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"Design & Control of Distributed Generations for Micro-Grid Applications"

By

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Design & Control of Distributed generations for micro-grid applications"** submitted by **Yam Krishna Poudel** in partial fulfilment of the requirements for the degree of Master of Science in Power System Engineering.

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ABSTRACT

Climate change, its influence on the environment, and natural resources scarcity necessitate scientific research and creative technical solutions for a modern power system. This research aims to develop scientific and technological approaches to “green” technologies, which are environmentally beneficial and long-lasting. Energy and power supply are major priorities. The design and control of distributed power generation systems for micro grid applications was the prime focus of this thesis. A 20 KW micro grid is designed to operate in both modes, albeit primarily in the isolated mode, where solar photovoltaic, wind energy, and battery energy storage modules are included. Maximum Power Point tracking (MPPT) was used to obtain the highest power production from solar photovoltaic and wind energy sources. We used lithium-ion batteries of nominal 48V to store energy produced by PV and wind systems. To maintain a constant voltage of 220V on the DC bus, bi-directional converters were used to control charging and discharging process. The inverter, which is based on a voltage sourced inverter (VSI) was used for supplying power to the AC load. Novel control approach methods were used to maintain power quality and frequency resynchronization. Synchronous reference frame theory (D-Q) with voltage oriented dual control was applied as a control algorithm. Bio inspired metaheuristic technique Particle swarm optimization (PSO) was applied for PID tuning. Islanded mode and grid feeding conditions of micro grids were analyzed, discussed and presented.

The results reveal that the system performs satisfactorily under varying generation and load consumption. The PV module consists of total 14 parallel strings and the series connected module per string was set at 6. The output variations were observed from 13KW to 21KW with variations of irradiance of and temperature. The wind power output was 6 KW to 2KW with variations of Speed 12- 8m/s. Lithium-ion batteries rated 420Ah with a nominal discharge current of 182.6887A were used with a normal voltage of 48V. The load variations used were 5KW to 45KW. Higher order filter (LCL filter) was utilized to enhance power quality and performance of two different micro grid cases (i) Islanded mode and (ii) Grid feeding mode was analyzed. This research has a significant impact on the development of micro grids.

ACKNOWLEDGEMENT

Over the past three years, it has been a great experience of learning, grit, harvesting, and growth. I owe many people my gratitude. I'd like to thank my supervisor Assoc. Prof. Dr. Netra Prasad Gyawali, for all of his help throughout my entire studies, including advice, understanding, patience, and strong support. Without him, this would never have happened. Dr. Gyawali has the knowledge to identify the problem's root cause and offer solutions.

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ABBREVIATION

ABC	$Artificial\ Bee\ Colony$
fg	$Grid\ frequency$
$fres$	$Resonant\ frequency$
fs	$Sampling\ frequency$
fsw	$Switching\ frequency$
GA	$Genetic\ algorithm$
Ig	$Grid\ line\ current$
iL	$Inverter\ output\ line\ current$
LCL	$Inductor\ capacitor\ Inductor$
MG	$Micro\ grids$
MPC	$Model\ predictive\ Control$
P_batt	$Battery\ power$
P_load	$load\ power$
P_pv	$PV\ power$
P_wind	$wind\ power$
PID	$Proportional, Integral, Derivative$
PLL	$Phase\ locked\ loop$
$P\ \&\ O$	$Perturb\ and\ observe$
PSO	$particle\ swarm\ optimization$
PWM	$Pulse\ width\ modulation$
SRF	$Synchronous\ reference\ frame$
THD	$Total\ harmonic\ distortion$
V_ac	$AC\ voltage$
V_{dc}	$DC\ bus\ voltage$
Vg	$Grid\ phase\ voltage$
VLL	$Line\ to\ line\ voltage$
VSI	$Voltage\ source\ inverter$
Xd	$Direct\ component$
Xq	$Quadrature\ component$
w	$Angular\ velocity$

CHAPTER 1: INTRODUCTION

1.1 Background

During the recent Java blackout, which took place from August 4, 2019 to August 5, 2019, 120 million people in Indonesia were affected, and 140 million people were affected by the Pakistan blackout of 2015. In India, a massive blackout happened in 2012. It was the world's most severe power outage in recorded history. Six hundred twenty to seven hundred million people, or around 50% of India's population (which is about ten percent of the world's population), were affected by this blackout [6]. Blackouts have occurred in numerous countries recently, including 2009 blackouts in Brazil and Paraguay, 2005 blackouts in Java and Bali, 2003 blackouts in the Northeastern United States, 1999 blackouts in Southern Brazil, etc. It impacts millions of people, their activities and businesses. There are several reasons for these blackouts happen. One reason is Overdraw of grid electricity from the grid. Another reason is when the equipment that has technical failures and their malfunction. Sometimes, mistakes made by human, like the operators, can also cause blackouts. Additionally, bad weather conditions or natural disasters can also lead to blackouts. During and after the blackouts, the affected area in several countries was left in anarchy [7]. Only a few (one or two) major events often cause these huge outages [8]. A single power system failure can throw modern society into disarray. Using an example, enormous blackouts can be illustrated. When a transmission line fails, power must be transferred to load by other transmission lines in the area. As a result, the nearby power lines get overloaded and transfer some of their load to other parts, which leads to a cascading failure.

Cascading failures are called secondary failures compared to main failures. Furthermore, when power plants must be brought back up after a prolonged blackout, restoring power can be difficult [9]. Airports and major companies, on the other hand, were unaffected because backup during these blackouts [10]. In hospitals, industrial areas, campuses distributed generation (DG) backup generators are often used as emergency and standby generators. Many researchers have recently turned their attention to the concept of decentralization of power systems with green and clean energy. This is due to growing worries about traditional fossil energy shortages and other environmental challenges in recent years. As a result, power systems have undergone significant changes, not only to ensure sustainable development but also to make significant breakthroughs in solving power problems in remote areas. One such notable innovation is the micro-grid (MG), which can integrate various types of energy sources and power electronics interfaced with (DG) and (RES) [1].

(RES) such as wind, the sun, and biomass are abundant in many regions. Renewable energy sources, properly designed and controlled, can provide reliable, high-quality power in such places. Autonomous wind energy systems and autonomous solar wind hybrid technology have been presented by many authors.

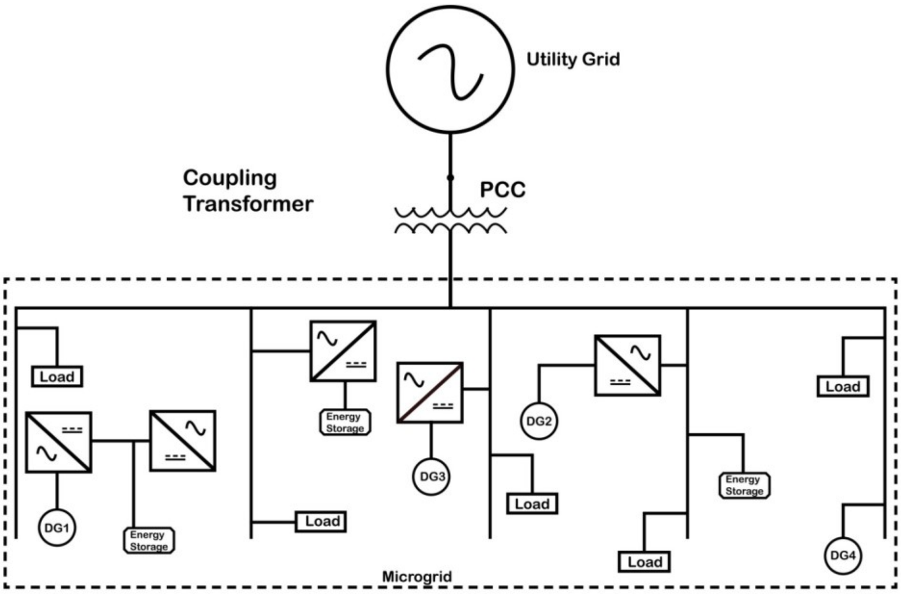


Figure 1-1:conceptual micro-grid architecture

1.2 Rationale

Micro grids can be created by combining renewable energy systems with energy storage and intelligent control. Which is distinct from the traditional power system transmission network, but comparable to the distribution grid in that it incorporates DG and renewable energy sources. Injecting renewables into the micro-grid has an impact on the power quality of the network (systems) due to the varying magnitude of solar and wind powers and different issues of DG sources with control of different DG sources make the micro-grid practical and implementable in various locations all over the world, albeit research shows there are many areas on the micro-grid where improvements can be made. Technical devices are tools that can convert and switch energy, as well as transmit information and communicate with each other's. These tools help make it easier for energy to be transferred from objects with their power sources to a centralized electrical market. The creation of technologies that combine multiple small-scale power generators requires solving a few technical problems. Many groups and scientists are doing research in this field. They are primarily concerned with maintaining stable operation, selecting appropriate structures, ensuring information and energy transfer between elements, and making sure relay protection and automation work properly [2, 3].

The AC/DC hybrid micro-grid reduces power loss and unwanted harmonic component caused by converting between AC and DC or DC and AC. It helps improve efficiency by decreasing power loss and harmonic currents generated from these conversions. The micro-grid can function in both mode grid connected mode and islanding modes [3]. The Whittling Refinery in Indiana built the first modern industrial micro grid in the United States in 1955. However, most people don't know the concept is far older. When Thomas Edison established his Pearl Street Station in 1882, there was no standard for an energy generation and distribution system, so he designed it as he did. Edison Pearl Station meets all today’s micro-grid criteria. It was self-contained, with six giant generators driven by coal-fired steam engines. His generators each generate 1100 KW DC. According to the data, there are 1869 micro grid small scale projects totaling 20.7 GW in operation worldwide. These projects have many parallel pipeline projects in adjacent India and China. The presented figure1-2 justified the genuine need for micro grid s in the green and clean energy concept.

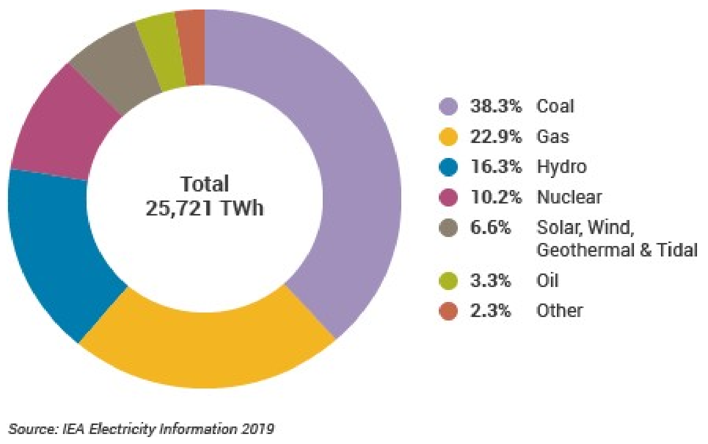


Figure 1-2:IEA Electricity information 2019

1.3 Problem of statement

The traditional existing power system network cannot cope with increasing power demand. Modern transmission infrastructure is very expensive. The existing centralized system has high transmission losses and low reliability. Global concerns regarding fossil fuel scarcity and their environmental issues raise the question of sustainable development. The micro grid can function in both mode when connected to the main power grid and in isolated mode. It can easily switch between the two modes. When a micro grid is linked to the main grid, it can provide auxiliary services. The micro grid can exchange energy with the main grid. When the micro grid functions independently of the main grid, the power provided by the micro grid, along with the power stored in the energy storage system, should be equivalent to the energy required by the local loads.

Micro grid s help reduce carbon emissions and provide reliable electricity by using the renewable energy sources. Micro grid s also provide protection against harsh weather and natural calamities by eliminating the need to maintain massive assets and other infrastructure. All of these parameters are held when they are properly designed and optimized to make them more reliable, efficient, and resilient. To address those issues, a novel approach to micro grid design and control is required.

1.4 Research Questions?

- Is it possible to operate micro-grid in grid connected mode and islanded mode with satisfying power quality issues?
- Is there any architecture model for maintaining islanding mode?
- Is it possible to optimize the DG sources? Can modeling of DG sources help in grid efficiency and reliability?
- What are the different control strategies are used for micro-grid?

1.5 Motivations for the Research

The major motivations for doing this research were

1.5.1 Primary motivation

Nepal has an old, inefficient, and congested system for transmitting electrical power. It is important to now consider trying new and creative methods. This will fulfill the information economy's future energy needs. This is without significant operational modifications or capital investment over the next several decades. Nepal needs to take initiative in this area. In Nepal, there are a lot of renewable sources and it seems possible to implement them in practice. Clean and green energy concepts have emerged in nowadays due to worldwide concerns regarding the environment. As a result, this study aims to reduce the environmental impact of electricity generation while meeting development and economic growth needs. From a technological standpoint, we'd like to increase the renewable energy content of the micro grid while also using a storage system to compensate for grid stability.

1.5.2 Technical motivation

It's difficult to predict renewable energy generator output. For example, wind turbine output changes according to weather conditions. Wind turbine output power is proportional to wind speed. When the difference between total load and renewable energy output is determined. The associated storage system must respond to this unpredictable load. We want to contribute to micro grid design, modeling, control, and simulation. In addition, we'd like to provide a framework for such systems that incorporates sub-systems with varied costs, behaviors, and advantages that work together to increase overall system performance without incurring significant costs or controlling the effect of investment.

1.6 Objectives and Scope

This research aims to develop micro grids, test their performance under different conditions (Islanded mode and Grid feeding mode). To mitigate these goals, the specific objective is

- To extract the maximum power from the Distributed Generations.
- Modeling of Energy storage system.
- To implement the higher order filter (LCL) filter.
- To optimize the PID tuning by (PSO) algorithm.
- To develop the complete model of micro grid and analyze the power quality issue.

1.7 Boundary for Research

This thesis focuses on design of a micro grid with analyze the power quality in islanded mode and grid feeding condition. A micro grid consists of solar photovoltaics, wind energy, and a battery storage system. MPPT system is used for solar photovoltaic and wind energy systems. This model is developed and analyzed in MATLAB. There are a number of PID optimization techniques available, however, PSO is preferred here due to its speedy operation and unaffected by the problem magnitude. VSI is used so for control PWM technique is applied.

1.8 Outline of Thesis

This research works has been organized and summarized into five chapter.

Chapter 1 provides a context for the need for micro grid, its history, development, and control, as well as the research's objective and boundary.

Chapter 2 provides a summary of the literature review with a focus on Micro grid development, as well as a solid outline of prior research.

Chapter 3 describes the model micro grid consider in this research with necessary theoretical and mathematical background.

Chapter 4 describes control principle, methodology and related flowchart and algorithm for the defined model development consider in this research.

Chapter 5 describes the simulated results. The results of different mode are studied, discussed, and presented.

Chapter 6 describes the conclusions and future research directions are suggested.

Lastly, the thesis concludes with a list of references, which provides a solid foundation for the research. In addition, an appendix that was used is attached.

1.9 Research Contributions

From this research, following conference paper and journal was published.

- Harmonics reduction in three-phase grid-connected inverter by using the third-order filter, international Conference on (ICITRR) organized by Yazhli Global Multidisciplinary Research Organization (YGMRO) 10 January, 2022. -Yam Krishna Poudel, Best paper presentation award
- Harmonics reduction in three-phase grid-connected inverter by using the third-order filter by Yam Krishna Poudel, SCITECH Nepal volume 16, issue 1
- Design and control of Distributed generations for micro grid applications, 13th IOEGC Conference, 2023 paper presentation by Yam Krishna Poudel
- Design and control of DC islanded Micro grid, IEEE PES chapter conference may 14-15,2023 paper presentation by Yam Krishna Poudel

CHAPTER 2: LITERATURE REVIEW

2.1 Distributed Generation

The IEEE defines DG as energy generation by facilities that are smaller than central power plants. This allows connectivity at practically any point in a power system. Micro sources are another name for them [11]. Comparable to centralization systems, they are technically 'small.' To prevent transmission losses, DG is placed near loads. Traditional centralized generation (CG) is not replaced by DG, albeit it offers a stable, high-efficiency, and cost-effective solution to supply sufficient electricity to load centers. There is limited prospect of installing new transmission lines due to land limits, popular will, and environmental damage. As a result, even though there is sufficient power capacity, during peak hours, it is challenging to fulfill the load center's energy demands. By putting DG at the top of the priority list, power demand can be met locally if there is a nearby load center. Different generation configurations are represented by the letters DG and CG. Appropriate ones should be deployed based on fuel availability, environmental demands, renewable resources, prices, and load characteristics [36]. Centralized generation was unquestionable three decades ago. The main reason for this was that cost savings from larger power plants offset the higher expenses of delivering electricity to customers. In the 1960s, DG was essentially non-existent [42]. Albeit, from liberalization of the electricity business and the promotion of low-carbon foot print policies and sustainable development goals by governments aiming at decreasing emissions associated with climate change, DG is getting popularity. The reliance on fossil fuels can be decreased through the micro grid since renewable energy has inherent advantages over fossil fuels. This results in significant reductions in CO_2emissions [47].

Cogeneration or combined heat and power (CHP) facilities, on the other hand, produce both heat and electricity simultaneously. Rather than being discarded into the environment, unused waste heat produced from the generating process might be utilized to benefit industrial activities or provide heat to local communities [12]. These applications can quadruple system efficiency [14]. There are a variety of sources of energy used in DG, including IC engines, micro turbines, solar PV, wind turbines, and fuel cells. Micro turbines, solar panels, and fuel cells are among the prime movers that require inverters to connect to distribution system networks [15]. Power electronics inverters guarantee that the output voltage and frequency are grid compatible [42]. The alternate current (AC) generated by the inverter, on the other hand, will not be a perfectly sinusoidal wave. In some cases, switching (DC) to alternating current (AC) can result in strong harmonics [16]. It is critical that harmonic distortion levels are kept within industrial standards. Most importantly, because renewable energy sources' output is uncontrolled, fluctuating power generated may degrade electricity quality, including voltage and frequency [17]. Many applications do not work well with DG deployed individually.

2.2 From Distributed Generation to Micro grids

The array of technological difficulties associated with controlling a large number of micro sources is a fundamental concern for distributed generation. Individual distributed generators have the potential to produce as many issues as they can solve [19]. A better way to utilize the potential of DG (distributed generation) is by integrating generators and their associated loads in a specific area as one system called a “micro grid”. Which makes power system more reliable. Micro grid s is a group of electrical sources, storage, and users that can work together with or separately from the main power grid. Micro grid s are small and modern power systems [42]. Micro grid s work differently than regular power networks. Micro grid s has many benefits. They make the quality of power better, increase the reliability of the system, require less money and reduce carbon emissions, provide different sources of energy, and can make money. It usually entails a number of generators ranging in capacity from a ten of kilowatts to a megawatt [2].

Micro grid s has distributed generators (DGs), these generators function differently within a micro grid than when they are used as independent power sources. Wind turbines and solar panels are types of DG that produce electricity. They are not completely predictable. They are used in small power networks called micro grid s. The weather has a big impact on them. A controlled DG is like an IC engine. Micro grid s uses small generators that can be easily turned on and off. This helps to increase the amount of time a specific power plant can be used. Micro grid generator can go from no power to its maximum power. In a normal power plant, generators need to keep working. Micro grid s can either be connected to a larger electricity grid or operate independently. By connecting the small power grid to the main power grid, we can use renewable energy in the small power grid without needing extra control over the electricity frequency. MG are small-scale power systems that are located close to where electricity is needed. They can provide more efficient services compared to large power plants that are far away. Micro grid s can also manage both electricity and heat needs [27].

Controlling a micro grid by itself is more intriguing and difficult because the frequency is not influenced by the larger electric grid. It can be hard to control the frequency of a micro grid when the power demand or use of renewable energy keeps changing. During power outages, the equipment that produces electricity and the devices that use electricity can be disconnected from the system that delivers electricity to buildings and homes. This keeps the micro grid 's electricity use separate from the power outage, without causing any harm to the main power system. Intentionally separating power generation and usage on an island can offer consumers better reliability and power quality compared to the regular power supply from the utility grid [15].

2.3 Impact of Micro grids

Regarding the distribution system, energy storage devices improve overall system reliability by assisting Distributed Generation (DG) power capability when they cannot produce the entire amount of power required by consumers. Micro grid s reduces power losses in the electric distribution network. They increase grid power capacity, assist with frequency and voltage regulation, increase reliability, and reduce emissions. Micro grid s also lower network upgrade investment costs [20]. Micro grid s is a novel way of integrating distributed generation into the electric grid. End-users, energy utilities, transmitters, and distributors can all benefit from integrating DERs into micro grid s to service a variety of loads. Local utilities can be benefited from micro grid installation by allowing system repair without disconnecting customers, permitting dispatch able loads during peak power circumstances, and reducing stress on the T&D system [21]. Micro grid s increase consumer reliability while also improving distribution system security and ensuring targeted performance through generation redundancy. Micro grid s operating in islanded mode can reduce disturbance impact in upstream networks. To isolate problems and enable steady autonomous operation, this necessitates control, communication infrastructures, and advanced protection.

2.4 Type of Micro grids

Direct Current (DC) or Alternating Current (AC) Micro grid s can be developed. Energy systems typically use an AC power network. This means that the AC voltage can be easily transformed into different levels, like transmitting power over long distances. This has been helpful for using AC current since 1800s. In recent years, renewable energies have transformed the manufacturing sector and introduced the DC Micro grid s [44],[45].

2.4.1 AC Micro grids

AC buses are connected to power generators. The AC power output line is either connected or isolated.

2.4.2 DC Micro grids

PV and fuel cells produce DC power that is connected to the DC bus; DC current is also used for many loads (LEDs).

2.4.3 Hybrid Micro grids

In this case, hybrid AC/DC micro-grids connect power electronic interfaces between AC and DC sub-grids to manage the flow of power for all distributed sources.

2.5 Micro grid s Architecture

Micro grid s can be built in a variety of ways; we'll go over some of the most frequent connection methods that have been published in recent years.

2.5.1 Radial Grid Configuration

This type of configuration is the structure that is used most often. A radial grid is a system of power lines that are connected to a main line. This main line is used to connect power consumers (like homes and businesses) to power generators (such as power plants). This design is very easy to make and use, especially in rural areas [23].

2.5.2 Ring Grid Configuration

Ring arrangement made up of lines that form a geometrical loop or ring shape, allowing electricity to flow in two directions to every point on the network [21], [22], [23]. As a result, voltage stability and power losses are improved, but more complex protection mechanisms are also required.

2.5.3 Mesh Type Micro grid s Configuration

The Mesh design adds more redundancy to the network by providing numerous alternate connections to all nodes. In addition to providing the most flexibility, it is also difficult to protect and operate Micro grid s.

2.6 Operation and Control of Micro grids

In a grid energy management is maintained when the amount of power that comes out is the same as the amount of power that goes in, even when taking into account any power that is lost. Integration of renewable energy sources into Micro grid s using power converters requires control measures to ensure a stable voltage and balanced power distribution between the different sources of power, energy storage, and electrical loads. Micro grid s can easily meet a wide range of system requirements, such as efficiency, security, reliability, power quality, and so forth, due to power converters, which are normally used to manage and connect micro-source DGs to the grid. Micro grid s can be adjusted to meet different needs for efficiency, security, reliability, and power quality by coordinating and controlling power electronics interfaces. Moreover, by implementing proper rules and clear communication, a small-scale electrical grid composed of various distributed generators can offer many additional services to the primary power grid. Grid-connected micro grid s and isolated micro grid s are two types of micro grid s. To operate cost-effectively and steadily, micro grid s must be properly controlled. Generally, a micro grid control structure has the following functions [14]. It maintains the power flow control and optimizes the operating cost, maintains the proper load sharing between different distributed generations, it has the capability of resynchronization with the main grid and when switching between connected and isolated modes, transients should be handled properly and desired conditions should be restored.

2.7 Micro grid s Control Classification

There are four different types of micro grid control systems. Which are illustrated as in figure below.

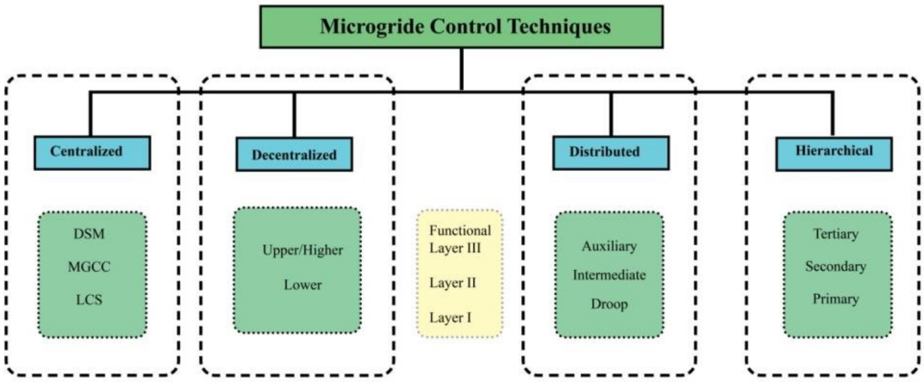


Figure 2-1:micro grid control module

2.7.1 Centralized control

According to the centralized method, a central processing unit compiles all measurements and decides on the next step in micro grid coordination. The purpose is to schedule and synchronize generators and controllable loads to maximize revenue from energy market participation.

2.7.2 Decentralized control

Controllers in distributed nodes are recommended in the decentralized approach [17]. By utilizing local measurements, the decentralized control technique makes decisions at the component level using predefined algorithms implanted in every node. Control that is dispersed in the distributed control architecture is an independent technique in which each local controller communicates with its neighbors. This is to get some of the benefits of a centralized design intended to the entire micro grid. Which means that every single device is managed based on local measurements and neighbors' responses.

2.7.3 Hierarchical control

The variation in time scales of various control requirements leads to a hierarchical control framework. Micro grid s uses several control loops. To ensure effective operation, power systems require control strategies. All system temporal scales must be considered in control techniques. This is commonly accomplished using a hierarchical control system for MGs. This may include three control levels to maintain the same AC grid structure: Figure depicts a hierarchical pyramid.

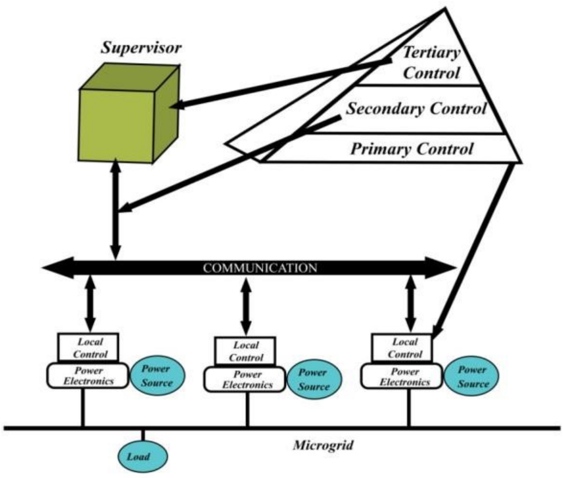


Figure 2-2:Hierarchical control

The main controller regulates local voltage as well as ensures proper power distribution across many DG units and stable micro grid operation. Micro grid s is aided by secondary and tertiary controllers, which include concepts like prediction, communication, and optimization. The main control uses a strategy where each DG unit can operate independently. Primary controllers are responsible for keeping the system stable and reliable. The main controller needs to be fast, meaning that it should respond within microseconds. This happens because micro grid s change quickly and don't have much spinning energy. This control system in the area keeps the internal voltage and current of the DGs stable. It does this by monitoring and adjusting local signals. Utilizing a communication-based technique for parallel DG building, secondary control corrects voltage and frequency irregularities brought on by changes in load and local control operation [17]. In a local power distribution network, the associated tertiary reserve allocation and tertiary control level are designed to maximize distributed energy resource dispatch and load balancing. Dispatching optimization can incorporate economic, technological, and environmental optimization [6].

This third level of control watches over the functioning of several connected Micro grid s. It also keeps track of transactions with the main grid, like buying or selling electricity, as well as providing extra services such as helping with voltage and regulating frequency. Sending messages to the lower level to small power grids and other parts of the whole power system. This level of control typically requires several minutes to hours to complete. In contrast, secondary controls in Micro grid s and sub-systems coordinate internal primary controls in a matter of minutes. Finally, important controls are designed to work on their own and quickly respond to local events in specific ways.

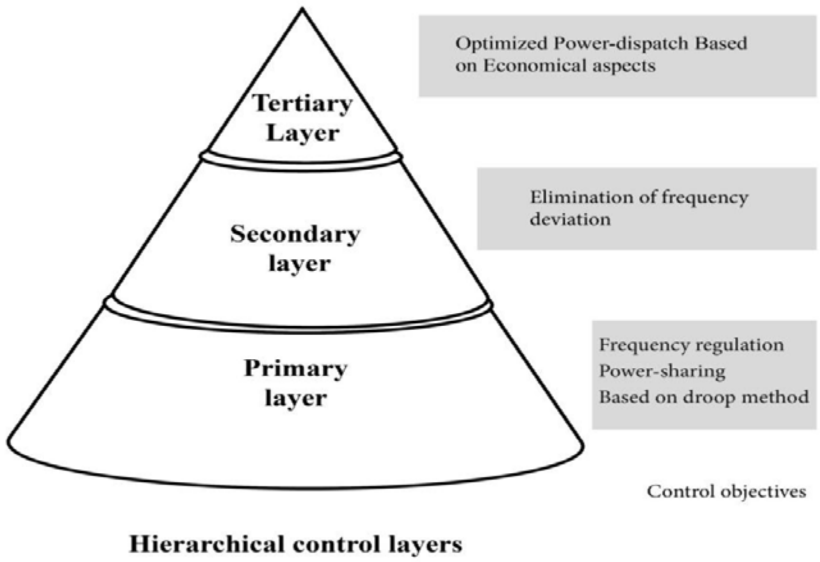


Figure 2-3:Pyramid of Hierarchical control

2.8 Overview of Control in Micro grids

Different control strategies, such as PI/PID linear quadratic control, linear control and sliding mode, have been used in the control of Micro grids in the past.

2.8.1 PI/PID linear control

The PI/PID controller is often used in the industrial sector for power systems because it has a simple design. PID/PI is a good control system that works well if it is set up correctly. It is strong and dependable, and can give almost perfect control system performance [7]. However, PI/PID tuning procedures have limited ability to correctly tune PID gains for nonlinear and complex systems. The effectiveness of the PID inside this framework is dependent on the selection of PID parameter values. Additionally, because it is a linear approach, the system's performance may vary significantly depending on the operating range.

2.8.2 Linear quadratic regulator

The major goal of LQR is to find the best control strategy by minimizing or maximizing a utility cost function. The perfect choosing of weighted matrices Q , R to provide a right response is difficult with a linear quadratic regulator.

2.8.3 PI/PID Nonlinear control

Micro grids are nonlinear systems, hence nonlinear techniques like feedback linearization and PI/PID are applied. These systems' controllers are created by utilizing nonlinear control and back stepping.

2.8.4 Sliding mode control

For nonlinear robust control to assure stability under parameter limitations, sliding mode control has been extensively researched.

2.8.5 Model predictive control

To foresee the reference signals, predictive control techniques are improved. These systems have the potential to reduce tracking error which is an intriguing feature.

2.8.6 Artificial-intelligence-based control

Several heuristic techniques have been used in the literature to improve the control and optimization of micro grids and distributed generations units. These techniques include PSO, ACO, fuzzy logic, neural networks, and genetic algorithms. Thus, both grid-connected and islanded modes of micro grid operation can benefit from intelligent and evaluation methodologies.

2.8.7 Adaptive control

This control technique is mostly used to deal with parametric possible uncertainties and disruptions. Adaptive control techniques, without a doubt, can successfully assure sustained stability, resilience convergence, and system dynamics tracking under mild conditions. system's current operating status is subject to change. As a result, plant controller performance may not be optimal. The possible options are widely used for quasi-optimal operation conditions to solve such obstacles.

2.9 Micro grids

Micro grids is made up of many power sources, like generators, and other electric parts that are used to send, store, and share the power. The micro grid manager is a crucial that controls through computer program. People who work with the system make sure it is working well, but they don't play a big role in operating micro grids. The micro grid manager talks to all parts of the micro grid and uses special instructions to make sure everything works well together. This is a control system that helps the micro grid run safely and efficiently, whether it is connected to the main power grid or not. It has two main jobs: managing and controlling micro grids. it optimizes the load on generators to reduce fuel consumption. When the micro grid manager controls voltage and frequency, it ensures power quality and system stability. These two responsibilities are carried out by the micro grid manager at the same time. Optimization and controllable generation aren't the only benefits [37]. Generation that is limited or uncontrollable Manager of Micro-Grids. The micro grid health status, which are not fully accessible yet, should be included in an ideal micro grid [8]. With a micro grid, consumers can receive electricity from a wide range of sources. Its plug-and-play functionality allows it to be used in both modes depending on the load. Micro grid s has the potential to meet future power requirements. Micro grids can quickly repair failures and respond to malfunctions. Cyber-attacks can be mitigated with micro grid s

Control and optimization of Micro grids becomes a significant problem as renewable energy shares increase [21]. When the amount of electricity being produced is not the same as the amount being used, a device that can store and release electricity quickly is used to make the electricity system work better. Load and generation imbalances are caused by a variety of factors, including load fluctuations, variable renewable energy generation, and time delays, among others. For improved micro grid functioning, an energy storage system may be required. However, because storage is so expensive, large energy density storage systems are impossible. A clever micro grid manager will use the least amount of storage necessary to satisfy the needs and improve performance.

Energy and power density requirements can categorize storage capacity. They're employed to meet medium- to long-term, as well as short- and very-short-term needs [5]. Storage systems respond faster than other generation units, giving micro grid control more flexibility. Storage systems can also improve micro grid performance. To begin with, when an energy storage system is used in power mode, it reduces the frequency and speed with which renewable energy sources change their power output [34]. As a result, they can address the problems of renewable resource instability and intermitted. Second, they are employed as an energy method, contributing to economic benefits by storing energy during low electricity price periods and utilizing it during peak electricity price seasons [43]. Third, they help stabilize DG units so that they can operate at a steady and consistent power output even when there are changes in the amount of electricity being used. In this situation, they are mixing power and energy settings. It is preferable to have a storage system with both a high-power density and a high energy density [1]. single type of energy storage system cannot fulfill all duties efficiently, the components of a micro grid storage of energy system are batteries, ultra-capacitors, and flywheels [11]. In general, storage systems are limited for creating a sustainable micro grid due to its high cost. To put it another way, a complex technique is required to optimally extract a storage system's maximal capacity [46], [47].

Micro grids offer a comprehensive power system architecture to handle future power demands. Its supporters claim that it is "a grid where anything is conceivable" and "an enabling sustainable engine for our economy, better environment, and future" [1]. It demonstrates significant benefits over extending and updating current centralized generation power systems [41]. Additionally, if maintaining or enhancing reliability or power quality is essential, it may offer a compelling investment opportunity [3]. Micro grids is a promising energy solution for both developed and underdeveloped nations. People may profit socially and monetarily from it. Before technological, economic, marketing, and security issues are solved, micro grids must be fully deployed [50], [51].

2.10 Critical review

Many studies about micro grids have been published in many different places. It's not possible to include all the work done in this area. But we talk about some of the scientific papers that are considered more trustworthy. The earlier efforts have laid a solid basis and provided insight into the future direction of this research. The way micro grids is set up, their features, how they're managed and controlled, their current situation, future directions for development, issues they face, and the different markets they're used in are discussed in articles [1], [3], [5], [9], [10], [14], [15], [16], and [17]. We talk about and solve problems related to technology and rules in this text. These problems include self-driving, and control of power quality issue. Controlling and managing a micro grid is very important to ensure it works well and makes money. We looked into different areas of control and management as part of studying the control management issue. We are studying Micro grids that operate independently, like on islands. A control system for Micro grids ensures it operates safely when it is disconnected from the main power grid (islanded mode) and when it is connected to the grid (grid-tied mode) [25].

Furthermore, a micro grid controller needs to handle uncertainties in parameters and unpredictable changes in system behavior that cannot be specifically predicted. According to [4], there are two different ways to control micro grids: a centralized method and a decentralized method. These two types of control are the same as islanded and grid-tied control, respectively. They are at the micro grid supervisory control level. Due to the large number of rotating masses in a centralized system, the frequency is practically constant. The entire system has much greater inertia than the connected micro grid [29],[30],[31]. Grid frequency control, on the other hand, is a difficult challenge in islanded mode, as indicated in [5] and [4]. There are very few rotating masses that are directly coupled, such as flywheel energy storage. When there are generation and load mismatches, the micro grid frequency is shifted. Each LC is designed to increase overall system performance rather than maximize revenue. Power quality in an integrated circuit factory, for example, is critical. When a micro grid is used in these situations, the amount of renewable energy content is less significant than power quality. As a result, each LC is set up to optimize grid performance. However, cutting expenditures is sometimes more significant. RES content is optimized by employing LCs on energy sources, such as solar unit (MPPT) control and wind energy turbine pitch angle control.

There are different ways to control renewable energy sources, like wind turbines. One method is called (MPC), which can be used to adjust the blade pitch angle of the turbine. This method was suggested and used in a study. In [22], a better way to control the frequency is given. However, the method suggested is basically like a PID control method. To put it simply, when there are many DGs, we have to use multiple PID loops. Each controller can only respond to one result in this arrangement. It can't easily change and adapt like a MIMO control strategy does. Some other control systems used for LC control are neural networks, fuzzy logic control, and classical controls. The paper [12] about a specific type of control system called Ziegler-Nichols PID control. This control system is being used along with another type of control called H control.

In [5], an Islanded control approach is applied to a "swing source" that can be allocated to regulate frequency. When two or more DG units are actively engaged in grid control, voltage-droop and frequency control are used for islanded control. Traditional droop control is used in [6], [7], [8], and [9]. [22] and [25] investigate improved droop controllers. [19] and [11] investigate a more advanced adaptive droop control approach. Complete micro grid installations are provided and micro grid control is developed in [3] and [4]. Advanced control algorithms, on the other hand, are not implemented. In other instances, there is no certainty.

A storage system is connected to the micro grid in islanded mode to provide (or absorb) the immediate power difference between generation and load. For dynamic simulations, there are several generic battery models available, such as. The voltage, current, and State of Charge of the battery are the most critical factors (SOC). more-accurate and efficient battery model is difficult to create and necessitates electrochemistry knowledge. This information is not required for our application [33]. With easily retrieved information from the manufacturer's data sheet, an appropriate model can accurately depict battery dynamics. For micro grid control applications, it is sufficient [36],[37]. The verifying outcomes suggest that model may adequately encapsulate typical behavior for controller analysis and design. In [9], [1], and [6], many voltage source inverter models (VSIs) are available. [18] and [20] offered a very precise three phase inverter average model from control standpoint. This has been used in our studies.

CHAPTER 3: MICRO GRID MODEL DEVELOPMENT

3.1 Model Development

In order to supply electricity for local loads and/or link to the grid or micro grid. These systems are developed by connecting two or more renewable production sources, such as wind power, solar power, electric cells, and micro turbine generators. Due to the characteristics of these distributed generations is related to the efficiency of combined power generation. This is significantly more efficient than individual power supplies. A sizable battery bank is necessary for each load in order to maximize the electricity generated by the PV array and the wind. DC grids have recently recovered due to renewable DC power sources. In addition, they have experienced DC loads' benefits in different applications. DC micro grids have been suggested. On the other hand, normal AC loads require DC/AC converters and must be converted from AC to DC before being connected to a DC grid.

When RES can offer 100% of the power. It is no longer necessary to use high-voltage long-distance transmission. DC Micro grids are being proposed as a way to make it easier to connect RES. Albeit, the AC output power of Wind energy must be converted to DC using AC/DC converters and DC/DC converters that are connected to an DC grid. In order to reduce the number of reverse conversion procedures in a single AC or DC grid and to link a variety of renewable AC and DC sources and loads to the power grid, this effort developed a DC micro grid. Once the grid is operating in both grid-tied and islanding modes, coordination control schemes between different modes are proposed to maximize power from renewable energy sources, to lessen power transfer between AC and DC networks, and to keep DC grids operating steadily in the face of fluctuating supply and demand.

The use of modern power electronics and control technologies can result in a much smarter future grid. Because solar and wind electricity are inherently intermittent and unpredictable, increasing their penetration in current grids could pose significant technological issues, particularly for weak grids or stand-alone systems lacking adequate storage capacity. The impact of the variable nature of solar and wind resources will be partially alleviated by combining the two renewable resources into an optimal combination, and the total system will become more reliable and cost-effective to operate. There are numerous configurations that present a state-of-the-art review. The developed model for this research is given below. Which consists of PV array, wind system, battery storage connected to DC bus. Inverter is used to connect with grid and loads.

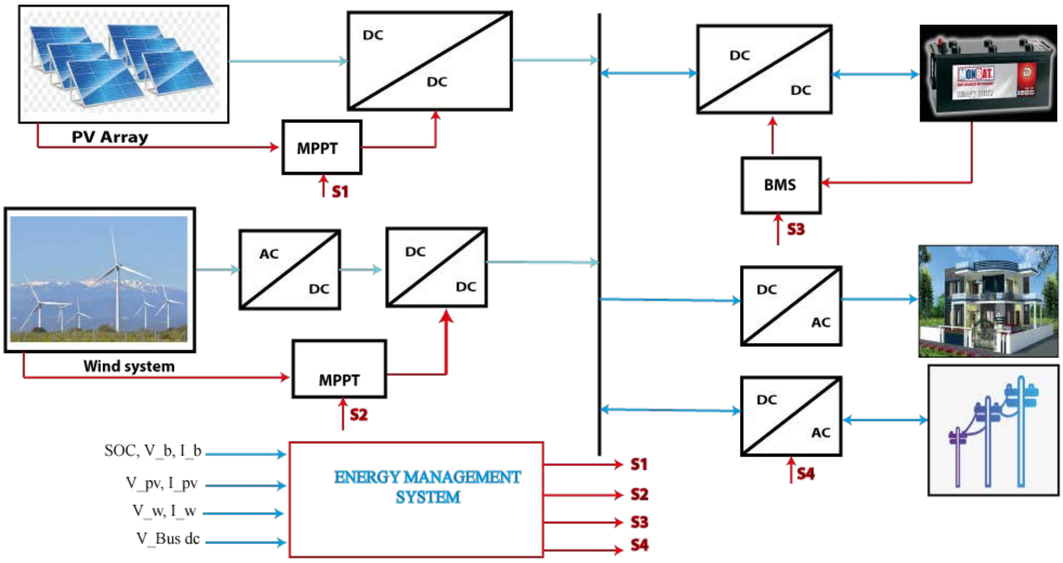


Figure 3-1:Micro grid research model

3.2 Modelling of a PV Cell

At high temperatures, a semiconductor comprising boron and phosphorus atoms produces a two-layer p-n junction. In these two layers, there are positive and negative particles resembling P-holes and N-electrons. Then, two electrodes, one on top and one on the bottom, are added to make electric circuit. Finally, the glass is given an anti-reflective coating. This cell uses the photo voltage effect to convert light into electrical energy. In practical application, the resistances are implanted and connected to the PV diode rather than part of a standard solar cell.

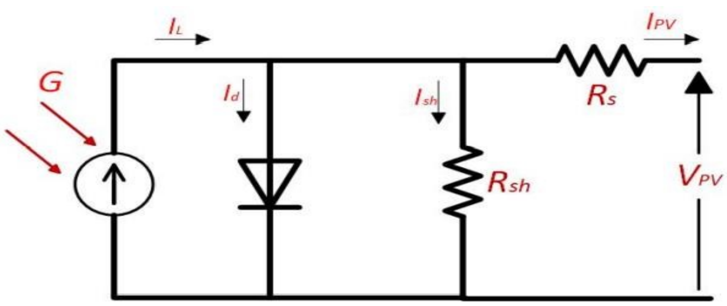


Figure 3-2: PV cell

This is because of elements like the size of the PV semiconductor's resistance and a subpar PN junction diode, which lead to the use of series and shunt resistance. To determine the current generator from a solar cell, utilize Kirchhoff's law.

$I_{pv} = I_L - I_d - I_{sh}$ …. Equation (3.1)

The I_L symbol represent the current generator is

$I_l = G\{I_{sc}[1 + k_a(T - T_{stc})]\}$ … … ..Equation (3.2)

The symbol G is the solar irradiance, T is the climate conditions' ambient temperature, I_{sc} is the PV cell's short circuit current, and k_a is the temperature coefficient $T_{stc}$is the PV cell's temperature operation under standard test circumstances (STC), and I_d is the PV diode's current, as determined by Shockley's Eq.

$I_d = I_0\{\exp\left(\frac{qV_d}{nkT}\right) - 1\}$ …. Equation (3.3)

Where I_0 is the PV diode's saturation current, V_d represents the voltage across the diode, q represents the electrical charge (1.69e-19 C), k represents the Boltzmann constant (1.38e-23 J/K), and n also known as PV diode factor. As of right now, equation for the PV cell's (I-V) chart is

$I_{pv} = I_l - I_0\left[\exp\left(\frac{q(V_{pv}+I*Rs)}{nkT}\right) - 1\right] - [\frac{V_{pv}+I*Rs}{R_{sh}}]$ … Equation(3.4)

Where, I_{pv} and V_{pv} is the PV output current and voltage.

3.3 DC-DC Boost Converter

Boost converters are the most widely used DC-DC converters for PV-generated systems despite the fact that other DC-DC converters like buck, chuck, and boost converters have also been developed. This is so that the DC-DC boost converter can regulate and create an output voltage that is higher than the input voltage while using a lower output current. A loss power equation predicts that in this case, the loss power will be quite low. The transistor at the center of the DC-DC boost converter, as depicted in Figure, is controlled by a controller and manages the amplified processing. When the MOSFET is turned on, current travels through an inductor (L) in the opposite direction, storing the energy by creating a magnetic field. The current change in the inductor I_l throughout time period (t) is given by

$\frac{\Delta I_l}{\Delta t} = \frac{V_i}{L}$.… Equation (3.5)

V_i denotes the input voltage. The changing value of I_l grows at the end of the ON-state, and hence is provided by

$\Delta I_{lon} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i$……Equation (3.6)

The energy stored and the primary source are coupled in series when the MOSFET transistor turns off in state two, resulting a voltage. In this situation equation becomes

$V_0 - V_i = L\frac{di_l}{dt}$……. Equation (3.7)

The output voltage is denoted by V_0. As long as the MOSFET switch is open, the inductor current changes linearly. When the MOSFET is turned off, the I_l's rating changes as follows:

$\Delta I_{loff} = \int_{DT}^{T} \frac{(V_i - V_0)dt}{L} = \frac{(V_i - V_0)(1-D)}{L}$ …. Equation (3.8)

steady-state mode, the overall rating value of the current through the inductor must be zero.

$\Delta I_{lon} + \Delta I_{Loff} = 0$ …...Equation (3.9)

These leads

$\frac{V_i * DT}{L} + \frac{(V_i - V_0)(1-D)*T}{L} = 0$……...Equation (3.10)

$-ViD$ = $(Vi - Vo)$ $(1 - D)$ …...Equation (3.11)

To find the value of the inductor

$L = \frac{V_i * Dmax}{\Delta i_l\, fs}$…...Equation (3.12)

$C_1 = \frac{Dmax}{8L\Delta V_i f_s^2}$ …...Equation (3.13)

$C_2 = \frac{Dmax}{R\Delta V_0 f_s}$…...Equation (3.14)

Where V_i and V_O are known as ripple input and output voltage, R is the output resistance. the diode boost converter's reverse rating current is taken into account. This setting ought to enable input current flow to the load in the OFF-state. Therefore, the maximum current load of the PV system should be equal to the forward current diode of the DC-DC converter. Various states of a DC-DC boost converter's waveform are displayed. As shown, the inductor's current starts to increase at the ON-state when it is at its lowest value and decrease when it is at its highest value at the OFF-state.

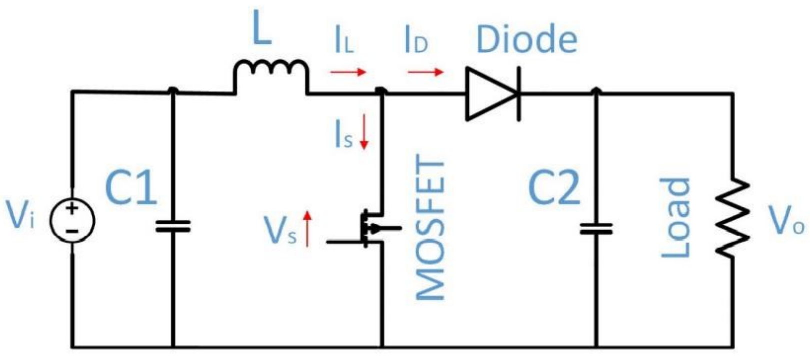


Figure 3-3: Boost converter

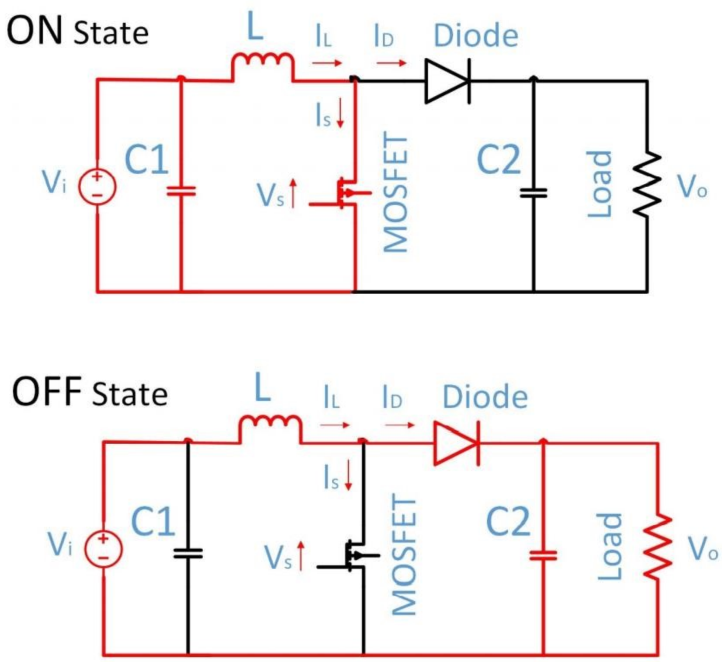


Figure 3-4: Different state condition of boost converter

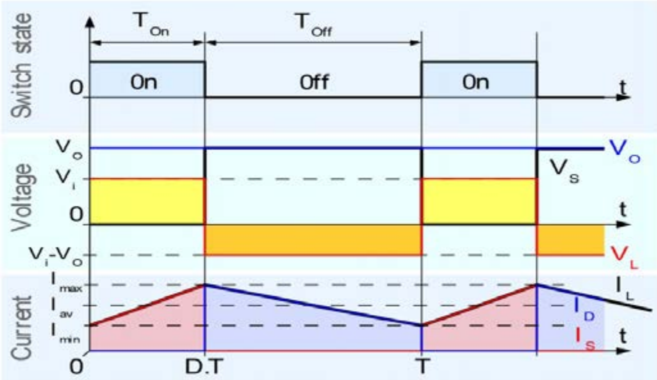


Figure 3-5:wave form of converter

3.4 Control Scheme of a PV System

The MPP is a distinct point on the P-V curve of a PV array that changes with the weather. MPPT technology connects PV arrays and the load or grid. It is used with the PV power conversion system to continuously monitor the MPP. This technology makes it easier to track the power generated by PV systems. It does this by adjusting the duty cycle (D) of the system based on the current and voltage of the PV panels, as well as the amount of sunlight and temperature. The duty cycle is changed into a signal by using pulse width modulation (PWM), which is shown in the figure. The PWM circuit uses a signal that shows the length of time the signal is on compared to off. It compares this with a signal that goes up and down like a saw blade to create a pulsating signal. If the saw tooth signal is smaller than the duty cycle signal, the output PWM signal is in the ON-state (Ton). Otherwise, it is in the OFF-state (Toff), as shown in the figure. This process is done again and again to make the PV array work better when the weather changes. The position of the operating MPP on the P-V curve decides the best duty cycle. When the operational point moves to the right, the D will increase until it reaches the MPP. Otherwise, it will decrease. We use a small computer system called a microcontroller to make the MPPT algorithms work. This power controller helps a PV system by making the PV panels work better, making the PV energy produced more stable, and making the entire PV system more reliable. The Perturb and Observe (P&O) algorithm is commonly used for MPPT because it is cheap and easy to use, even though there are other options available. The main problems with this strategy are that it takes a long time to reach the desired outcome, there is a lot of fluctuation around the best point, and the technique is affected by irradiance.

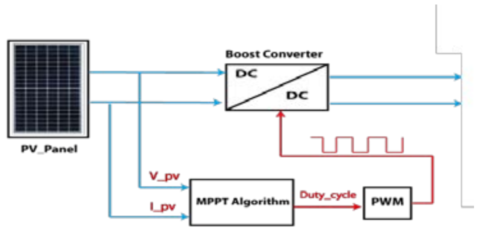


Figure 3-6:MPPT for PV

The P&O algorithm is often chosen for PV-MPPT methods because it is inexpensive and easy to use. Using the measured voltage and current from the PV array, this method calculates the power generated by the PV. The duty cycle of the DC-DC converter is changed based on the comparison of some measurements to the previous power level. This helps to determine the correct direction for the P&O algorithm.

$D(k+1) = D(k) \pm \Delta D \ldots$. Equation (3.15)

D is the size of a small step that D takes, and D (k+1) and D (k) are the changes that happened to D before and after. The P&O algorithm moves in the same direction when the voltage and power of the PV array go up because of an increase in D. Otherwise, it moves in the opposite direction. The process continues until it reaches the most productive point, and then it moves up and down around that point. Table lists the general characteristics of the P&O direction. Three main problems hamper P&O-MPPT operation: a lengthy convergence period, significant oscillations around the MPP, and a drift issue brought on by rapidly varying irradiance. The answers to these questions are as follows. A large D definitely causes rapid steady-state and significant variation after MPP. On the other hand, smooth swings and a slow steady state are produced by a small D. This theory states that changing the operation of the system depends critically on the size of D. Another drawback is that the MPPT tracker loses its proper heading when the weather suddenly changes. This thing shown in the picture can happen when point A (the lowest point), which shows the maximum power point at a low amount of sunlight, moves between B and B and then goes to point C or D (the highest point) because the sunlight is getting much stronger. Because of the basic features of the traditional P&O algorithm, the algorithm moves away from the new maximum power point. This is shown in Table. On the other hand, this effect only occurs when the irradiance increases.

ΔP	ΔV	Direction of Perturbation
+	+	+
+	-	-
-	+	-
-	-	+

Figure 3-7: P&O algorithm with probabilities of direction

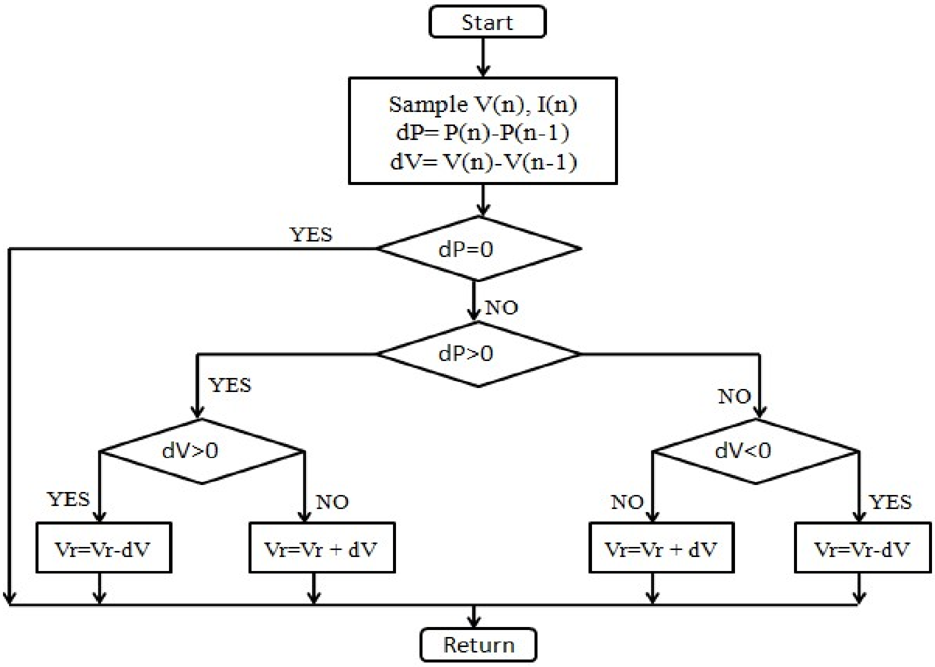


Figure 3-8:Flowchart of MPPT algorithm

3.5 Wind energy system

The mathematical expressions for power output's cubic relationship with wind speed, its square relationship with air density, and its square relationship with the rotor's swept area are all given below.

$P = 1/\ 2\ \rho A V^3$

Here,

P is Power output of wind turbine (Watts)

A is Swept area (m^2)

V is Velocity of wind (m/s)

ρ is Density of air (kg/m^3)

The output of a turbine is affected by the rotor type, frictional losses, blade design, viscosity and pressure drag on the rotor blades. In addition, there are losses at electrical system components, and swirls caused by rotor movement against air. The maximum output power of a wind turbine is known as the Betz limit. This was developed by Betz after generalizing and examining these characteristics. The greatest power a wind turbine can generate is this number, or 0.59. The limitation is met by the highest 50% efficiency wind turbines can currently achieve [32]. Wind turbine performance coefficient is determined in this manner. Consequently, the wind turbine output power can be converted into

$P_{mean} = \frac{kCA\rho V^3}{2}$.... Equation (3.16)

Wind turbine generated power is given by

$P_m = 0.5\pi\rho Cp\ (\lambda, \beta)(R)^2 * (Vw)^3$ ...Equation (3.17)

In this equation, R stands for the diameter of the turbine, V_w for wind speed, δ for air density, C_P for power coefficient, λ for tip speed ratio, and $\boldsymbol{\beta}$ for pitch angle. In this case, $\boldsymbol{\beta}$ is set to 0. The expression for the tip speed ratio is

$\lambda = \frac{W_r R}{V_w}$.... Equation (3.18)

Where W_r is the angular speed of the turbine. The wind turbine's dynamic equation is given by

$\frac{dw_r}{dt} = \left(\frac{1}{J}\right)[T_m - T_L - FW_r]$.... Equation (3.19)

Where T_m is the turbine torque, J is the system inertia, F is the viscous friction coefficient, T_l is the torque owing to load, known as generator torque, and T_m is the torque due to the turbine. The optimum power of a wind turbine is expressed as

$Pmax = K_{opt} * W_{ropt}^3$......Equation (3.20)

Here,

$$K_{opt} = \frac{0.5\pi\rho Cpmax * R^5}{\lambda_{opt}^3}$$

$$W_{ropt} = \frac{\lambda_{opt} V_w}{R}$$

The graph shows how much power a turbine can produce as the rotor spins at different speeds. The power of a wind turbine is highest when it is at a certain rotor speed called the optimum rotor speed. The best tip speed ratio (opt) matches this speed. The turbine must always be in the ideal position to maximize its power output. To make this happen, the turbine's spinning speed is adjusted so that it always spins at the perfect speed.

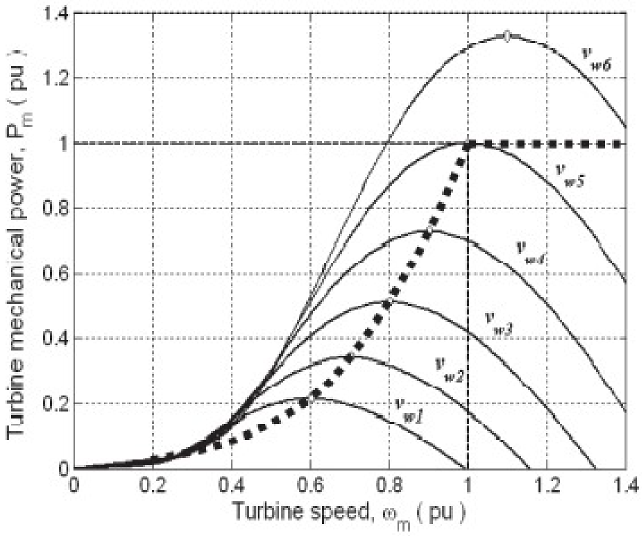


Figure 3-9:Turbine mechanical power for various wind speeds

3.6 Battery management system

The "H" factor, a parameter in the suggested model, is used to determine how the battery's state of charge and one of its voltages drop components are related. The battery data sheet is used to determine this type's properties. The definition of the model's datasheet parameters is given. The actual li-ion battery is evaluated by comparing the battery sample to it. Here, we model a battery-based storage system. Assumptions in the Development of a Battery Model Before we begin developing the battery model, we'll go through some of the assumptions that have been used to model the battery [33].

It is considered that the battery parameters are uniform. The model ignores self-discharging and temperature effects on batteries. There is no change in battery capacity and internal resistance, and polarization is linearly related to current amplitude. The Battery Discharge Model Figure. Displays a typical battery discharge curve. The discharge time on the x-axis shows how long it takes to completely drain a battery at a certain current. This period of time is inversely proportional to battery capacity in the case of constant drain current. A battery discharge curve uses battery capacity (Ah) as shown in x-axis.

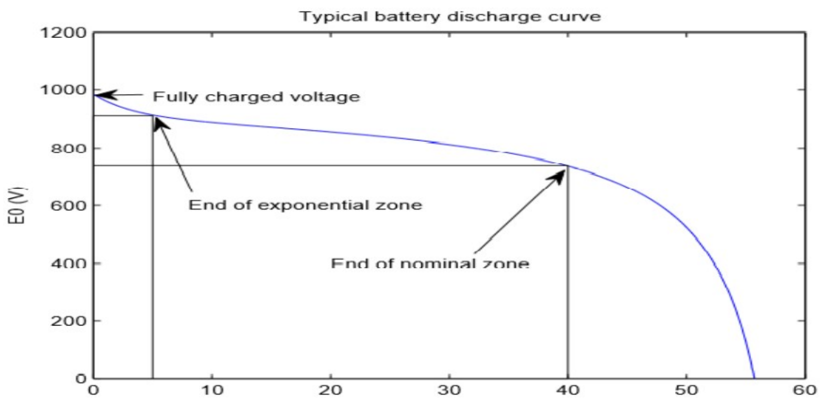


Figure 3-10:Battery discharge curve

This battery model was originally published in [28]. This is based on the voltage profile of the battery's discharged cathode E_c. Let's clarify:

$E_c = E_{sc} - K_c * I_{am}$ …. Equation (3.21)

E_{sc} stands for the potential constant (V), K_c for the cathode coefficient of polarization, and I_{am} for the current flowing through the active material:

where Q_c is the active cathode charge that is accessible (in Ah);

$I_{am} = \frac{Q_c}{(Q_c - it)} * i$…Equation (3.22)

The slow voltage dynamic is represented by i, a filtered current, where "t" is discharge time. Here, i is a constant, and Q_{batt} is actual. The charge of the battery If nothing else is supplied, $Q_{batt} = idt$. When a battery is 100% charged, it equals zero. It's evident that $'it'$ refers to the difference between the battery's completely charged capacity and the present charge it carries. To put it another way, The charge is what has generated its power. When 'it' gets close to being fully charged, when the battery is fully drained, according to Q_{cap}.

From Equation, we get:

$E_c = E_{sc} - K_c \frac{Q_c}{(Q_c - Q_{batt})} * i$…Equation (3.23)

The following outcomes are produced both modelled using the same parameters:

$E = E_0 - K * \frac{Q}{(Q - Q_{batt})} * i$.... Equation (3.24)

The battery potential between the terminals is $E = E_a + E_c = 2E_c$. The constant potential of the battery is $E_0 = E_{sa} + E_{sc} = 2E_{sc}$. Similarly, $K = 2K_c = 2K_a$ is the polarization constant. $Q = Q\_c = Q_a$ which is known as Shepherd's model. In this research, $Q = Q_{cap}$ is used as a symbol. In other words, when the battery is fully charged, the voltage potential is approximated by active material accessible in coulombs. If the internal resistance of the battery is constant, E_q becomes:

$E = E_0 - K * \frac{Q}{(Q - Q_{batt})} * i - R * i$...Equation (3.25)

Here, a new term is added to mimic the initial voltage exponential decline. This exponential term can be written as follows:

$E_{exp} = Ae^{-B*Q_{batt}}$.... Equation (3.26)

Here, the symbols A and B are constants which are calculated from a battery manufacturer's discharge curve or determined empirically. A and B stand for, respectively, [3.26] indicates a universal battery discharger model.

$$E = E_0 - K * \frac{Q}{(Q - Q_{batt})} * i - R * i - Ae^{-B*Q_{batt}} \ldots .eqn(3.27)$$

A new word named "Polarization Voltage" is introduced. The (OCV) behavior is function of SOC is represented by this additional term.

$E_{pol} = K * \frac{Q}{(Q - Q_{batt})} * Q_{batt}$.... Equation (3.28)

The voltage drops across a battery, on the other hand, is linked to the drain current of the battery. K, the polarization constant, with, we introduce a coefficient ‘H.' This newly introduced coefficient has the following definition:

$H = 4 - \frac{i}{Q_{batt}}$...Equation (3.29)

As can be observed, the 'H' fit coefficient is directly related to the battery's charge as well as its drain current. It improves the model's sensitivity to changes in both signals. There is no need for further parameter identification because it is a function of a current. Now In order to obtain the adjusted battery discharge model:

$E = E_0 - K * \frac{Q}{(Q - Q_{batt})} * i - R * i + Ae^{-B * Q_{batt}} - H * \frac{Q}{(Q - Q_{batt})} * Q_{batt}$….*Equation (3.30)*

Model of Battery Charging The polarization resistance during charge grows suddenly, in contrast to the discharge model, and is modelled as:

$R_{pol} = K * \frac{Q}{Q_{batt}}$…. Equation (3.31)

Because it equals 0 when the battery is 100% charged, $R_{pol} = \infty$. In practice, Albeit, about 10% of the battery's capacity changes the polarization resistance. As a result, the following polarization resistance expression is obtained,

$R_{pol} = K * \frac{Q}{(Q_{batt} - 10\%Q)}$…. Equation (3.32)

The rest of the terms are identical to those in the discharge model. As a result, the following is a generic battery charging model:

$E = E_0 - K * \frac{Q}{(Q - Q_{batt})} * i - R * i + Ae^{-B * Q_{batt}} - K * \frac{Q}{(Q - Q_{batt})} * Q_{batt}$…. Equation (3.33)

then i > 0 and i < 0 are two conditions for the battery being discharged and being charged.

Calculation of SOC It is critical to estimate the SOC of the batteries in order to get the most out of them. SOC is calculated in this dissertation using the charge remaining in the battery and is stated as:

$SOC = (1 - (\int_0^t i(t)dt)/Q) * 100$…. Equation (3.34)

CHAPTER 4: CONTROL METHODOLOGY

Here we discuss the inverter control architecture, which incorporates grid synchronization via a PLL and optimal LCL output filtering. The current loop is constructed using a PID controller that operates in two modes. The signals are fed to the current loop via the PLL, which is detailed first. Additionally, presented and demonstrated are the LCL filters thorough mathematical modeling and explanation as well as a flowchart with the PSO algorithm.

Due to the current's orientation along the active voltage component (V_d), this technique is also known as voltage-oriented control. A PLL algorithm detects grid voltage, grid frequency, and grid phase angle. Reference frame adjustments and grid monitoring require frequency and voltage. If a PID current control is utilized, the currents are translated into a synchronous frame. The algorithm also achieves decoupling between two axes. For the standard alone, the inverter output terminals are kept at constant voltage using a typical PID controller. The PLL method and the technique used to control the output voltage of a solo inverter are very similar.

4.1 PLL for Inverter

Many different uses of PLL systems are found in various signal applications, such as radio, telephony, controlling electrical motors, and more recently in power electronics. PLL technology can handle frequencies that range from a few hertz to billions of hertz. Phase locked loop (PLL) systems have three main types for phase tracking: zero crossing, stationary reference frame, and synchronous rotating reference frame (SRF) based PLL. The SRF PLL can be employed in single phase and three phase applications, and it functions effectively in distorted and non-ideal grid setups [5]. The explanation for SRF PLL's improved synchronization performance.

4.2 PLL Theory

In the basic PLL arrangement. The phase voltage is obtained, and then the stationary reference frame voltage is changed into corresponding voltages V_d and V_q in a frame of reference synchronized by using the dq transformations to the utility frequency. The obtained angle θ* employed in these particular transformations is obtained by integrating a frequency signal which is symbolized as w*, and the initial angle in this integrator must be properly chosen as the beginning. Depending on the angle θ*, the voltage $V_d$and V_q

appear as DC values if the frequency command w* is equivalent corresponding utility frequency.

4.3 Voltage Control

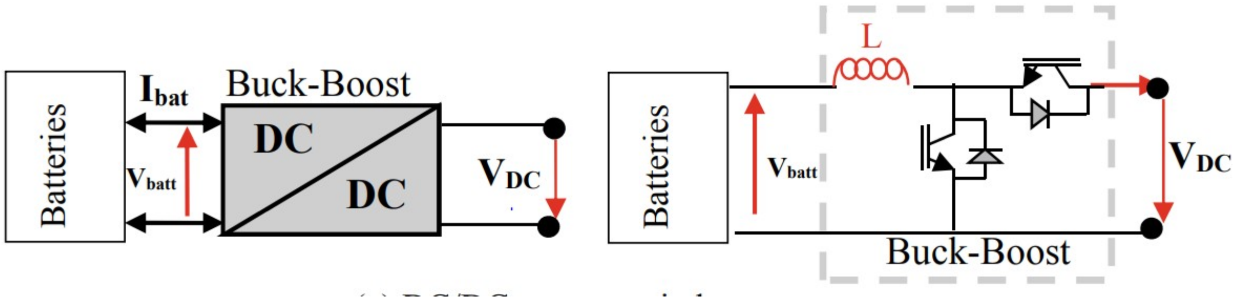
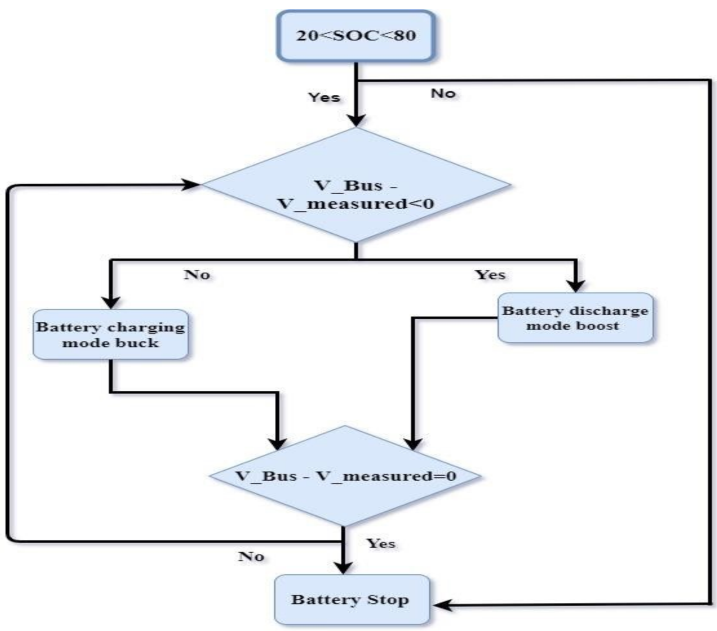


Figure 4-1:Batteries buck boost model

The DC bus voltage is maintained by comparing the VDC reference with the VDC bus voltage. The DC bus voltage is controlled using the flowchart. In a DC micro grid, DC bus voltage control is a major concern. Here the batteries control the DC bus voltage by charging and discharging based on load variation. When the load demand is high compared to generation, the battery acts as discharging mode i.e., the converter acts as boost mode whereas when load demand for a system is lower than generation, battery consumes the power and it is operated in charging condition where the converter operates as buck mode to recharge the battery [40], [41].



For battery protection and durability, the battery operating range is scheduled for 20% to 80% SOC level. The battery is charged up to 80% and discharged within 20%.

4.4 Grid connected mode

In grid connected mode, three phase V_{abc} voltage is converted into Vα, Vβ by abc to αβ transformation. Which gives the wt from the PLL. now Vα, Vβ is further converted into Ed, Eq by αβ to dq transformation. Here the control from the DC side. Current controller is used and it further again converted into V_{abcref} which is controlled the inverter by PWM technique. LCL filter is employed in suppress harmonic distortions. In grid connected mode single PID controller is used. Capacitor is utilized to keep the constant DC voltage for input of inverter. This controller is designed for the three-phase balanced load condition.

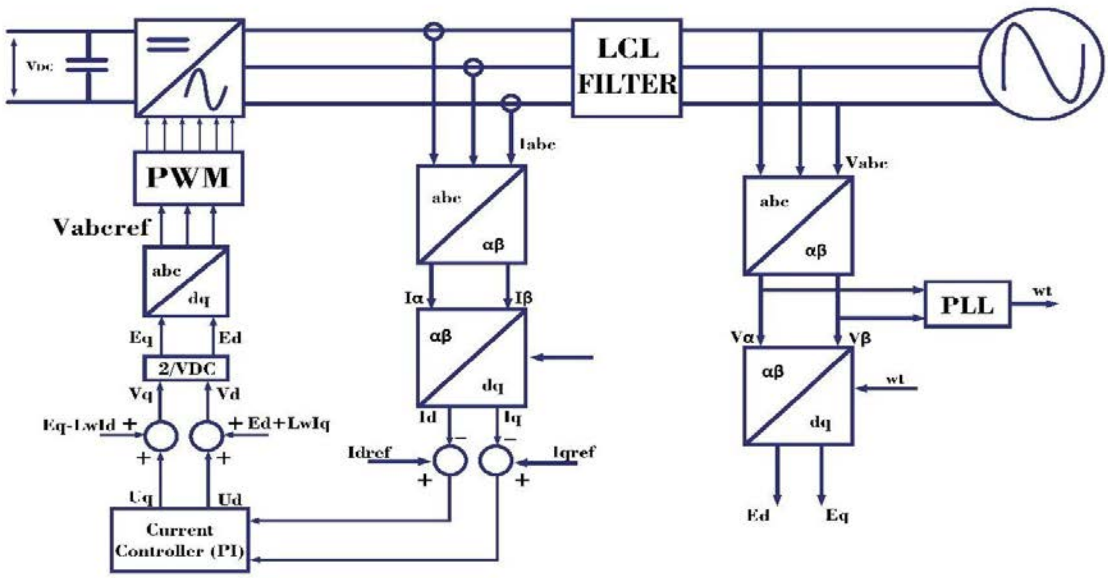


Figure 4-2:Inverter control for grid connected mode

4.5 Islanded mode

In island mode, wt should be given from the outside. here two PID controller is used. Two controller current controller and the voltage controller is used. V_{abc} is converted into V_d , V_q with injecting the wt by abc to dq transformation. For Islanding mode voltage reference is given which is denoted by V_{dref} , V_{qref} is set zero for the unity power factor. voltage controller PID produced the I_{dref} and I_{qref} which further used with I_d and I_q, error is minimized by using PID controller. Then it further converted into dq to abc transformation to generate inverter switch is control by PWM technique. V_{qref} is set zero for unity power factor mode.

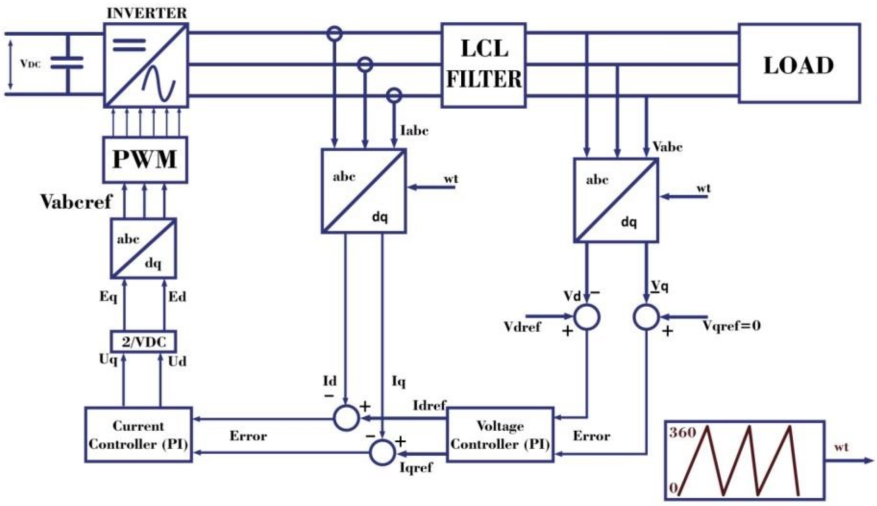


Figure 4-3:Inverter Control for islanding mode

4.6 LCL filter Modeling and Design

When building LCL filters, it's imperative to keep current ripple, filter size, and switching ripple attenuation in mind. Capacitor's effect on the grid's reactive power variation could lead to resonance, which could make the system run unsteadily. In order to achieve passive or active dampening, it is advised to change the controller architecture [20]. Because the simple inductor (L) filter only has 20 dB/decade attenuation over the full frequency range, the LCL filter is more effective [19]. The inverter switching frequency must be high enough to guarantee adequate attenuation of high current harmonics. With an increase in switching frequency, losses increase. Like the grid inductance, the resonance frequency of LC filters varies over time. As a result, they're not suitable for a shaky grid.

4.6.1 LCL filter Dynamic Analysis

For the design of an LCL filter as modeled as shown in the figure. Figure depicts the LCL filter per-phase model, in which L_1 symbol is used for inverter-side inductor, L_2 symbol is used to denote grid-side inductor, C_f denotes LCL filter capacitor, R_f is used as damping resistor, R_1 and R_2 symbol are inductor resistances, and V_i and V_g denotes the inverter input and grid voltages.

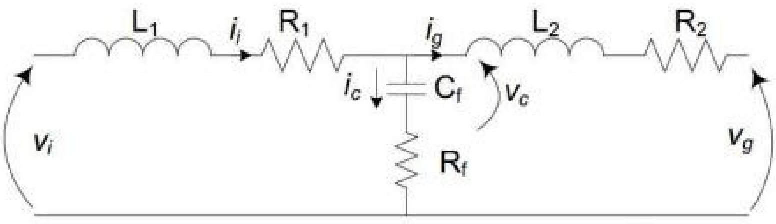


Figure 4-4:LCL filter per phase model

Three different current is appeared as here. They are known as Inverter output current, capacitor current, and grid current are represented by the currents $I_i, I_c, and\ I_g$, respectively. The LCL filter can be configured in star and delta however, star configuration is used for this research.

4.6.2 Star Connected Capacitors

The per-phase model is used to build the state space model with star connected capacitors, as shown in Figure 4-4.

$\frac{dv_c}{dt} = (i_l - i_g)/C_f$…Equation (4.1)

$\frac{di_i}{dt} = \frac{1}{l1}(V_i - V_c - R_f(i_i - i_g) - R_1 * i_i)$ …Equation (4.2)

$\frac{di_g}{dt} = \frac{1}{l_2}(V_c + R_f(i_i - i_g) - v_g - R_2 * i_g)$ …Equation (4.3)

The equations for each phase are the same since no cross couplings was found in there. Then output equation can be expressed as.

$$\begin{bmatrix} di_i/dt \\ di_g/dt \\ dv_c/dt \end{bmatrix} = \begin{bmatrix} -(R_1 + R_f)/l_1 & R_f/l_1 & -1/l_1 \\ R_f/l_2 & -(R_2 + R_f)/l_2 & 1/l_2 \\ 1/C_f & -1/C_f & 0 \end{bmatrix} \begin{bmatrix} i_i \\ i_g \\ v_c \end{bmatrix} +$$

$$\begin{bmatrix} 1/l_1 & 0 \\ 0 & -1/l_2 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} v_i \\ v_g \end{bmatrix}$$…Equation (4.4)

4.6.3 Design Procedure

This study has described the filter design technique step by step. If suitably damped, resonance issues can be avoided [19]. The technique for establishing the LCL filter settings takes into account the converter's power rating, the grid operating frequency, and the set switching device frequency. Each stage of the LCL filter design method is discussed in the parts that follow and is validated by a filter design.

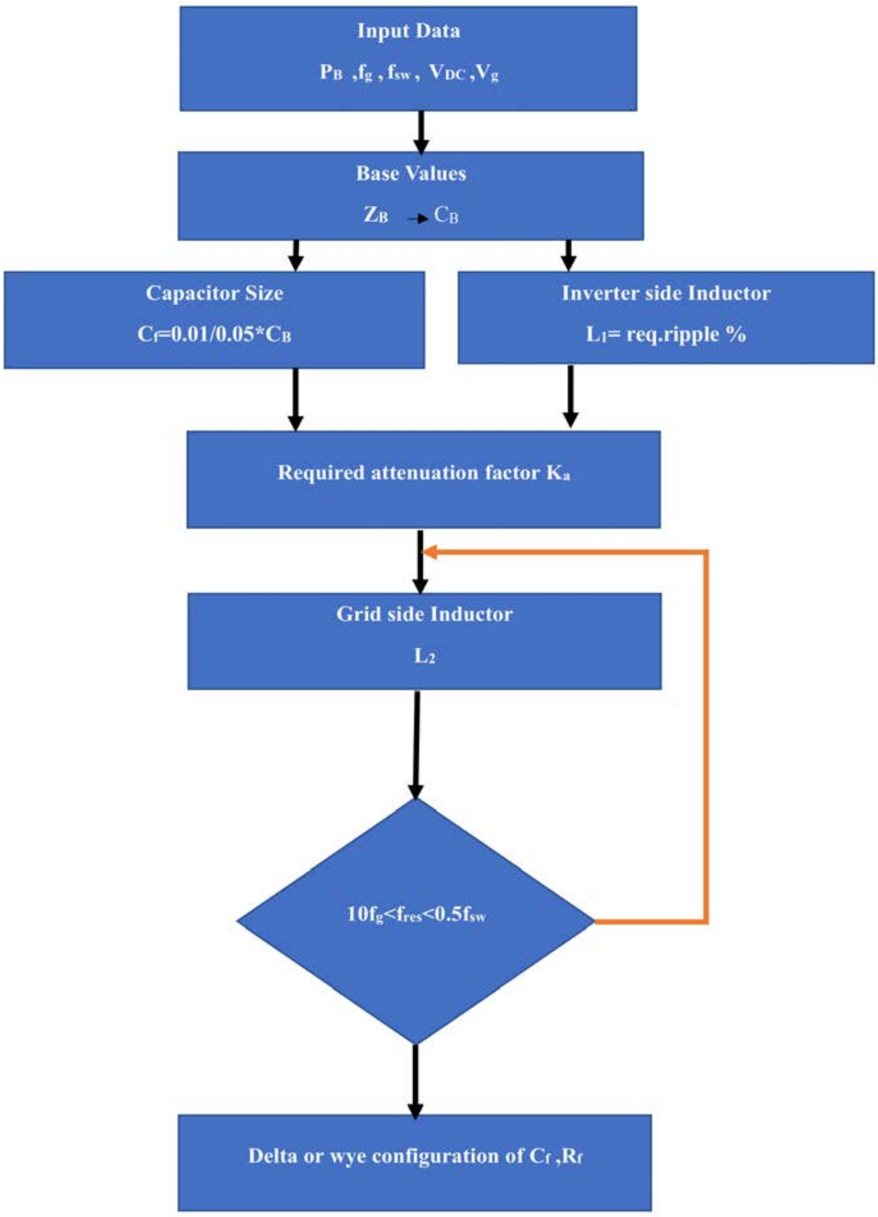


Figure 4-5:LCL filter algorithm

Equations following define the base impedance in equation (4.5) and base capacitance in equation (4.6). As a result, in terms of the base values, the filter values can be expressed as a percentage:

$Z_b = \frac{V_{ll}^2}{p_n}$.... Equation (4.5)

$C_b = \frac{1}{wnz_b}$.... Equation (4.6)

The greatest power factor fluctuation perceived by the grid is estimated to be 5% when the value of the system's base impedance is multiplied by $C_f = 0.05C_b$ for the filter capacitance design. It's worth noting that factors more than 5% can be employed because they compensate for the inductive reactance designed for the inductors on the filter, resulting in a smaller impact on the system's power factor than expected. The ripple current at a DC/AC inverter's output is

$\Delta I_{lmax} = \frac{2V_{DC}}{3L_1}(1-m)mT_{sw}$...Equation (4.7)

Here,

m is used as the symbol of modulation factor.

At m = 0.5, the highest peak to peak current ripple is recorded, followed by

$\Delta I_{lmax} = \frac{V_{DC}}{6f_{sw}L_1}$.... Equation (4.8)

Where L_1 is the symbol for inductor on the inverter side. For design specifications, 10% is consider as the ripple current of the rated current is provided by

$\Delta I_{Lmax} = 0.1I_{max}$.... Equation (4.9)

$I_{max} = \frac{p_n\sqrt{2}}{3V_{ph}}$.... Equation (4.10)

$L_1 = \frac{V_{DC}}{6f_{sw}\Delta I_{Lmax}}$...Equation (4.11)

In this case, lowering the projected current ripple limit and reducing harmonics are the main objectives of this design. To reduce the ripple in LCL filter, it is initially investigated using an inverter. The relationship between inverter and grid current is given by the following relation:

$\frac{i_g(h)}{i_i(h)} = \frac{1}{[1+r[1-l_1 C_b w_{sw}^2 x]]} = Ka$…. Equation (4.12)

$L_2 = \frac{1+\sqrt{\frac{1}{K_a^2}}}{C_f w_{sw}^2}$…. Equation (4.13)

Here, K_a is attenuation. $C_f = 0.01/0.05C_b$

The relationship between inductance of two side given by the relation introducing the constant r.

$L_2 = rL_1 \ldots eqn$ (4.14)

The resonant frequency of the system is given by the relation

$W_{res} = \frac{l_1+l_2}{2l_1 l_2 C_f}$…. Equation (4.15)

$10f_g < f_{res} < 0.5f_{sw}$……Equation (4.15)

To satisfy Equation, the resonance frequency must be checked. The parameters should be re-chosen if they don't work.

$R_f = \frac{1}{3w_{res}C_f}$…. Equation (4.16)

4.7 PID Controller Tuning

4.7.1 Conventional Method of Tuning

Controller tuning is traditionally based on trial and error. This makes it difficult to use in many situations. Due to this method necessitates continual adjustment of parameter values and observation of the reaction. This takes a lot of time and effort and is laborious There is no guarantee that the outcome produced after so much variance will be the best. That indicates that all of the time and effort put into a particular problem will be in vain. All of these flaws urge us to use more advanced strategies to achieve the best results.

4.7.2 Particle Swarm Optimization

R.C. Eberhart and James Kennedy and developed (PSO) in 1995. In order to explore the search space, a stochastic (random variable connection) evolutionary computation method is applied. This approach is based on swarm behavior and intelligence. This method, based on swarm behavior, uses a population-centric strategy. The birds often follow the quickest path when seeking food. On the basis of this behavior, this algorithm was developed. Each of the many particles it uses is a point in N-dimensional space. Based on its comprehension of the appreciable answer and by comparing its best value to the swarm's best value up to that point, each particle moves faster in the search space. It is well described by the idea of social interaction since each particle searches in a certain direction and by engaging with the bird that is now at the optimal spot, they attempt to reach that location by adjusting their velocity.

Advantages of PSO

Few settings require such simple adjustments. PSO does not use the survival of the fittest, implying that the entire population is involved in the process. In contrast to GA, PSO is unaffected by the magnitude of the problem. PSO overcomes the fault of GA, namely premature convergence. Because it only has two equations, it's quite simple to put into practice. Even huge problems require fewer than a hundred repetitions.

Velocity modification equation:

$V_i^{k+1} = vw_i^k + c_1 rand_1 * (p_{besti} - s_i^K) + c_2 rand_2 * (g_{besti} - s_i^k)$ ....Equation (4.17)

Where, v^k = velocity of agent i at iteration k

w =weighing function

c_i =weighing factor $rand_i$ =random number generated in between 0-1 p_{besti} =p-best of available agent i s_i^k=current position of agent i at iteration k g_{besti} =g-best of the group

The first term, wv^k, refers to the component of inertia that causes a particle to move in the same direction it was before. If the value of ‘w' is low, the convergence will be sped up; otherwise, exploration will be encouraged.

Second term:

$c_1 rand_1 * (pbest_i - s_i^k)$ …, Equation (4.18)

This cognitive element serves as the particle's memory.

Third term

$c_2 rand_2 * (gbest_i - s_i^k)$ …. Equation (4.19)

The social component, which explains why the particle moves to the best region the swarm has discovered thus far. each particle position can be updated using the equation of position modification after the velocity of each particle has been computed.

Position modification equation:

$s_i^{k+1} = s_i^k + v_i{}^{k+1}$......Equation (4.20)

Where s_i^k, s_i^{k+1} ,

Current search points and modified search points.

$v_i{}^{k+1}$ =Modified velocity

Unless and until specified halting requirements are met, the process is repeated.

4.7.3 Flow chart for PSO Algorithm.

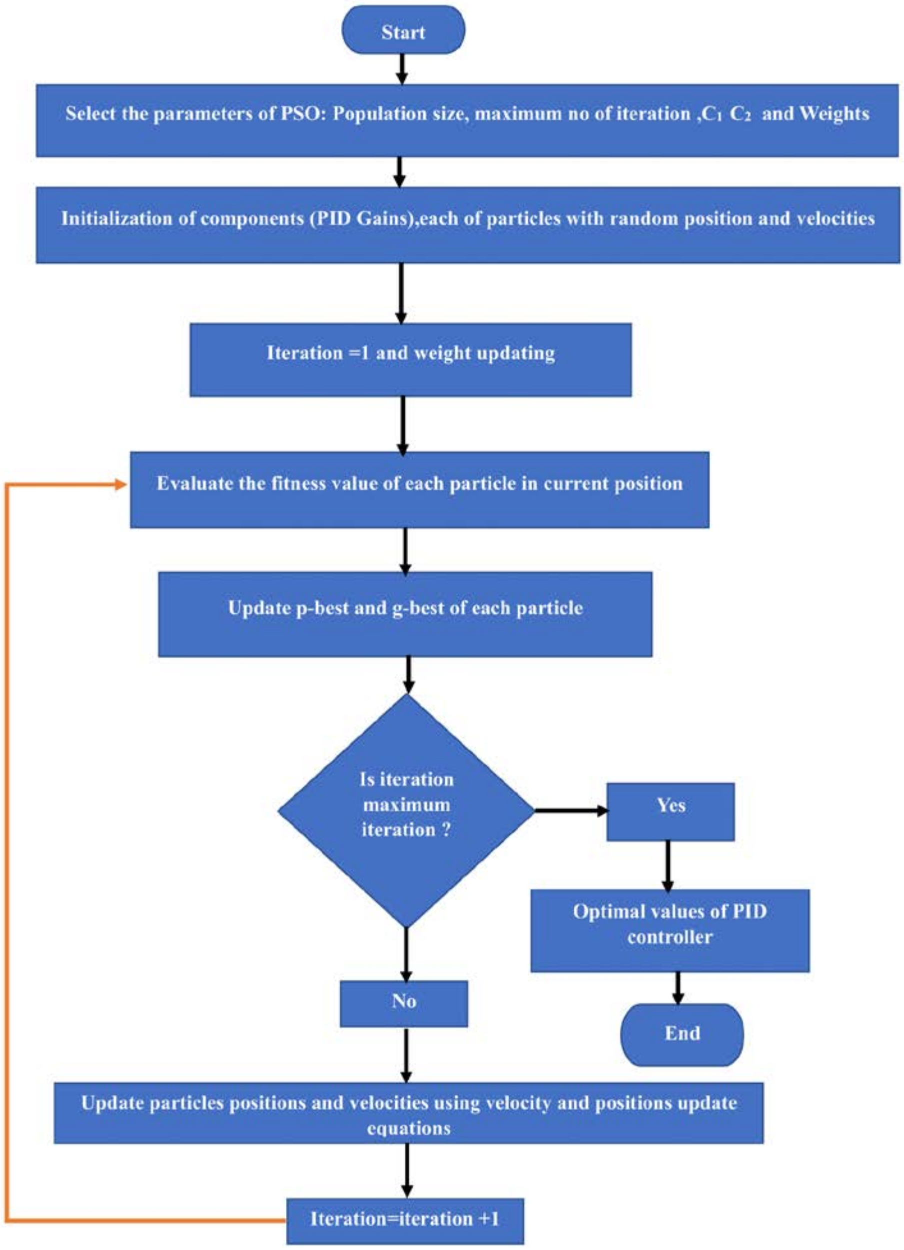


Figure 4-6:flowchart for PSO algorithm

4.7.4 Algorithm

Step1: The initial particles are set to some linear position in the range of Kp, Ki and Kd

Step2: Their Velocities are set to zero

Step3: Initial ITAE is set to some values

Step4: Evaluate the ITAE for the particles at their corresponding positions

Step5: Initialize Pbest for each particle.

Step6: Find Gbest based on minimum ITAE

Step7: Start iteration 1

Step8: Update the positions.

Step9: Calculate ITAE at their corresponding position.

Step10: Accordingly update Pbest and gbest based on ITAE

Step11: update velocity

Step12: Iteration= iteration +1

Step13: IF iteration <=maximum iteration, go to step 8 otherwise continue.

Step14: The obtained gbest is the optimum set of parameters of PID controller.

CHAPTER 5: RESULT & DISCUSSION

The micro grid model uses a battery storage system, wind energy, and solar photovoltaic. Where two of them solar and wind are intermittent and unpredictable, uncontrolled distributed generations. Lithium-ion battery was used for the Storage system. Micro grid model is developed and simulated in MATLAB 2021Ra and simulated for the 7 seconds. Two distinct situations were created to test the performance of the micro grid.

(i) Islanded Mode

(ii) Grid feeding mode

Result obtained in a MATLAB simulation was described as follows.

5.1 PV output

The PV output voltage is in the range of 260V to 275V. Here the output current is in the range from 78 A to 48 A. Due to the irradiance range from 1000 to 600 **W/m^2**, MPPT is done and variable power is obtained in the range of 13KW watt to 21KW. In this research the temperature variation range is 20 to 30 degrees Celsius. The Vector of irradiance [1000 1000 800 800 700 700 750 750 600 600] and Vector of time [0 2.000 2.00000001 3.000 3.00000001 4.000 4.00000001 5.000 5.0000000001 7.0] was setting in order to reflect the practical situations. For the temperature variations the Vector of temperature [20 20 25 25 25 30 30 30 22 22]. Was setting corresponding to Vector of Time [0 2.000 2.00000001 3.000 3.00000001 4.000 4.00000001 5.000 5.0000000001 7.0].

From the obtained results, it shows that an increase in irradiance results in an increase in voltage, current and power respectively. However, the solar panel output current increases exponentially as temperature rises. In contrast, the output voltage of the solar panel decreases linearly since the reduction in voltage is more significant than the increase in current. As a result, the solar cell's output power decreases as the temperature rises. When the temperature rises by 1°C, solar photovoltaics' energy conversion efficiency decreases by 0.3%.

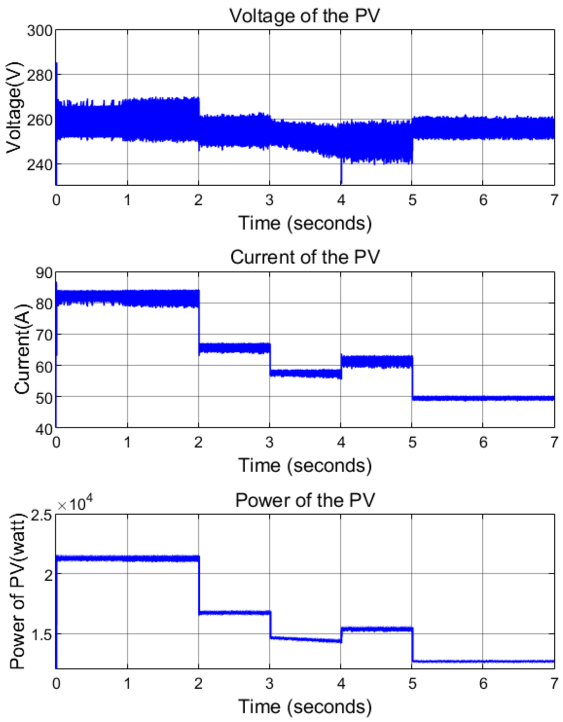


Figure 5-1:PV output

The PV module consists of 14 parallel string and series connected module per string in series was 6. The maximum power obtained per module was 249.952 watt. The obtained maximum power point voltage and current was 42.8V and 5.84A.

5.1.1 Wind output

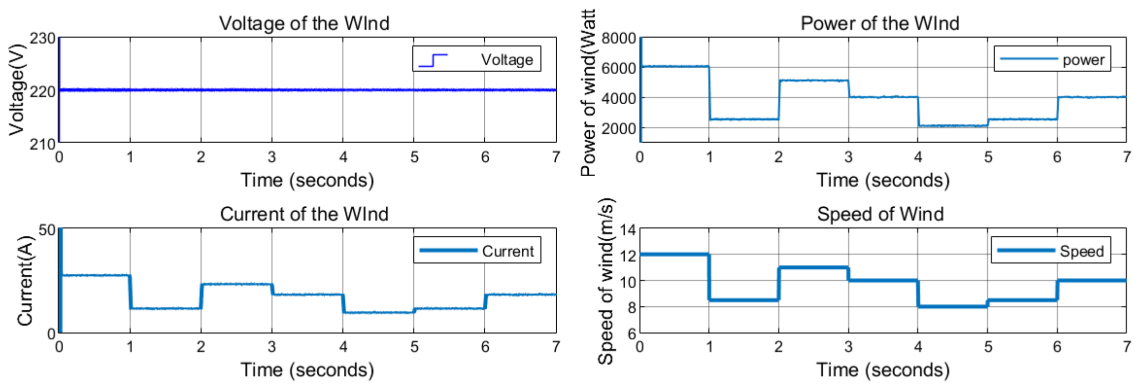


Figure 5-2:Wind Output

Wind power is changed corresponding to the change in wind speed. When the wind speed is changed, current is changed as a result wind power is changed. Here wind speed was changed in the range of 8-12 m/s and obtained corresponding power 2KW to 6KW were as show in figure 5-2: Wind output. The nominal mechanical output power was 30watt.The base generator speed was 1.2 pu. The start or phase resistance and armature inductance was 0.048 ohm and 0.00016 Henrry. The turbine power characteristics with different wind speed from 5m/s to 11m/s was observed as shown figure 5-3 below.

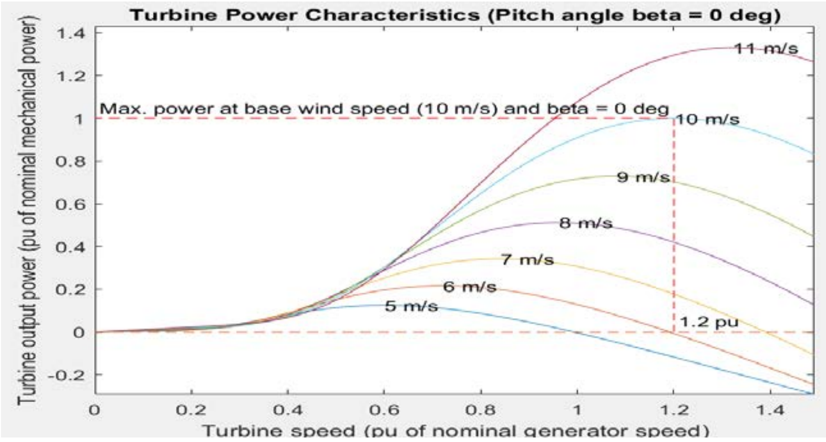


Figure 5-3:Turbine output with different speed

5.1.2 Battery output

The voltage of the battery is 48V DC-DC converter is used to regulate the DC voltage. The negative power in the battery signifies that battery absorbs the power and battery is charging. No temperature effect and aging effect are considered in simulation. The increase in SOC of the battery indicates that the battery was in charging condition and its stores the energy. The rated capacity of battery was 420Ah.for this research experiment initial state of charge was 50% and battery response time was 0.1 sec. The battery cut off voltage was 36V and fully charged voltage was 55.8714V and nominal discharge current was 182. 6087A.The exponential zone voltage and current capacity was 51.8585V and 20.6348AH.

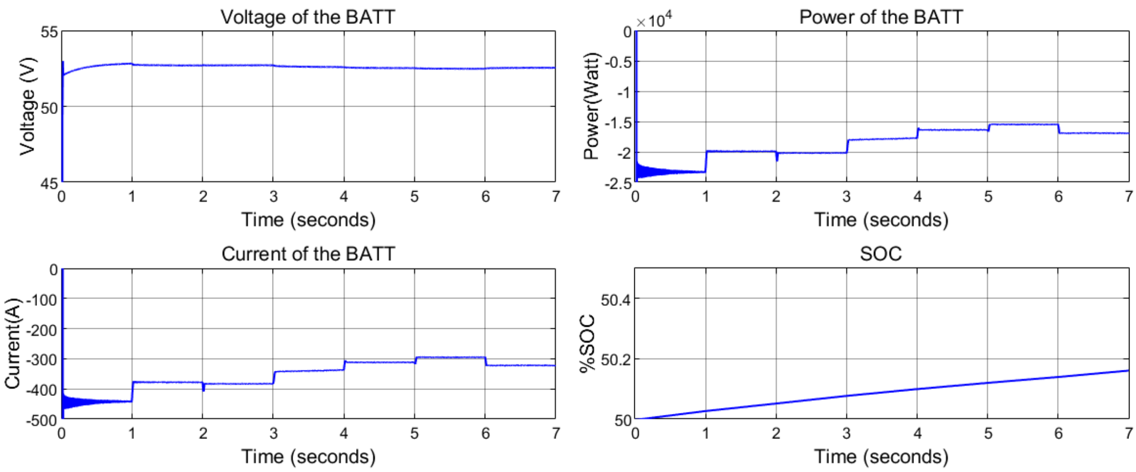


Figure 5-4:Battery Output

5.2 Islanded mode

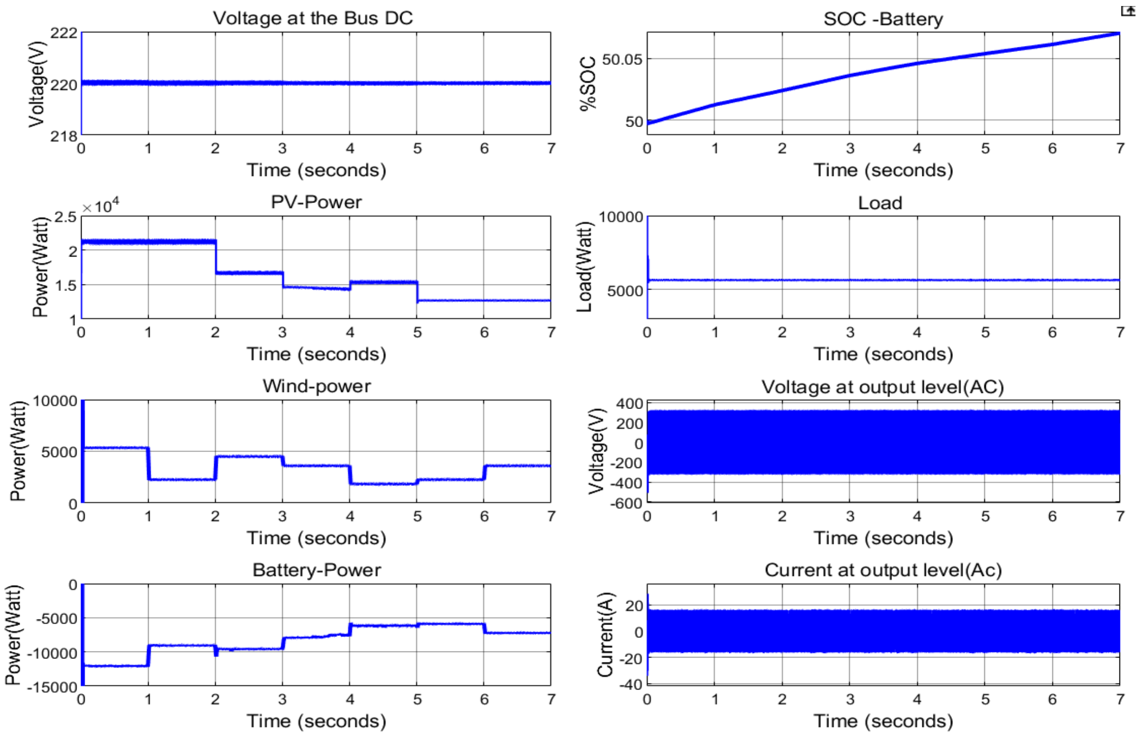


Figure 5-5:Islanded mode with battery charging

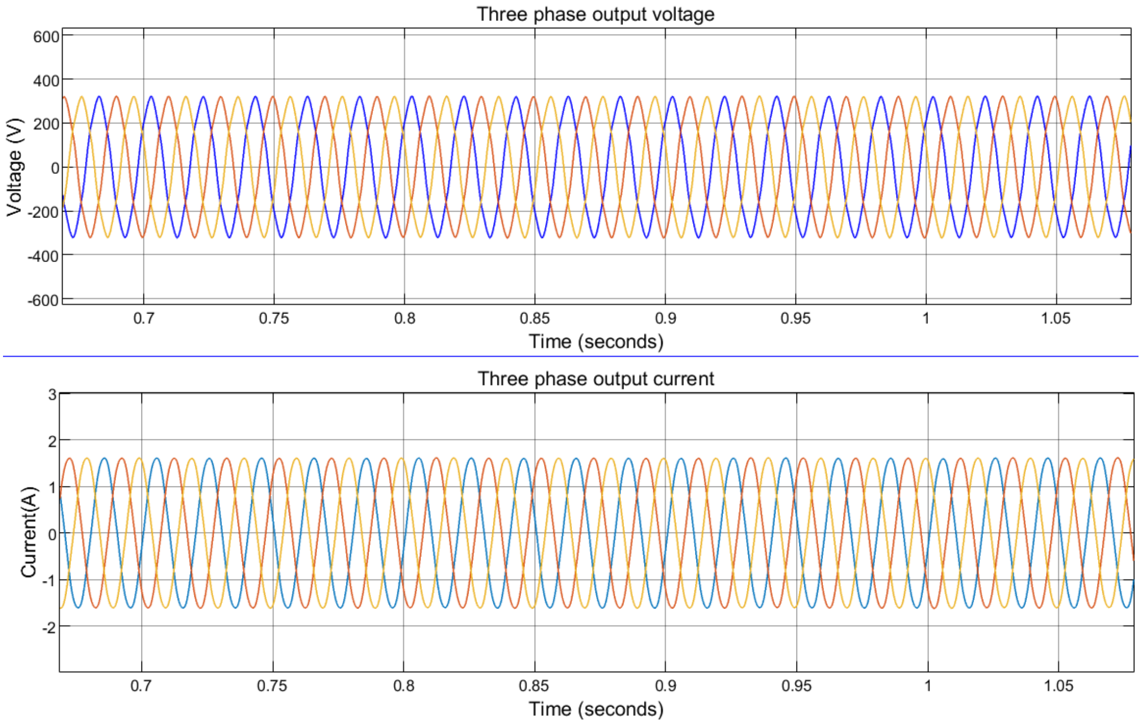


Figure 5-6:Output AC voltage and current waveform

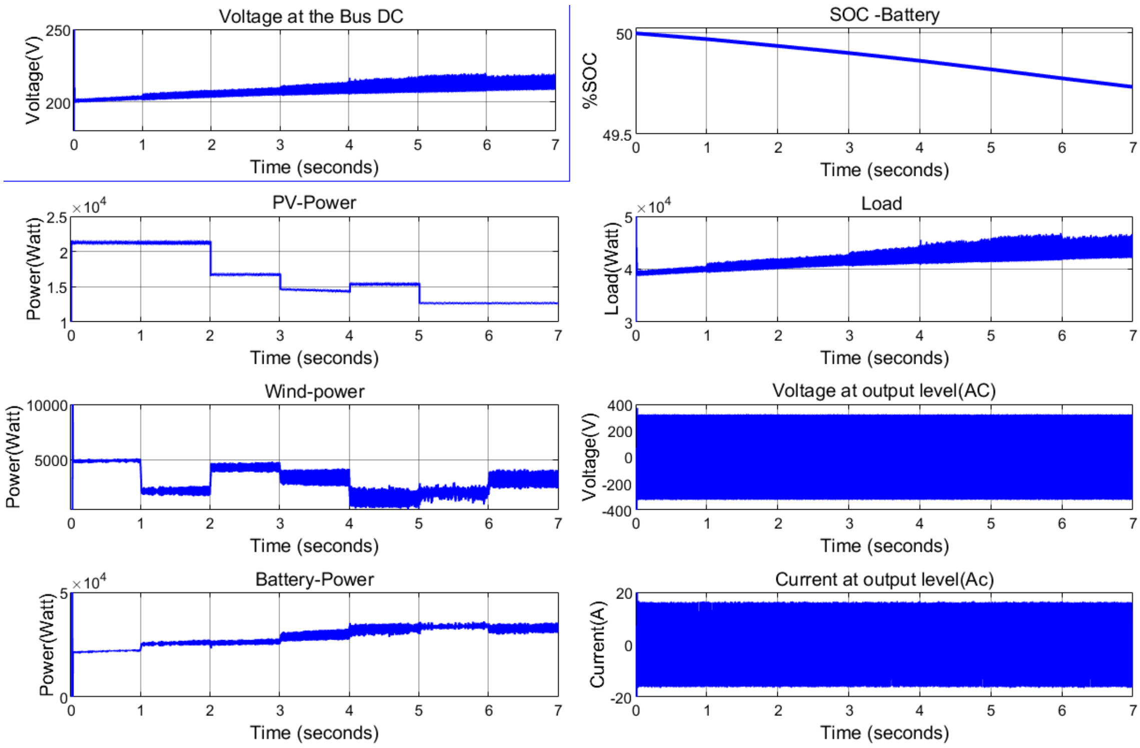


Figure 5-7:Islanding mode battery discharging condition

In islanding condition, when load is greater than generation, in such a case power is maintained by storage system. In figure, the positive power on battery shows that it delivers the power to the load and SOC of the battery is decreasing with time. This figure clearly illustrates that, when generation is high, battery supplied is low and overall, it maintains the load power. When generation is low, battery delivers the high power to maintain the power balance

$$P_{pv} + P_{wind} + P_{batt} = P_{load}$$

$$P_{gen} + p_{storage} = P_{load}$$

Where,

$$P_{gen} = P_{pv} + P_{wind}$$

$$P_{storage} = P_{batt}$$

5.2.1 Different load conditions

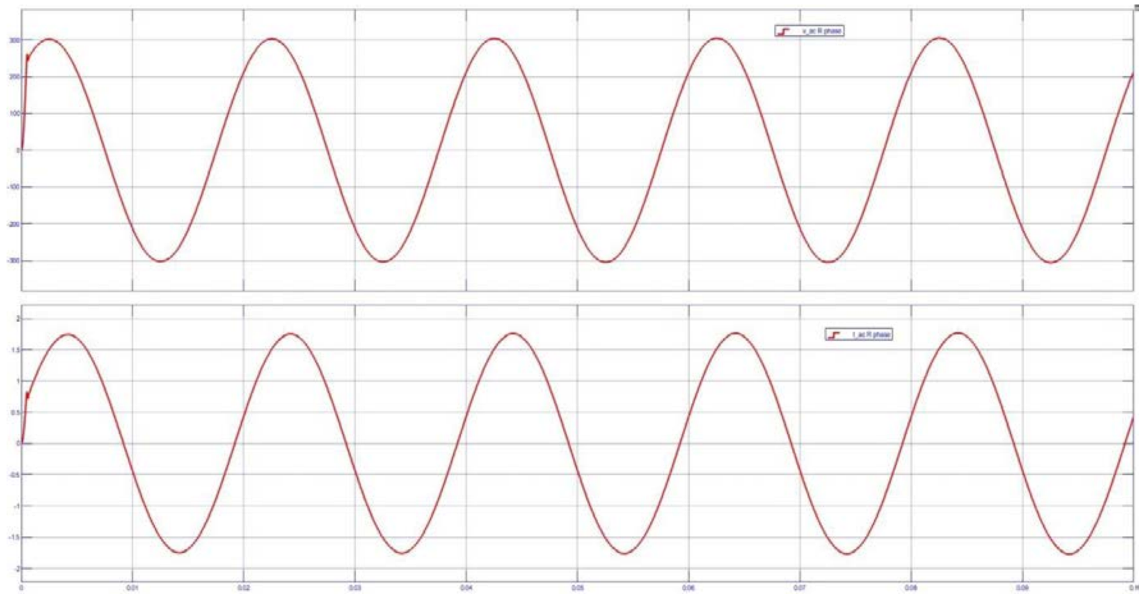


Figure 5-8:output waveform (voltage and current) at load 1

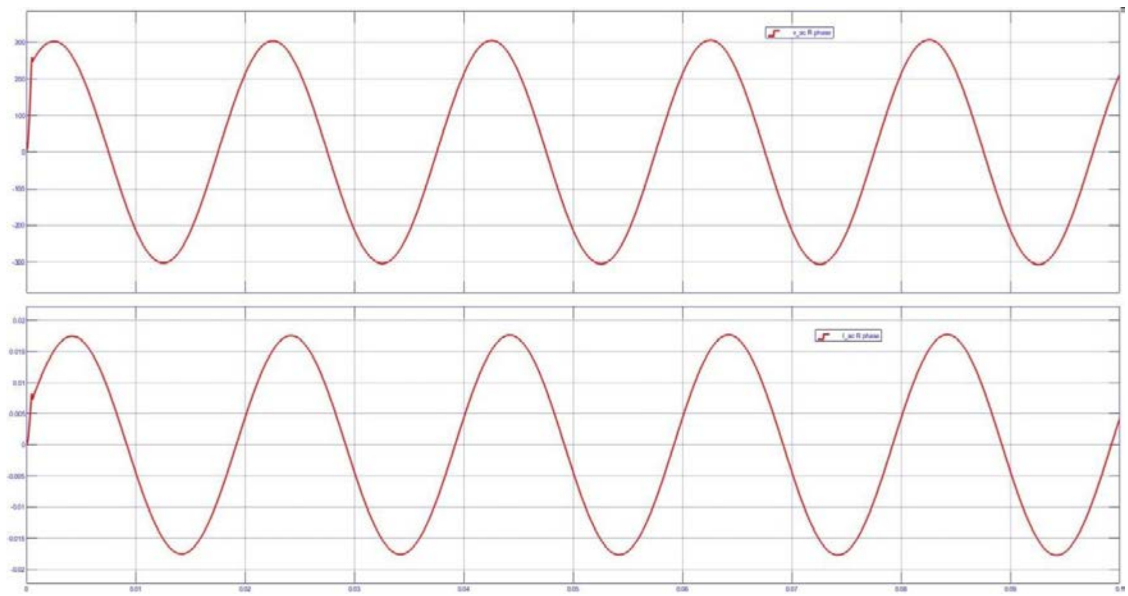


Figure 5-9:output waveform (voltage and current) at load 2

In grid forming mode, the DC bus voltage is maintained at 220V, which is fluctuating in the range from 119.6 to 220.8 with production and load varies with time. The output of AC voltage is rms 230 V. The negative power in battery shows that it absorbs the power and SOC of the battery is increased. Battery is charged. The output voltage and current at two different load conditions are shown in figure 5-8 and 5-9.

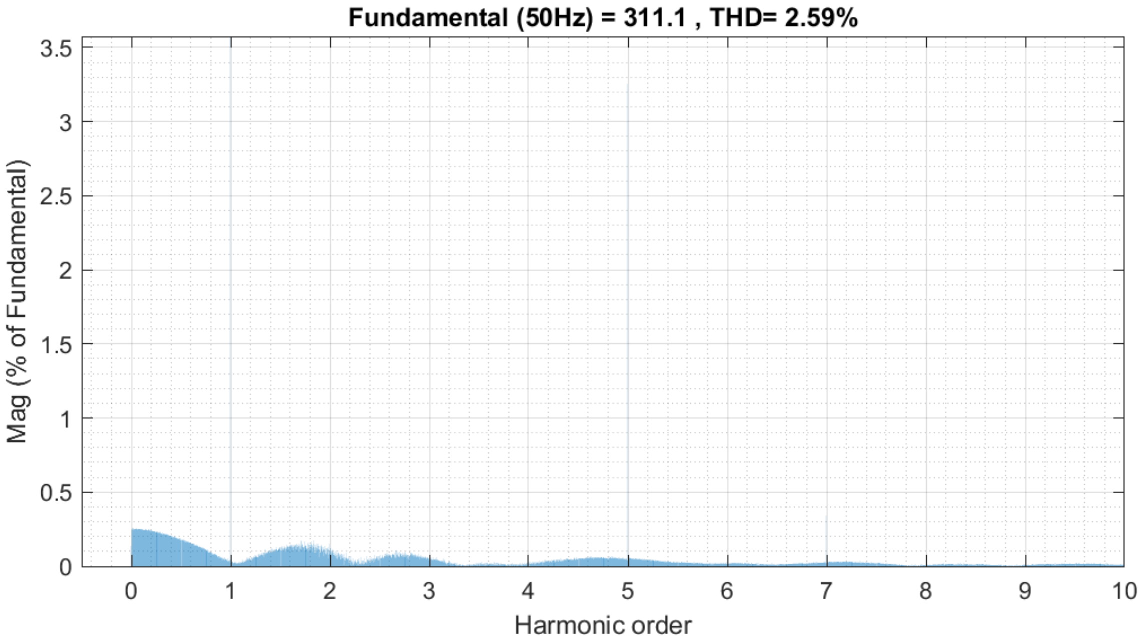


Figure 5-10:THD for Islanded mode

In islanded mode, total harmonic distortion (THD) was found to be 2.59 % in current waveform. Which is acceptable as per IEEE standard and it assures the quality power to the load. The different level of harmonic order is shown in figure 5-10.

5.3 Grid feeding mode

This was a case where some amount of power was fed to the grid and the battery was also charged. Negative power in the battery indicates that it absorbs power. In charging conditions, the SOC of the battery increases with time. We saw that battery SOC was increased to 50.2 from 50 within in 7 seconds. The bus voltage at DC bus was maintained at 220V. The figure illustrates DC bus voltage, power output from PV, wind systems, battery saturation, and feeding grid voltage and current.

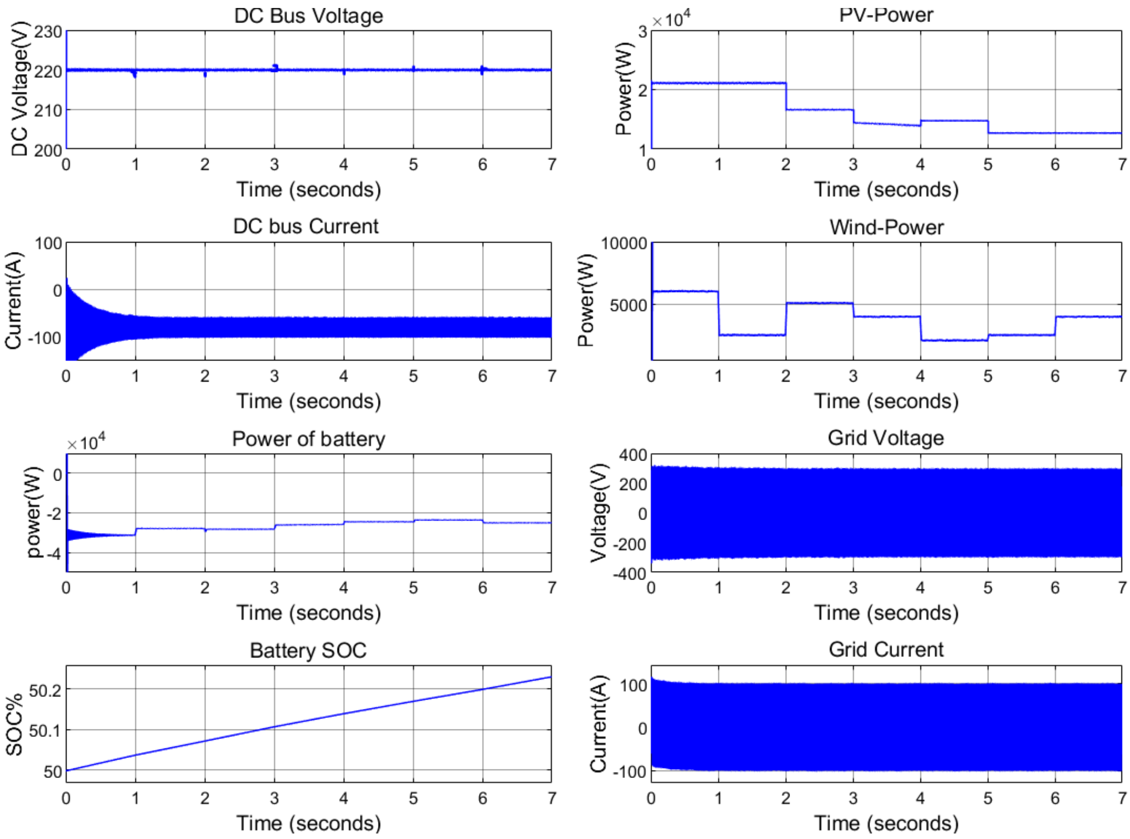


Figure 5-11:Grid Feeding mode

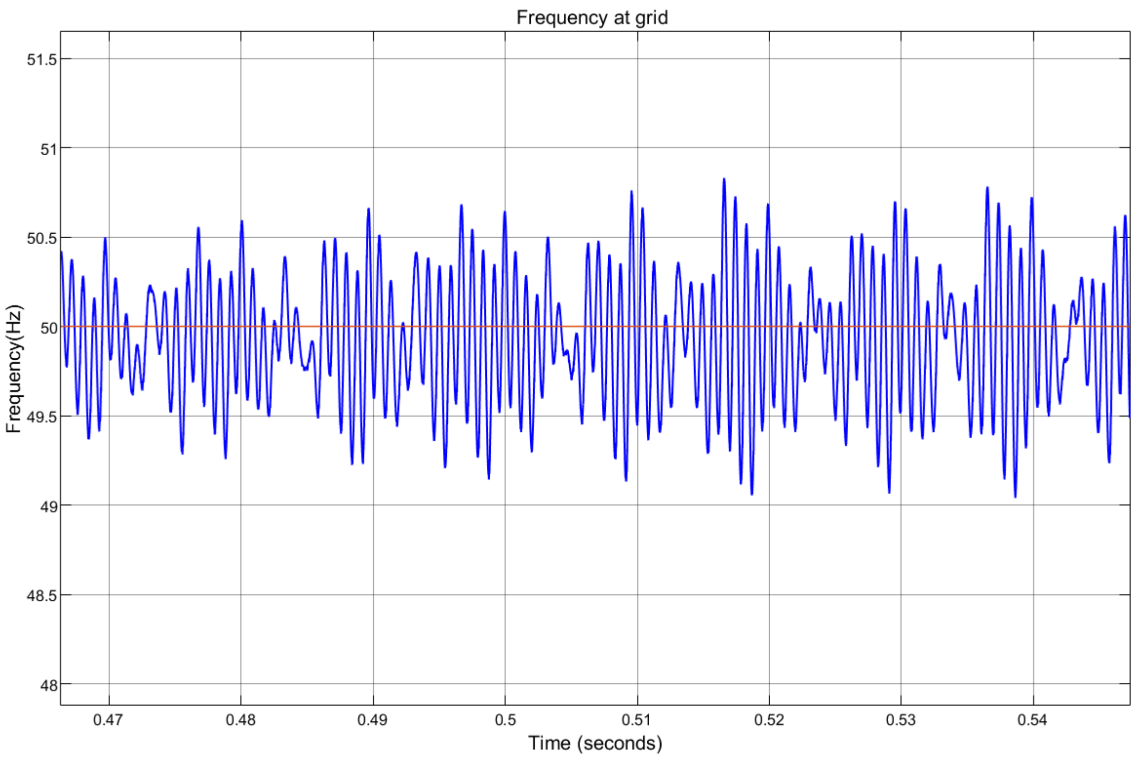


Figure 5-12:Frequency Output

In grid feeding condition, the reference frequency for the grid was 50 Hz. From the simulation it values was fluctuating in the range of 49.30 to 50.60 Hz due to change in generations and load.

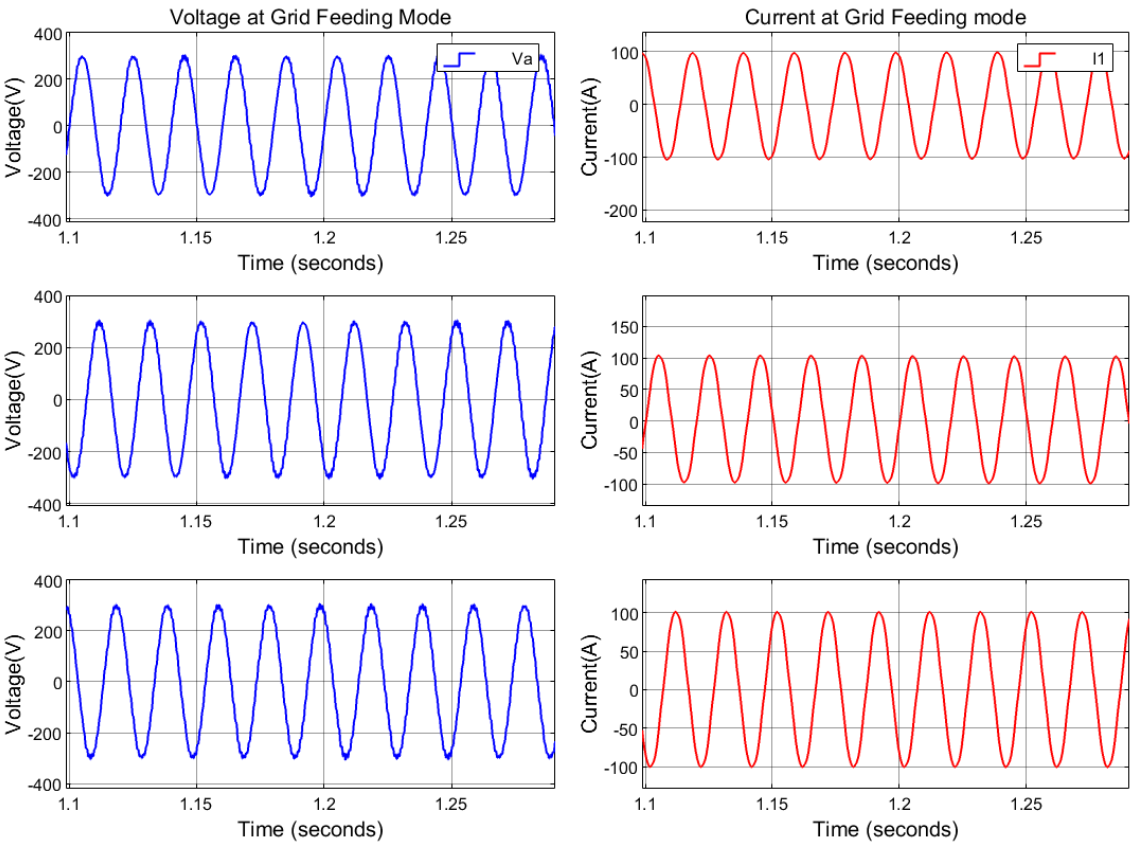


Figure 5-13:Grid Voltage and Current

Output grid voltage and current was found to be in phase and the three-phase voltage is perfectly sinusoidal. The RMS voltage is 230.2V and 100A current is feeding to the grid. The figure 5-13 illustrate the voltage and current waveform.

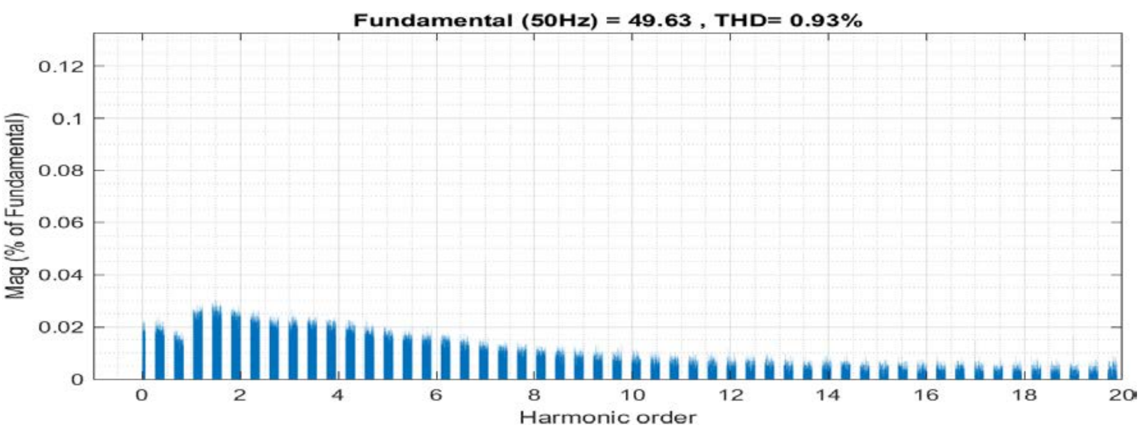


Figure 5-14:THD for Grid current

The total harmonic distortion (THD) was found to be 0.93% in current waveform in grid feeding mode which is acceptable ae per IEEE standard. The quality power was ensured to the load and DC bus voltage at 220V was maintained. The perfect sinusoidal waveform was observed in inverter. The PID parameters were perfectly tuned by using the bio inspired metaheuristic technique.

5.4 Summary of Result:

The result was successfully tested from the designed model. A 20KW micro grid was developed consisting of three different sources solar photovoltaic, wind energy and electrochemical energy storage system. Battery storage systems with high energy density are used. Solar photovoltaic input variations were irradiance and temperature and varied from 600-1000W/m2 and temperature variations 20-30°C. It was found that the output power was 13KW to 21KW. Wind speeds varied between 8-12m/s and the power output were 2KW to 6KW. 420Ah lithium-ion batteries were used in this experiment. The battery aging effect is neglected. A bi-directional converter regulates DC bus voltage. The load variations were 5KW to 45KW. Two different cases of islanded and grid feeding have been successfully tested. The measured THD level is 2.43% for islanded mode and 0.93% for grid feeding mode. DC bus voltage is 220V. In this way, the micro grid model was successfully built, analyzed, and presented. The load sharing between the sources was monitored and optimized. The system was able to maintain bus voltage within a range of ±2%. Results obtained from this system were satisfactory and in line with the desired performance.

CHAPTER 6: CONCLUSIONS

6.1 Conclusions

Design of a DC micro grid that can function in both grid feeding and isolated modes is completed in this thesis. Through analysis, simulation, and investigations, this research has been successfully completed. Simulation results justify the research and its overall objective.

A 20KW micro grid consisting of solar photovoltaics, wind energy, and battery storage systems was successfully developed in this research. In order to ensure the maximum power output from the source, the P & O Maximum power point tracking method was successfully applied. For battery storage, a bi-directional converter was used. The DC bus voltage was regulated at 220V and maintained the IEEE Standard with generation and load variations. 100 KVA voltage source inverter was used to feed power to the three-phase load. Dual inner current control and outer voltage control method with LCL filter was successfully implemented to ensure the power quality to load as per IEEE standard.

DC Micro grids have been developed with a control strategy and stability analysis. Such systems require complex control strategies and power flow management. A hierarchical control system that maintains the stability of all variables in the current situation's DC bus voltage. Synchronous Reference frame theory with d-q Control algorithm with islanded mode and grid feeding mode has been successfully implemented. Bio inspired metaheuristic algorithm (PSO algorithm) was successfully implemented for PID tuning.

we have described the MATLAB simulation results for designed Micro grids to confirm and validate the results. The outputs for various models are analyzed, discussed and presented and this result mitigate the objective as we defined.

From this presented research dissertation on Micro grids leads the conclusion that Micro grid islanded mode is possible with satisfying power quality issue and stability perspective. Storage device is more important due to the fact that Micro grids controllable DG sources have low inertia and there is slow ramp-up –rates and in the case of uncontrollable DG sources for power balance operation. The perfect combination of inverter mode is necessary for the islanded operation. The storage devices will continue to inject power into the MG even if there are no controlling micro sources there. This is done until their energy is consumed and a blackout occurs. The research shows that no single Distributed Generation is suitable for Micro grids.

In today's fossil fuel scarcity, this research promotes using renewable energy to make a micro grid. Furthermore, it helps leapfrogging sustainable development by using natural resources that are clean, green and have low carbon footprints. Moreover, it illustrates how to control the micro grid in both conditions to minimize upstream faults and power outages. It opens the door to the concept of net zero energy consumption and of consumers themselves as producers. Thus, the research's overall objectives have been achieved through this research.

6.2 Future scope

In this topic further advancement of research like frequency resynchronization time comparison with one, controllable DG sources, one two or more. From another aspect, the dynamic behavior of the MG under various disturbance conditions, including single micro source failures, load following, unequal loads, and faults in MG feeders, compare the PID tuning of different conventional algorithm with newly developed Artificial Bee Colony (ABC) algorithm, and many more is possible. Furthermore, there is a scope for real field implementation of this research because this research was simulated in MATLAB software.

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APPENDIX

Code:MPPT for PV function

```
duty      =      MPPT(vpv,ipv)
duty_init=0.1;    duty_min=0;
duty_max=0.95; pas=0.001;
persistent Vold Pold duty_old; if
isempty(Vold)     Vold=0;
Pold=0;     duty_old=duty_init;
end P=vpv*ipv; dV= vpv-Vold; dP=
P-Pold; if dP~=0      if dP<0
if dV<0              duty =
duty_old -pas;          else
duty= duty_old + pas;          end
else         if dV<0
duty = duty_old + pas;
else                 duty =
duty_old-pas;          end
end else     duty=duty_old; end
if duty >= duty_max     duty=
duty_max; else if duty<duty_min
duty=duty_min;     end end
duty_old=duty;
Vold=vpv;
Pold=P;
```

Mppt for wind

```
function
duty =
MPPT(vpv
,ipv)
duty_ini
t=0.1;
duty_min
=0;
duty_max
=0.99;
pas=0.00
1;
persistent Vold Pold duty_old;
if isempty(Vold)     Vold=0;
Pold=0;     duty_old=duty_init;
end P=vpv*ipv; dV= vpv-Vold; dP=
P-Pold; if dP~=0      if dP<0
if dV<0              duty =
duty_old -pas;          else
duty= duty_old + pas;          end
else         if dV<0
duty = duty_old + pas;
else                 duty =
duty_old-pas;          end
end else     duty=duty_old; end
if duty >= duty_max
duty= duty_max; else
if duty<duty_min
duty=duty_min;
end end
duty_old=duty;
Vold=vpv;
```

```
Pold=P;
```

Code for PSO algorithm: for PID control

```
%
% Copyright Er.Yam Krishna poudel
%    function out = PSO(problem,
params)

    %% Problem Definiton

    CostFunction = problem.CostFunction;  % Cost Function

    nVar = problem.nVar;          % Number of Unknown (Decision) Variables     VarSize
= [1 nVar];          % Matrix Size of Decision Variables

    VarMin = problem.VarMin;     % Lower Bound of Decision Variables
    VarMax = problem.VarMax;     % Upper Bound of Decision Variables


    %% Parameters of PSO

    MaxIt = params.MaxIt;    % Maximum Number of Iterations
      nPop = params.nPop;      % Population Size (Swarm
Size)

    w = params.w;            % Intertia Coefficient
    wdamp = params.wdamp;    % Damping Ratio of Inertia Coefficient
c1 = params.c1;          % Personal Acceleration Coefficient
c2 = params.c2;          % Social Acceleration Coefficient
    % The Flag for Showing Iteration Information
    ShowIterInfo = params.ShowIterInfo;

    MaxVelocity = 0.2*(VarMax-VarMin);
    MinVelocity = -MaxVelocity;

    %% Initialization

    % The Particle Template
empty_particle.Position = [];
empty_particle.Velocity = [];
empty_particle.Cost = [];
empty_particle.Best.Position = [];
empty_particle.Best.Cost = [];

    % Create Population Array
    particle = repmat(empty_particle, nPop, 1);

    % Initialize Global Best
    GlobalBest.Cost = inf;

    % Initialize Population Members
for i=1:nPop
```

```
        % Generate Random Solution         particle(i).Position
= unifrnd(VarMin, VarMax, VarSize);
        % Initialize Velocity
        particle(i).Velocity = zeros(VarSize);

        % Evaluation
        particle(i).Cost = CostFunction(particle(i).Position);
        % Update the Personal Best
        particle(i).Best.Position = particle(i).Position;
particle(i).Best.Cost = particle(i).Cost;

        % Update Global Best         if
particle(i).Best.Cost < GlobalBest.Cost
GlobalBest = particle(i).Best;         end

    end

    % Array to Hold Best Cost Value on Each Iteration
    BestCosts = zeros(MaxIt, 1);


    %% Main Loop of PSO
      for
it=1:MaxIt
          for
i=1:nPop

            % Update Velocity             particle(i).Velocity =
w*particle(i).Velocity ...                  +
c1*rand(VarSize).*(particle(i).Best.Position -
particle(i).Position) ...
                + c2*rand(VarSize).*(GlobalBest.Position -
particle(i).Position);

            % Apply Velocity Limits            particle(i).Velocity =
max(particle(i).Velocity, MinVelocity);            particle(i).Velocity
= min(particle(i).Velocity, MaxVelocity);

            % Update Position
            particle(i).Position = particle(i).Position +
particle(i).Velocity;

            % Apply Lower and Upper Bound Limits
            particle(i).Position = max(particle(i).Position, VarMin);
particle(i).Position = min(particle(i).Position, VarMax);
            % Evaluation
            particle(i).Cost = CostFunction(particle(i).Position);
            % Update Personal Best
            if particle(i).Cost < particle(i).Best.Cost

                particle(i).Best.Position = particle(i).Position;
particle(i).Best.Cost = particle(i).Cost;
                % Update Global Best                 if
particle(i).Best.Cost < GlobalBest.Cost
                    GlobalBest = particle(i).Best

end
```

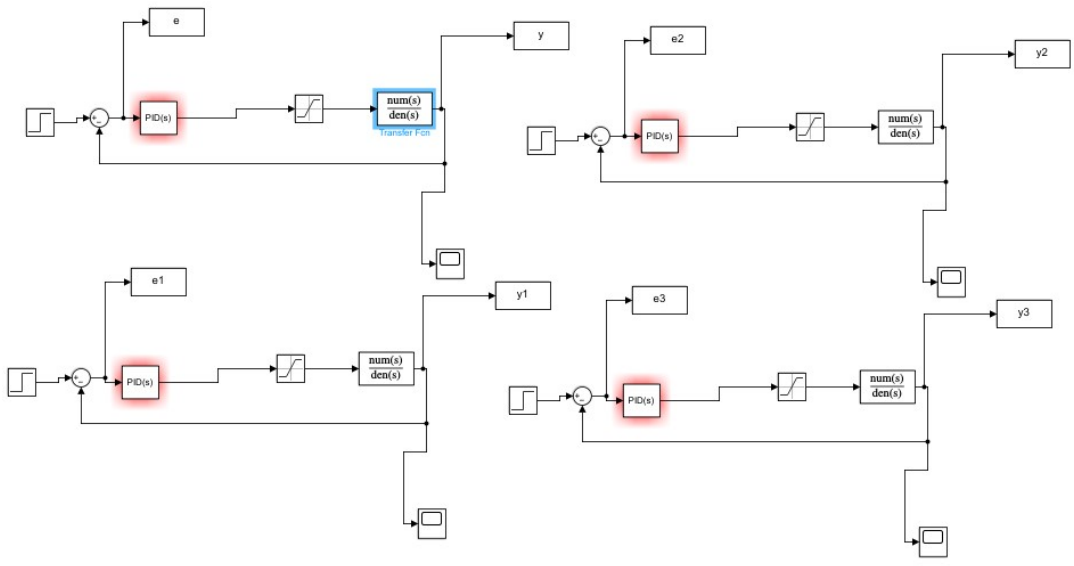
```
            end
end
        % Store the Best Cost Value
%         BestCosts(it) = GlobalBest.Cost

        % Display Iteration Information         if
ShowIterInfo             disp(['Iteration ' num2str(it) ':
Best Cost = ' num2str(BestCosts(it))]);         end

        % Damping Inertia Coefficient
        w = w * wdamp;

end
    out.pop = particle;
out.BestSol = GlobalBest;
out.BestCosts = BestCosts;
     end
```

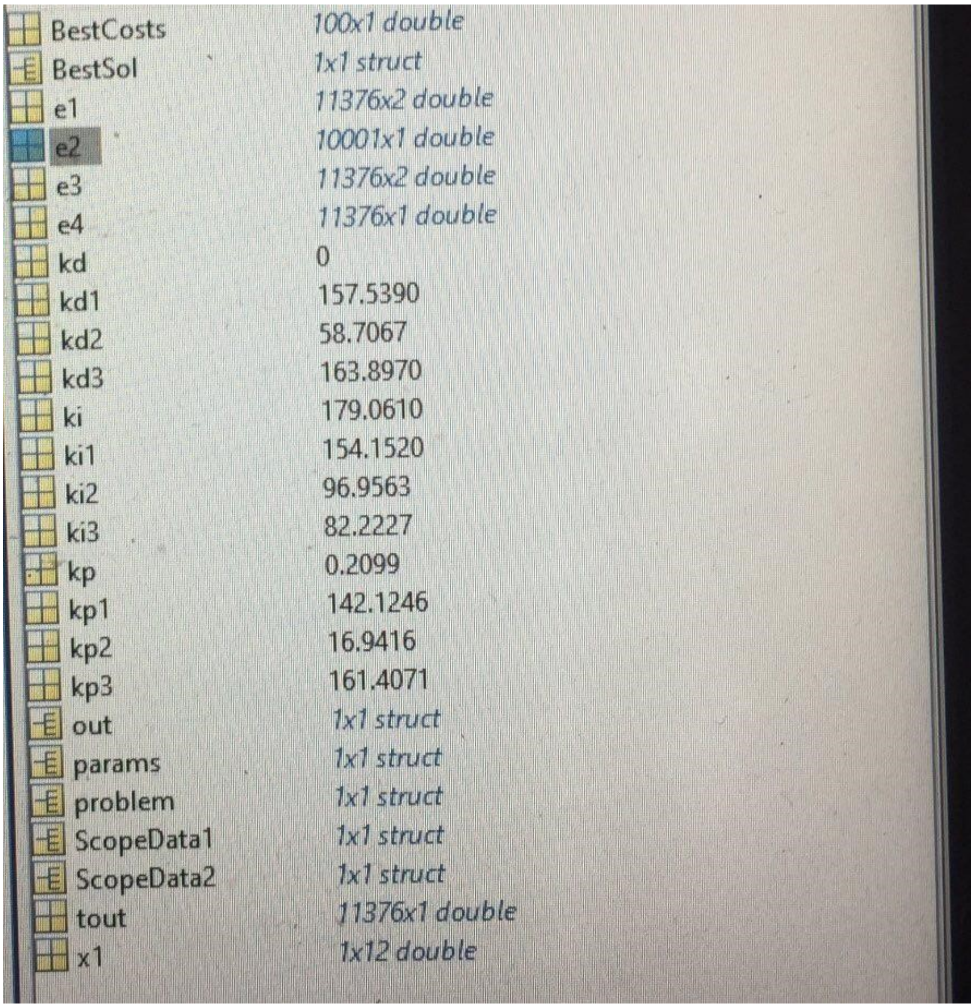
Main code for PSO

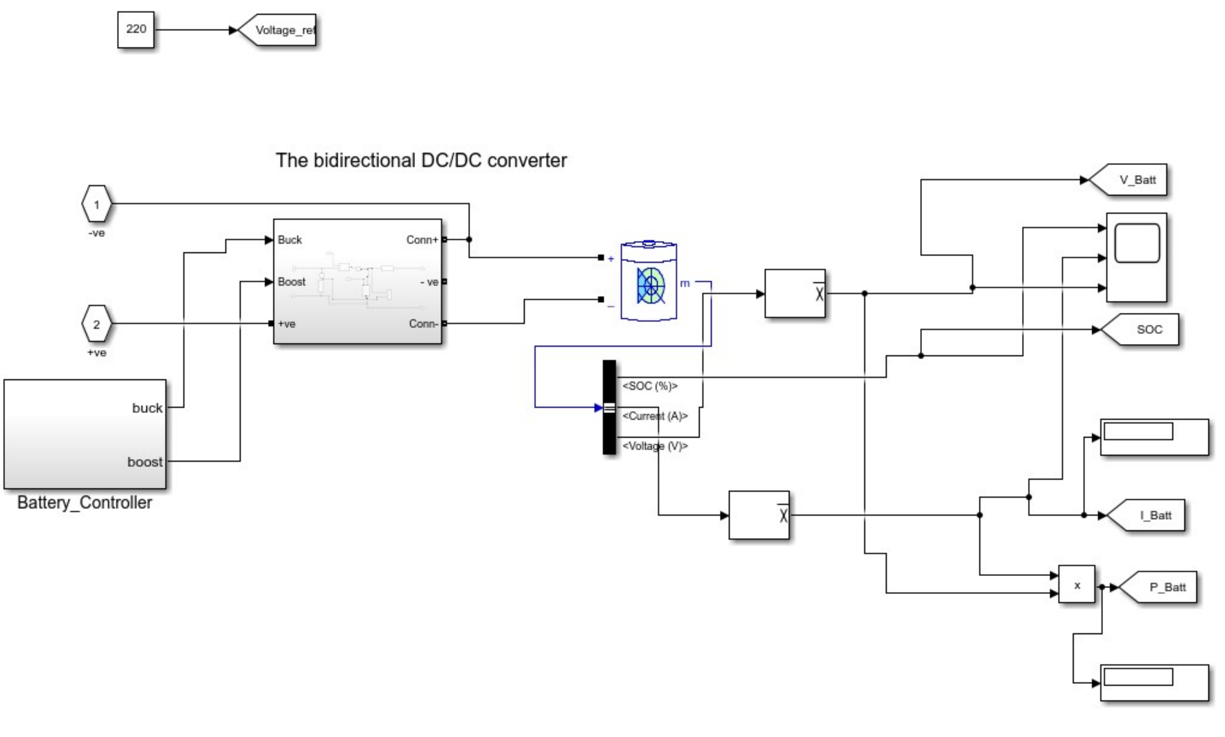
```
clc; clear; close all;
global kp  ki  kd % PID 1
global kp1  ki1  kd1 % PID 2
global kp2  ki2  kd2 % PID 3
global kp3  ki3  kd3 % PID 4
kp=30;  ki=20;  kd=1;
kp1=30;  ki1=20;  kd1=1;
kp2=30;  ki2=20;  kd2=1;
kp3=30;  ki3=20;  kd3=1;

%========================PSO==============================
problem.CostFunction = @(x) objv(x);      % Cost Function problem.nVar
= 3;      % Number of Unknown (Decision) Variables problem.VarMin = [0
0 0];   % Lower Bound of Decision Variables problem.VarMax =  [50 50
50];   % Upper Bound of Decision Variables
%=======Parameters of PSO============================ params.MaxIt = 4;
% Maximum Number of Iterations params.nPop = 10;  %200;           %
Population Size (Swarm Size) params.w = 0.5; %chi;             %
Intertia Coefficient params.wdamp = 1;           % Damping Ratio of
Inertia Coefficient params.c1 = 0.5;   % chi*phi1;      % Personal
Acceleration Coefficient params.c2 = 0.5;   %chi*phi2;       % Social
Acceleration Coefficient params.ShowIterInfo = true; % Flag for
Showing Iteration Informatin
%% Calling PSO
out = PSO(problem, params)
BestSol = out.BestSol;
BestCosts = out.BestCosts;
%% Results
x=BestSol.Position
kp=x(1);  ki=x(2);
kd=x(3);
figure(1);
plot(BestCosts, 'LineWidth', 2);
hold on;
```

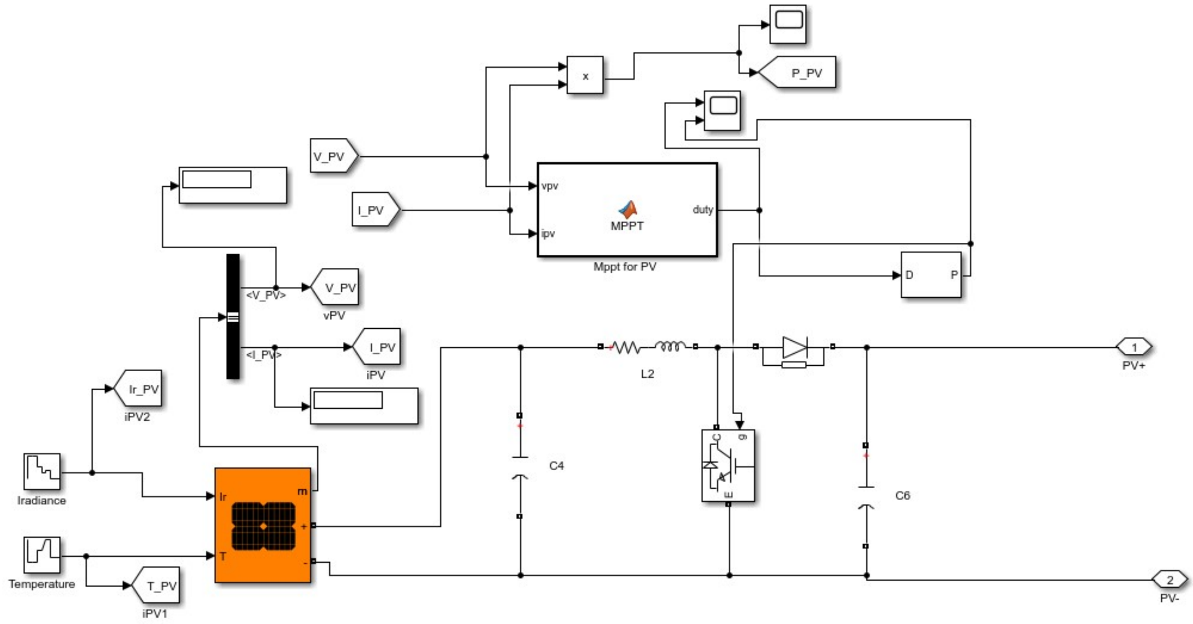
```
% semilogy(BestCosts, 'LineWidth', 2);
xlabel('Iteration'); ylabel('Best
Cost'); grid on;
%=================PSO ends======================
%=================PSO1 starts======================
problem.CostFunction = @(x1) objv1(x1);      % Cost Function
problem.nVar = 3;      % Number of Unknown (Decision) Variables
problem.VarMin = [0 0 0];   % Lower Bound of Decision Variables
problem.VarMax =  [50 50 50];   % Upper Bound of Decision Variables
%=======Parameters of PSO============================ params.MaxIt = 4;
% Maximum Number of Iterations params.nPop = 10;  %200;           %
Population Size (Swarm Size) params.w = 0.5; %chi;             %
Intertia Coefficient params.wdamp = 1;           % Damping Ratio of
Inertia Coefficient params.c1 = 0.5;   % chi*phi1;      % Personal
Acceleration Coefficient params.c2 = 0.5;   %chi*phi2;       % Social
Acceleration Coefficient params.ShowIterInfo = true; % Flag for
Showing Iteration Informatin
%% Calling PSO
out = PSO(problem, params)
BestSol = out.BestSol;
BestCosts = out.BestCosts;
%% Results
x1=BestSol.Position
kp1=x1(1);  ki1=x1(2);
kd1=x1(3); figure(2);
plot(BestCosts, 'LineWidth', 2); hold
on;
% semilogy(BestCosts, 'LineWidth', 2);
xlabel('Iteration1'); ylabel('Best
Cost1'); grid on;
%================PSO1 Ends==============
%=================PSO2 starts======================
problem.CostFunction = @(x2) objv2(x2);      % Cost Function
problem.nVar = 3;      % Number of Unknown (Decision) Variables
problem.VarMin = [0 0 0];   % Lower Bound of Decision Variables
problem.VarMax =  [50 50 50];   % Upper Bound of Decision Variables
%=======Parameters of PSO============================ params.MaxIt = 4;
% Maximum Number of Iterations params.nPop = 10; %200;           %
Population Size (Swarm Size) params.w = 0.5; %chi;             %
Intertia Coefficient params.wdamp = 1;           % Damping Ratio of
Inertia Coefficient params.c1 = 0.5;   % chi*phi1;      % Personal
Acceleration Coefficient params.c2 = 0.5;   %chi*phi2;       % Social
Acceleration Coefficient params.ShowIterInfo = true; % Flag for
Showing Iteration Information
%% Calling PSO
out = PSO(problem, params)
BestSol = out.BestSol;
BestCosts = out.BestCosts;
%% Results
x2=BestSol.Position
kp2=x2(1);  ki2=x2(2);
kd2=x2(3); figure(3);
plot(BestCosts, 'LineWidth', 2); hold
on;
% semilogy(BestCosts, 'LineWidth', 2);
xlabel('Iteration2'); ylabel('Best
Cost2');
grid on;
%================PSO2 Ends==============
%=================PSO3 starts======================
problem.CostFunction = @(x3) objv3(x3);      % Cost Function
```

```
problem.nVar = 3;       % Number of Unknown (Decision) Variables
problem.VarMin = [0 0 0];    % Lower Bound of Decision Variables
problem.VarMax =  [50 50 50];    % Upper Bound of Decision Variables
%=======Parameters of PSO============================ params.MaxIt = 4;
% Maximum Number of Iterations params.nPop = 10; %200;            %
Population Size (Swarm Size) params.w = 0.5; %chi;            %
Intertia Coefficient params.wdamp = 1;           % Damping Ratio of
Inertia Coefficient params.c1 = 0.5;   % chi*phi1;      % Personal
Acceleration Coefficient params.c2 = 0.5;   %chi*phi2;       % Social
Acceleration Coefficient params.ShowIterInfo = true; % Flag for
Showing Iteration Informatin
%% Calling PSO
out = PSO(problem, params)
BestSol = out.BestSol;
BestCosts = out.BestCosts;
%% Results
x3=BestSol.Position
kp3=x3(1);  ki3=x3(2);
kd3=x3(3); figure(4);
plot(BestCosts, 'LineWidth', 2); hold
on;
% semilogy(BestCosts, 'LineWidth', 2);
xlabel('Iteration3'); ylabel('Best
Cost3'); grid on;
%================PSO3 Ends==============


 %=========
 set_param('modexbyyam','AlgebraicLoopSolver','Auto');
sim('modexbyyam.slx');
```




BestCosts 100x1 double
BestSol 1x1 struct
e1 11376x2 double
e2 10001x1 double
e3 11376x2 double
e4 11376x1 double
kd 0
kd1 157.5390
kd2 58.7067
kd3 163.8970
ki 179.0610
ki1 154.1520
ki2 96.9563
ki3 82.2227
kp 0.2099
kp1 142.1246
kp2 16.9416
kp3 161.4071
out 1x1 struct
params 1x1 struct
problem 1x1 struct
ScopeData1 1x1 struct
ScopeData2 1x1 struct
tout 11376x1 double
x1 1x12 double


220
Voltage_ref
The bidirectional DC/DC converter
1
-ve
2
+ve
Buck
Boost
+ve
Conn+
- ve
Conn-
buck
boost
Battery_Controller
m
<SOC (%)>
<Current (A)>
<Voltage (V)>
V_Batt
SOC
I_Batt
P_Batt
x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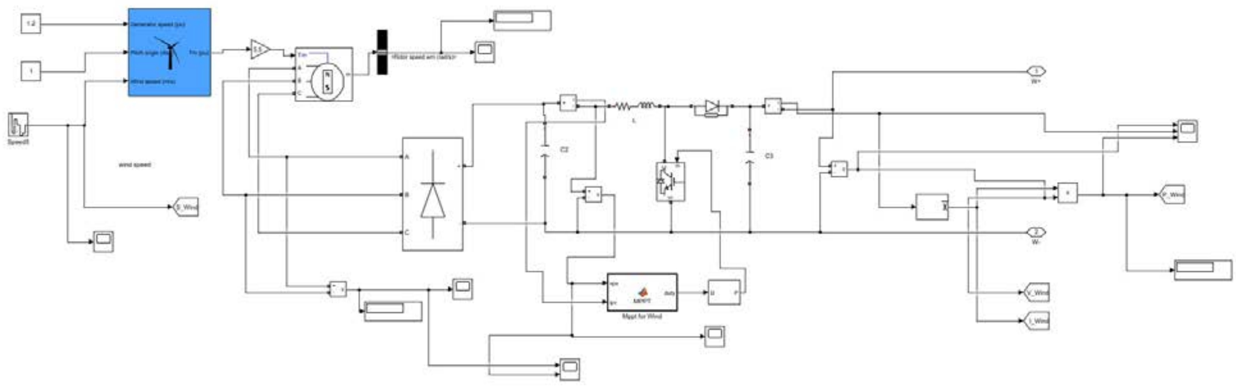

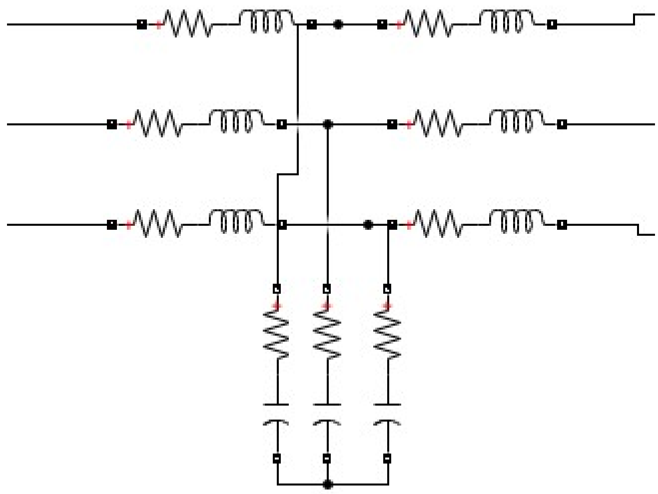

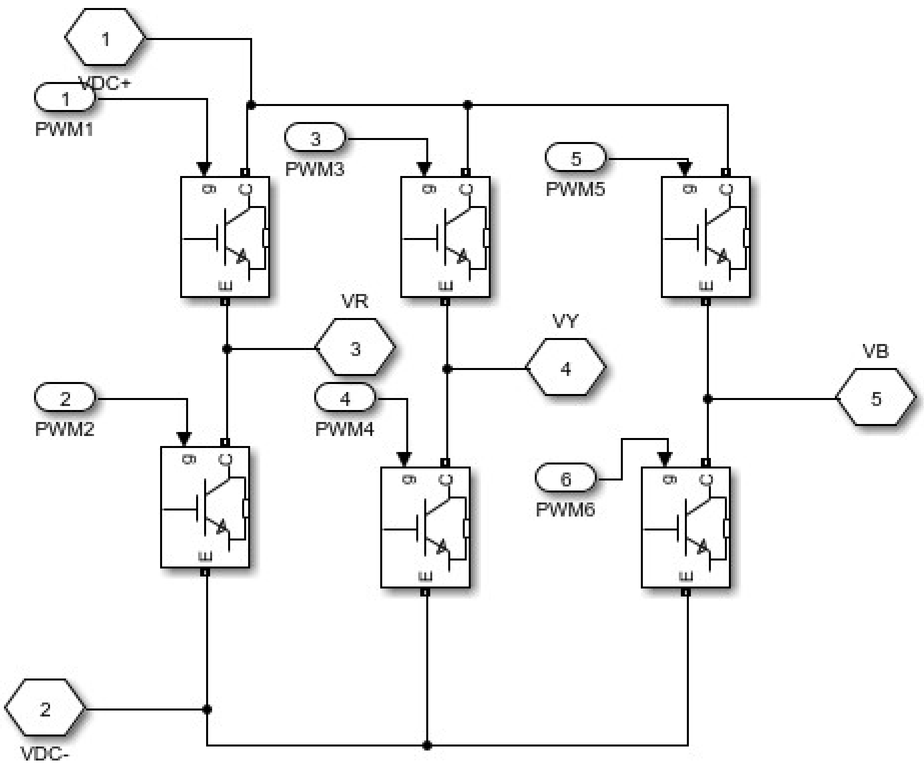
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VDC+
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PWM3
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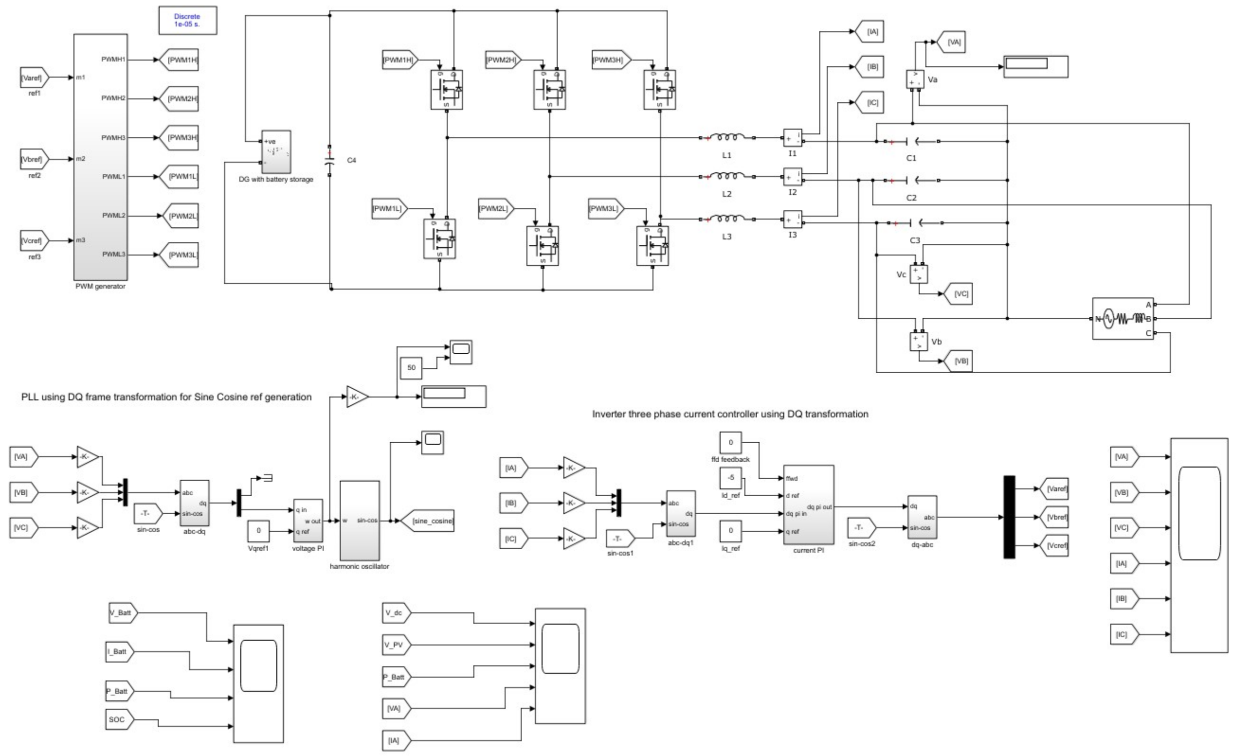
VDC-



Discrete 1e-05 s.
PWM generator
DG with battery storage
PLL using DQ frame transformation for Sine Cosine ref generation
Inverter three phase current controller using DQ transformation
voltage PI
harmonic oscillator
current PI
abc-dq
abc-dq1
dq-abc

Design & Control of Distributed Generations for Micro-Grid Applications

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