thinking about the system's unique features and its performance goals. For the proposed microgrid system, a new and more effective algorithm for managing power consumption and power sharing is implemented. The novelty of the proposed system is in their power management scheme that make the system differs from other conventional approaches[47], which are explained as the following mathematical equations and modes of operation.

Mode 1: Dominant generation mode ($P_D > 0$).

$$P_{PV} + P_W > L_D \tag{3.28}$$

In this context, P_D refers to "dominant production," and L_D refers to load demand and their units are watts (kW). In the event when the entire quantity of energy generated by sources such as the sun and the wind is more than the load demand (L_D), then conditions one and two are taken into consideration.

Condition I*:* The electricity produced from wind and solar must come to the load and should be integrated to the grid if the battery energy storage's SoC is more than 90%.

$$P_{PV} + P_W = L_D + U_g \tag{3.29}$$

Condition II*:* In the event that the BES state of charge is lower than 35%, the power produced will serve to both charge the battery and satisfy the load requirement.

$$P_{PV} + P_W = BES + L_D \tag{3.30}$$

Mode 2*:* Load dominant mode ($P_D < 0$).

$$P_{PV} + P_W < L_D \tag{3.31}$$

If the amount of power generated by the solar and the amount of wind that can be harnessed is insufficient to satisfy the demand, then conditions *I* and *II* are taken into consideration,

Condition I*:* If the amount of electricity generated by wind and PV is less than the amount of power needed to meet the load demand (L_D), then the utility grid (U_g) will be used to feed the load demand, and If the state of charge (SoC) of the backup batteries falls below 45%, the batteries will have to be charged by the grid.

$$U_g = L_D + BES \tag{3.32}$$

Condition II: In the case that the quantity of power produced by sources such as the sun and the wind is not enough to satisfy the load demand (L_D), and if the energy supplied by the utility grid is also not available, then the load demand should be satisfied by the battery backups (BESS).

$$BES = L_D \tag{3.33}$$

Mode 3: Standard situation ($P_D = 0$).

$$P_{PV} + P_W = L_D \tag{3.34}$$

In this mode, the generated power from the PV and wind is equal to the load demand, which the generated power from these sources will feed the load only, and will not be integrated to the utility grid.

Chapter 4 - Area of Application

Microgrids are localized electrical infrastructures that may function alone or in tandem with the larger utility grid. Microgrids can offer off-grid or island populations with an affordable and consistent electrical supply. Microgrids provide a viable alternative to expensive and environmentally damaging diesel generators for these areas. Using a microgrid may help commercial and industrial buildings save money on their electricity bills and increase their reliability in the event of an outage. In order to save money, these complexes may go off the grid and create their own microgrids to power their buildings. At times of crisis, such earthquakes, hurricanes, or wildfires, microgrids can be utilized to supply emergency electricity. They can also offer emergency power to facilities like hospitals and water treatment plants[55].

In addition, the military may benefit from microgrids by having a secure and resilient electrical supply that allows them to function independently from the main grid and lessens their susceptibility to power outages and assaults. When expanding the main grid is not a viable option due to cost or feasibility, microgrids may offer a low-cost alternative for bringing electricity to remote areas. There is a possibility that the use of microgrids will lead to an improvement in people's quality of life and economic prospects in rural areas by supplying consistent and low-cost energy. Microgrids are a versatile and adaptable method of power production and distribution that can be tailored to the demands of individual communities and businesses.

4.1 Solar System Applications

Solar power plants have the potential to make a major contribution toward reducing emissions of carbon dioxide. This is because, in contrast to power plants that run on fossil fuels and generate electricity by burning coal, oil, or gas, solar power plants do not emit any greenhouse gases during the energy generation process. Carbon dioxide (C_{O2}) and other greenhouse gases are released into the atmosphere when fossil fuels are burnt to create energy, contributing to climate change. Solar power plants, on the other hand, use a clean and renewable resource—the sun—to produce electricity[56]. Solar power plants may greatly cut emissions from fossil fuel power plants by displacing some of the energy they produce. This has the potential to positively affect the environment via climate change mitigation and decreased air pollution. As an added bonus, solar power plants may aid in the movement toward energy independence by cutting down on the use of fossil fuels[57]. Solar power plants contribute to a more sustainable and resilient energy system by producing electricity from a renewable source. Some of the key features and area of applications of the PV systems are highlighted as the following:

- **Production of Power for Homes and Businesses:** Powering houses, companies, and other structures with energy generated by solar panels is a viable option.
- **Infrared heating of water:** Heating water using the sun's rays instead of expensive fossil fuels is a big money saver for homes and businesses.
- **Landscape lighting:** One common use of solar energy is to power outdoor lights, such as those seen in streets, parking lots, and other public areas.
- **Desalination:** Particularly helpful in arid places with few freshwater supplies, desalination units can be powered by solar energy.
- **Transportation:** Electric vehicles, such as automobiles, buses, and trains, can be powered by the sun.
- **Agriculture:** Solar-powered irrigation systems can increase agricultural yields while assisting farmers in reducing their reliance on fossil fuels.
- **Satellites and spacecraft:** Spacecraft and satellites utilize solar panels to generate electricity in space.
- **Distant energy source**: Ungirded communities, especially in poor nations, may benefit from solar energy since it can be installed very cheaply.
- **Motorized home recreation:** RVs and boats may have solar panels installed to generate electricity for use in running electronics and keeping the lights on.
- **Disaster assistance:** In the event of a blackout or other emergency, solar-powered generators can be used to keep the lights on.

4.2 Wind (PMSG) Applications

Wind turbines are used because they are capable of converting the kinetic energy of the wind into useable electrical energy. Large-scale wind farms that provide electricity to the grid often use wind turbines in the form of utility-scale wind farms. These wind farms have the potential to produce a significant quantity of electricity and provide a sustainable power option for cities and companies. Distributed wind energy systems, which employ wind turbines to generate electricity, are primarily used to provide electricity to single buildings such as houses, farms, or businesses.

These setups are adaptable, allowing for placement on either flat surfaces or short structures. Wind turbines may be erected in arrays called offshore wind farms, which are often situated in larger bodies of water like oceans or lakes[58].

As winds are often stronger and more steady over bodies of water, offshore wind farms may produce more electricity than onshore wind farms. In order to build hybrid energy systems that are more stable and dependable, wind turbines may be integrated with other renewable energy sources like solar or hydropower. Off-grid regions, such those in rural or poor countries, may benefit from installing wind turbines to generate electricity. With these turbines, these towns will always have access to reliable power. In sum, wind turbines provide a sustainable and renewable energy source with many potential uses. They are gaining popularity as a means to lessen reliance on fossil fuels and combat global warming.

4.3 BESS Application

The BES has become an important component of microgrid infrastructure. Microgrids are smaller-scale versions of electricity grids that can function either autonomously or in combination with the larger main grid. BESS has the ability to store excess energy during off-peak hours and release it during peak hours, hence minimizing the peak demand placed on both the microgrid and the main grid. The BESS is able to maintain a consistent and reliable power supply by regulating the frequency of the microgrid through the storage and discharge of energy as required. By either injecting or absorbing reactive power, BESS is able to give voltage support to the microgrid. As a result, the voltage can be maintained within a predetermined range.

The microgrid is able to start up and function independently of the main grid thanks to the BESS's ability to provide backup power in the event that the grid is disrupted. By smoothing out fluctuations in output and providing backup power during periods of low or no supply, BESS can assist in the integration of renewable energy sources such as solar and wind power into the microgrid system. In general, BESS plays a significant part in enabling microgrid systems to function in a manner that is more efficient, reliable, and environmentally friendly.

4.4 Application of Power Inverter

An electrical device known as a power inverter is a piece of equipment that can convert DC into AC. It is used to power appliances, tools, and gadgets that are meant to work on DC power but need AC power to function properly. Some examples of these types of items include: At times of power outages or crises, power inverters may be used as a backup source of electricity. They are capable of providing power to equipment that are absolutely necessary, such as refrigerators, lights, and communication tools. In the case of renewable energy sources, such as solar panels and wind generators, power inverters are used to convert one kind of electrical current to another. These systems produce direct current (DC), which, in order to be useful, must first be transformed into alternating current (AC). Since recreational vehicles (RVs) and boats are not linked to a source of shore power, they often rely on power inverters to provide the electricity needed to run AC appliances[59].

In order to power tools and equipment while traveling in commercial vehicles like trucks and vans, power inverters are used. In houses and workplaces that do not have access to AC power outlets, power inverters may be utilized to provide electricity to equipment that need AC power. Laptops, chargers, and several other types of electronic gadgets may get their power from them. For activities such as camping and hiking, power inverters may be used to power equipment that need AC power. They are capable of providing electricity for items such as portable fridge, lights, and other camping gear. In general, power inverters are necessary equipment because they convert DC power into AC power and offer a source of power that is dependable and handy.

4.5 Limitations of the Proposed System

A microgrid system that uses solar (PV) panels, wind turbines, and battery storage to generate and distribute electricity for small towns or single residences is known as a PV-wind-BES (Battery Energy Storage) system. Although this technology has a number of benefits, it also has a number of drawbacks and shortcomings, such as:

- **Sporadic Power Supply:** It is challenging to forecast the quantity of electricity that the system will be able to produce since the power output of wind turbines and solar panels changes with weather conditions. The grid's stability and dependability may suffer as a result since it may not be able to handle the demand during peak use times.

- **Storage Space Is Limited:** Although battery storage offers the system a backup power source, its storage capacity is constrained. This implies that any extra energy generated will be lost once the battery is fully charged.
- **High Start-Up Cost:** The PV-wind-BES based microgrid system has a higher installation cost when compared to traditional power generating systems, which may prevent it from being widely adopted.
- **Maintenance Requirements:** Because several different components must be managed, system maintenance can be challenging. The system can need routine upkeep and the replacement of worn-out components.
- **Limited Scale:** The PV-wind-BES-based microgrid system is intended to supply electricity to single residences or small towns. As a result, it cannot be used in large-scale applications.
- **Environment-Related Issues:** The fabrication of the parts and the final disposition of the batteries might have a detrimental influence on the environment even if the system is designed to be ecologically benign.
- **Regulatory Obstacles:** Due to regulatory concerns and the requirement to work in conjunction with current utility companies, integrating renewable energy sources into the infrastructure of the existing grid can be difficult.

Chapter 5 - Result and Discussions

The proposed system was built in the Simulink environment. In order to ensure that the MG system functions properly in a wide variety of configurations, its components and models are subjected to rigorous testing. MATLAB environmental Simulink is used to construct a PV system with a 10 kW capacity and a 5 kW wind turbine PMSG generator operating at 690 V and 50 Hz. The BES system can store 3 kW of power for use in an emergency. As shown in Figure. 5.1, the proposed system's outcomes are calculated using PV power, wind power, grid power, and load power. The power consumption of the system is 3.5 kW. Between 0 and 0.1 seconds, the power from the PV is turned off, and the load draws electricity from the grid, as shown in Figure 5.2. From 0.1s on, the PV is serving the load and delivering electricity into the grid, totaling 11.5kW PV power. From 0.2s to 0.4s, the wind is turned on, producing 5kW of wind power that supplies the load and integrates with the utility system. As shown in Figure .5.1 the DC link voltage is constant from zero to 0.1 seconds and then slightly changes when the PV enables. Likewise, the DC link voltage rapidly changes from 700V to 900V when wind turbine is enabled which show the a fluctuation in the DC link voltage every time when a power source is injected. However, after some seconds the DC link voltage comes to its constant voltage of 700 as illustrated in the Figure 5.1.

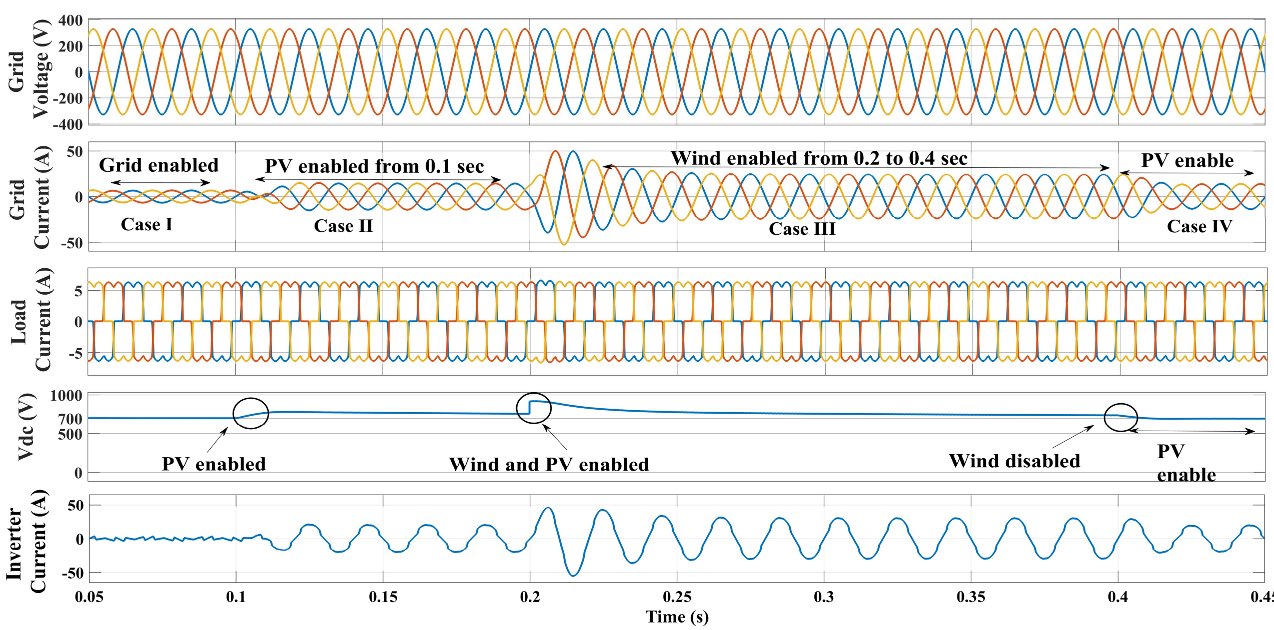


Figure .5.1 simulation results for grid voltage and current, load current, DC link capacitor, and inverter current

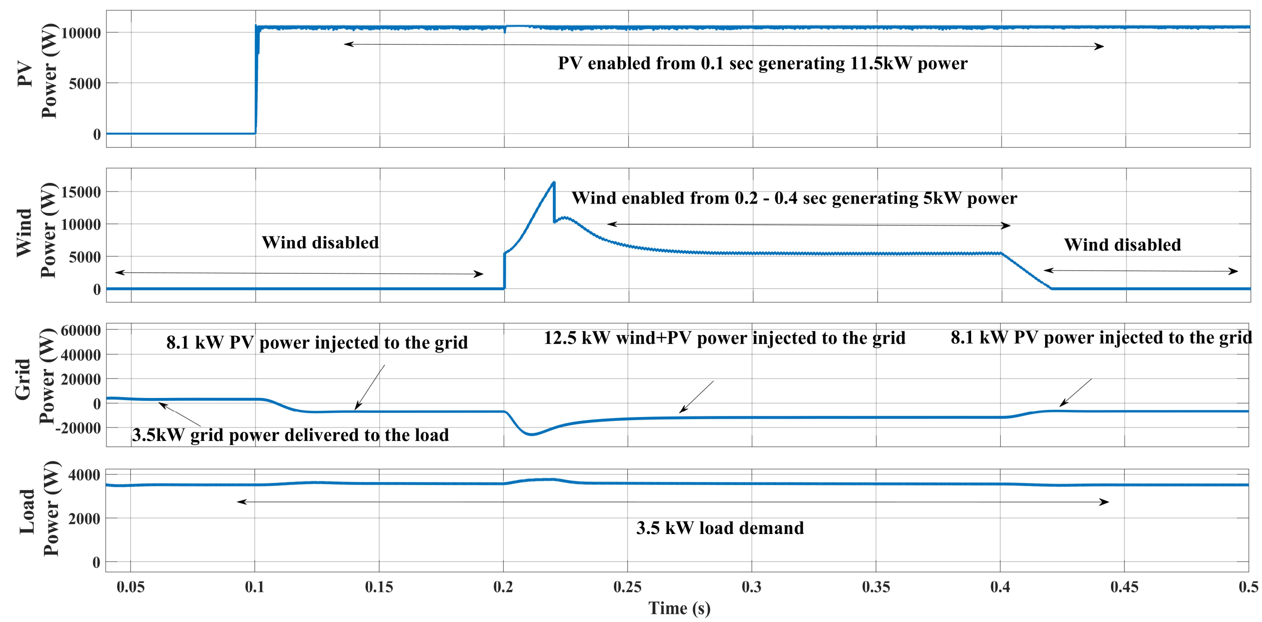


Figure .5.2 power generation from the renewable energy sources (PV and Wind)

Figure .5.1 depicts the grid connected mode of operation, which consists of the grid voltage, grid current, load current, the DC link voltage (Vdc), and inverter current in that order. The current across the grid can be broken down into four distinct categories, which are as follows:

Case 1: In mode one, the grid connection is activated, and the system draws 3.5 kW of electricity from the utility grid for 0.1 second to provide the load. In this mode, the grid connection is active only, and renewable sources are OFF.

Case 2: In this mode, the PV is engaged from 0.1 second forward, providing a total of 10 kW of PV power, of which 3.5 kW is supplied to the load while the remaining 8.1 kW is sent to the utility grid as illustrated in figure .10 section ‘’Grid Power’’.

Case 3: The wind system is activated from 0.2 to 0.4 generating kW of wind power and delivering it to the grid. As illustrated in Figure .10 and Figure .9, the total amount of power delivered to the grid after the activation of the PV and wind is 12.5kW respectively.

Case 4: In this point, the wind turbine is switched off and the PV system is remained enabled to feed the load. As illustrated in Figure .10, 8.1kW of generated power from solar is injected to the grid with no interruption or power delay.

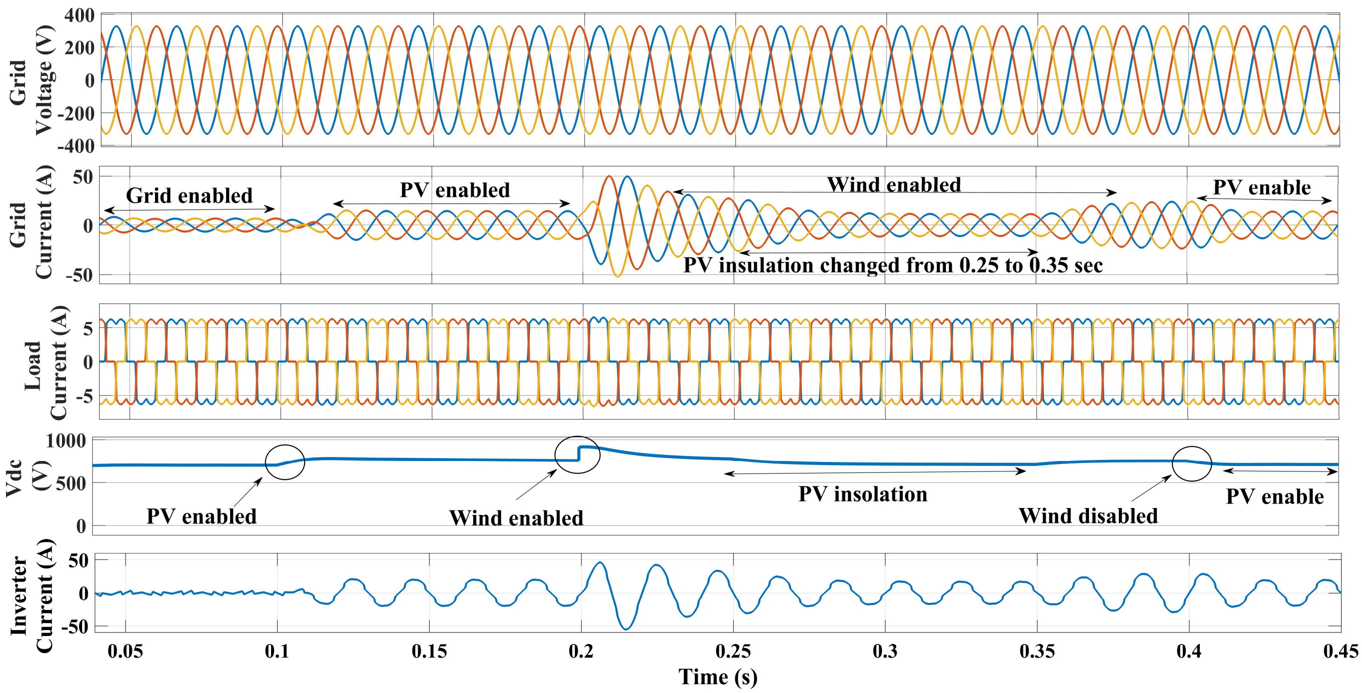


Figure .5.3 simulation results of the grid synchronization of the microgrid system

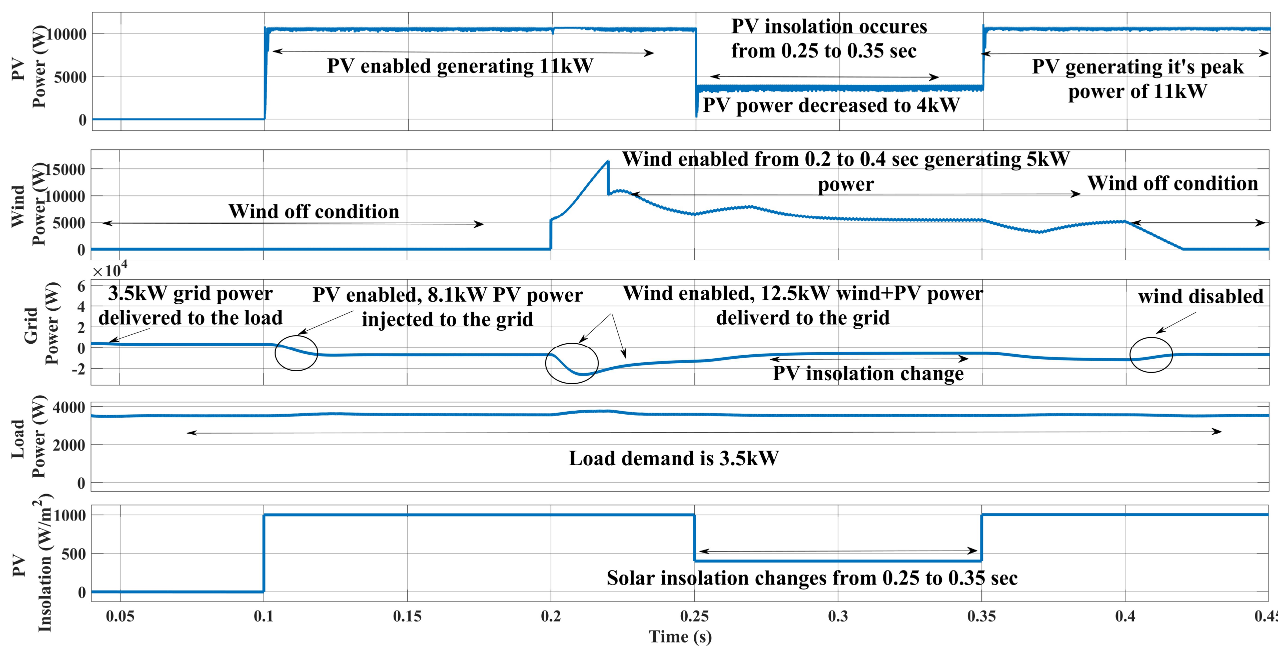


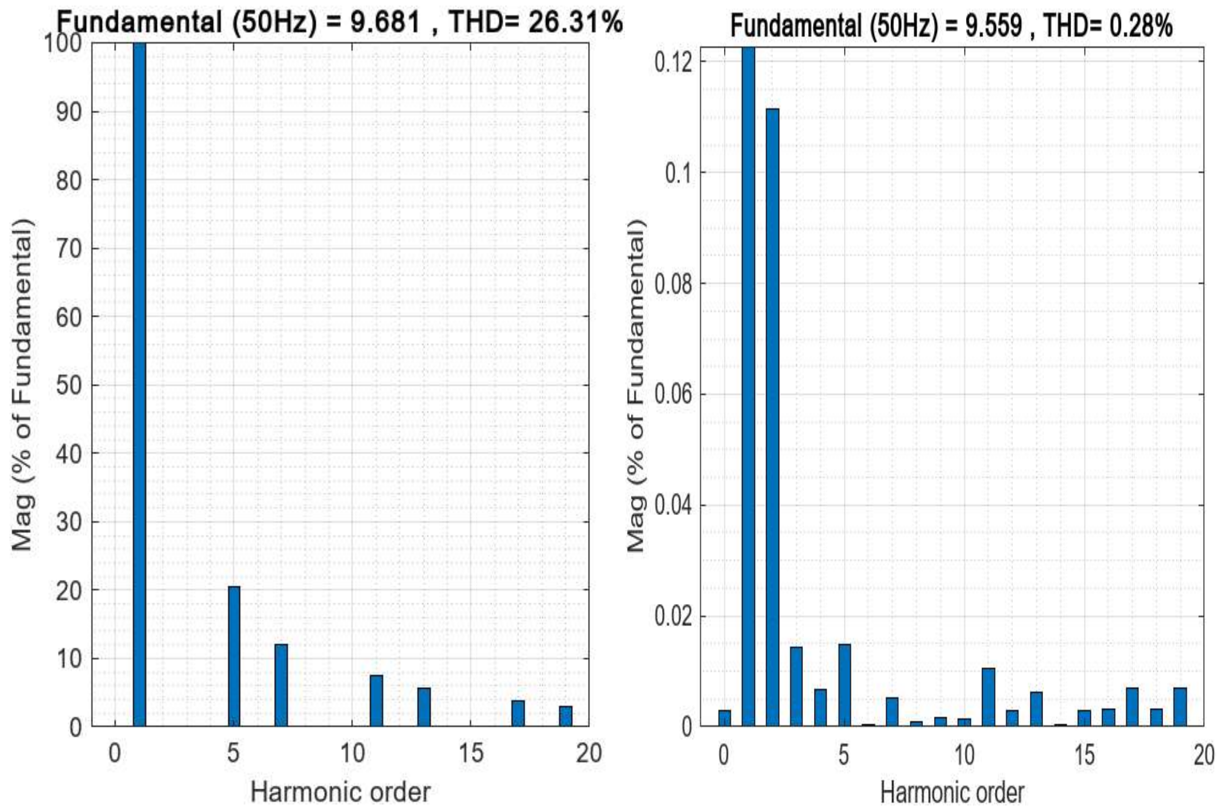
Figure .5.4 solar radiation adjustment

In order to assess the difference in power production and to determine the influence that this variation has on synchronizing the grid and the on the load, the PV insolation is modified from 0.25 seconds to 0.35 seconds, as shown in figures 5.3 and 5.4. With its improved power management scheme, the proposed system has conquered the problem and closed the resulting gap in power stability and delivery to the load, as seen by the graph's lack of power delay on the load side. Due to the fact that solar radiation varies during the day and throughout the seasons, this has an impact on power production and causes a disruption in the power stability between the source and the load. The sun radiation was adjusted from 0.25 to 0.35 seconds, which results in a 4kW reduction in power production.

5.1 THD Analysis

Total harmonic distortion analysis, often known as THD analysis, is a method that is used to determine the amount of harmonic distortion that is present in an electrical signal. Harmonic distortion occurs when an undesirable frequency component is present in a signal and that frequency component is a multiple of the fundamental frequency. Nonlinearities in electronic components, such as amplifiers or filters, may be the source of certain frequencies that are not intended. To determine the total harmonic distortion (THD) of a signal, first the root mean square (RMS) voltage of all of the harmonics in the signal are measured, and then this value is divided by the RMS voltage of the fundamental frequency. The resultant number, which is given in percentage form, reflects the degree of harmonic distortion that was found in the signal. THD analysis is often used in audio and power systems in order to assess the quality of the transmitted signal or power. As compared to high THD values, low THD values indicate that a signal or power has only a little amount of harmonic distortion, while high THD values show that a signal or power has a large amount of harmonic distortion[60].

In most circumstances, it is preferable to have a low THD value since harmonic distortion may result in unfavorable consequences in electrical systems, including noise, distortion, and a reduction in efficiency. As a result, THD analysis is an essential tool for engineers and technicians working in a wide variety of sectors. As Figure .5.5 shows, the total harmonic distortion (THD) of the grid current has dropped from 26.31% to 0.28%, which demonstrates the precision and efficiency of the system, measured in terms of THD, must be sufficient to fulfill the need of the grid. In addition, the graphs show that the system is compliant with the IEEE-519 standard.



(a) **(b)**

Figure 5.5: THD analysis of phase a grid current

5.2 Efficiency Analysis Based on Power Factor (PF)

As depicted in figure 5.6.a, the load power factor of the proposed system varies in the range of 0.91 and 0.97, with an average of 94% (PF=0.94). In contrast, the grid power factor is analyzed approximately to the unity power factor while turning on the PV, Wind, and Battery energy resources. The unity power factor of the grid under energy management topology indicates how the overall efficiency of the proposed system is improved to the unity power.

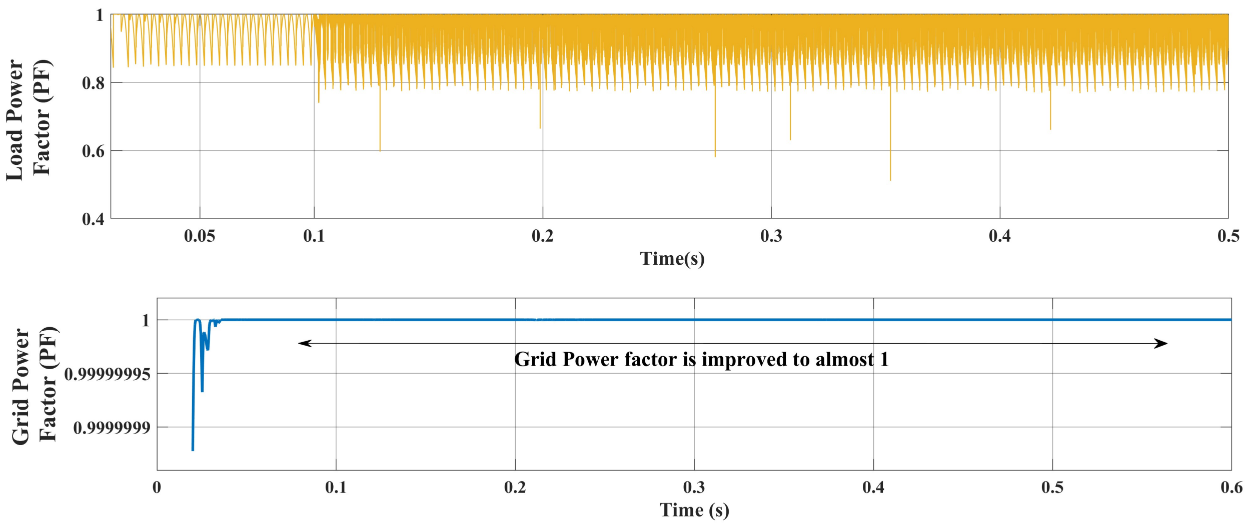


Figure 5.6: Power factor improvement of the proposed model

Chapter 6 - Conclusion of PV-Wind-BES Based Microgrid System

6.1 Conclusion

In this thesis, a PV-Wind-BES microgrid system together with its whole design, control, and power management is proposed. After conducting extensive research and analysis of the PV-wind-BES microgrid system, it can be concluded that this type of system is a highly effective and efficient solution for supplying remote areas and communities with reliable and sustainable electricity. The combination of photovoltaic (PV) panels, wind generators, and battery energy storage (BES) provides a microgrid with a flexible and resilient power supply that can satisfy its fluctuating energy needs. This type of system is ideally adapted for regions with abundant renewable energy potential and limited access to conventional power infrastructure.

The InC MPPT method has been used to monitor the maximum power flow in the PV and wind systems. To ensure that there are no disruptions in the provision of continuous power to the load and that the MG can easily connect with the utility grid, a new and improved power management system has been devised and implemented for the MG. The grid synchronization of the MG was accomplished by using a PBT-based method, and the results were evaluated under a variety of different circumstances. Based on power factor analysis the grid power factor of the proposed system is approximately one, which shows the accuracy and efficiency of the system. According to the findings of the Fast Fourier Transform (FFT) analysis, the overall harmonic distortion of the grid current has been reduced to 0.28%, which satisfies the requirements of the IEEE-519 standard as shown in Figure .5.2.1. It has been found, on the basis of the results of the MATLAB simulation, that the built microgrid fulfills all criteria for the stability of the power system and power quality. This conclusion was reached since the microgrid was able to maintain a stable power supply.

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Appendix I

PV Parameters:
V_{mp} = 54.7 V, I_{mp} = 5.58 A,
Number of series-connected module per string (Nser) = 7
Number of parallel string (Npar) = 5, P_{mp} = 10kW.
DC-DC Boost Converter for PV:
D = 0.45s, C = 0.15mF, fs = 15 kHz, L = 2.213mH, R = 49Ω.
Wind parameters:
P_w = 5kW, $L_w = 4.73mH$, $C_w = 1500\mu F$.
Battery parameters:
P_{Bat} = 3 kW, V_B = 350 V, C_B = 8.57 A, SoC = 85%
$K_p = 0.005$, $K_i = 10$.
Nonlinear load:
R = 90.012Ω, L = 25*mH.*
PI controller:
$K_{p1} = 0.25$, $K_{p2} = 0.11$, $K_{i1} = 1$, $K_{i2} = 0.31$.

Appendix II

MPPT Parameters:

final ▶ PV System ▶ MPPT Control (Incremental Conductance MPPT) 1

```
function D  = InCon(Param, Enabled, V, I)

% MPPT controller based on the IncrementalConductance algorithm.
% D output = Duty cycle of the boost converter (value between 0 and 1)
%
% Enabled input = 1 to enable the MPPT controller
% V input = PV array terminal voltage (V)
% I input = PV array current (A)
%
% Param input:
Dinit = Param(1);  %Initial value for D output
Dmax = Param(2);   %Maximum value for D
Dmin = Param(3);   %Minimum value for D
deltaD = Param(4); %Increment value used to increase/decrease the duty cycle D
% ( increasing D = decreasing Vref )
%
% Define constants
E = 0.002; % Maximum dI/dV error

persistent Vold Iold Dold ;

dataType = 'double';

if isempty(Vold)
    Vold=0;
    Iold=0;
    Dold=Dinit;
end
dV= V - Vold;
dI= I - Iold;

 if dV == 0 & Enabled ~=0
     if dI == 0
         D=Dold; % No change
     elseif dI > 0
        D = Dold - deltaD; % Increase Vref
     else
         D = Dold + deltaD; % Decrease Vref
     end
 else
    if abs(dI/dV + I/V) <= E
       D=Dold; % No change
    else
      if dI/dV > -I/V + E
         D = Dold - deltaD; % Increase Vref
      else
         D = Dold + deltaD; % Decrease Vref
      end
    end
 end

if D >= Dmax | D<= Dmin
    D=Dold;
end

Dold=D;
Vold=V;
Iold=I;
```

Figure II, InC algorithm MATLAB code