ARCHITECTURE, MODELLING AND SIMULATION OF AN INTEGRATED INTELLIGENT MICROGRID FOR REMOTE MILITARY STATIONS OF THE ARMED FORCES

A Thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy
in
Engineering

By
Brig CPS Pasricha, VSM

May 2022

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DECLARATION

I declare that the thesis entitled **Architecture, Modelling and Simulation of an Integrated Intelligent Microgrid for Remote Military Stations of the Armed Forces** has been prepared by me under the guidance of Dr. Rajeev Gupta, Distinguished Professor, Department of Physics, University of Petroleum and Energy Studies. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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ABSTRACT

Forward operating bases of the Armed Forces are located in remote areas where grid connection is normally not available and if available are vulnerable to outages due to vagaries of weather or action by adversary. In many such cases, these areas do not have their power requirements through the main grid supply and entire power requirement of the deployment is supplied by diesel generators. These diesel generators have high environmental impact due to emission of greenhouse gases and are highly uneconomical as logistic sustenance of remote bases for supply of fuel is very challenging, Fossil fuel has to be supplied by vehicles, helicopters, boats or manually carried to mountain tops. This increases the overall cost of deploying armed forces in remote areas. In recent years with the advancements in power electronic components and renewable energy, development in Microgrids have shown a way to reduce dependency on main power grids. Microgrids are generally more efficient and may provide electric power storage for emergency supply of electricity to mission critical equipment like surveillance systems, sensors, communication, command and control systems of such forward bases. In this work, design, modelling and simulation of a 1 MW specialised microgrid for remote bases of the Armed Forces is undertaken, catering for their special needs.

Several small independent microgrids can also be interconnected together to satisfy the energy requirements of remote military areas. Networking of several microgrids is developed with the aim to enhance efficiency, reliability and resiliency as well as load sharing between remote bases. Interconnection of microgrids at three remote bases of the armed forces is presented and simulated. The proposed power co-ordination strategy is designed in such a way that during peace time operation, it tries to minimize the overall requirement of fossil fuel for generators supplying the critical loads and in case of outages, it can tackle the emergency situation by automatically routing the power to critical loads from other operational bases. The entire system has been simulated and verified using MATLAB 2018.

Based on the architecture, four microgrids have been designed and are being constructed as part of the research work for remote island bases of the Armed Forces in Andaman and Nicobar Islands to cater for the additional load and to increase self-reliance by exploiting renewable energy sources. The design, specifications and construction of these microgrids is being developed by the Military Engineering Services (MES). The projects consist of Solar arrays with energy storage systems connected to existing power houses, with the entire distribution being controlled by microgrid controllers having capability to switchover to

energy sources as per economic criteria and availability. The microgrids in remote islands of Armed Forces will be the first of its kind in the country.

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Abbreviations

AC: Alternate current

AFFSMC: Adaptive fractional fuzzy sliding mode control

ANN: Artificial neural network

BCHP: Biomass combined heat and power

BESS: Battery energy storage system

BIPV: Building integrated PV

C&I: Commercial & Industrial

CHP: Combined heat and power

CPS: Central protection system

DC: Direct current

DER: Distributed energy resources

DG: Distributed generator

DGs: Diesel generators

DFT: Discrete fourier transform

DT: Decision tree

EDS: Economic dispatching stage

ES: Energy storage

ESS: Energy storage system

EV: Electric vehicle

FOB: Forward operating bases

HESS: Hybrid energy storage system

HFA-IOSELM: Hybrid fire fly algorithm based improved online sequential extreme learning machine.

HRES: Hybrid renewable energy sources

HV: High voltage

KKT: Karush Kuhn Tucker

LV: Low voltage

MG: Micro grid

MPP: Maximum power point

MPPT: Maximum power point tracking

OEMS: Optimised energy management system

PCC: Point of common coupling

PEI: Power electronic interfaces

PI: Proportional integral

PSO: Particle swarm optimization

P&O: Perturb and observe

PV: Photo voltaic

PWM: Pulse width modulation

RES: Renewable energy sources

RMS: Root mean square

RTAS: Real time adjusting stage

SC: Super capacitor

SCADA: Supervisory control and data acquisition

SOC: State of charge

SOFC: Solid oxide fuel cell

SPWM: Sinusoidal pulse width modulation

THD: Total harmonic distortion

VRB: Vanadium redox batteries

VSI: Voltage source inverter

WT: Wind turbine

1 INTRODUCTION

1.1 INTRODUCTION AND BACKGROUND

Energy security, from a military perspective, refers to an installation's ability to acquire reliable sources of electricity and fuel to use them in order to secure and provide enough energy to support important operations during an extended outage of the local electric grid. Energy security can also be considered on a multidimensional scale, ranging from national policy to tactical or local installation level. The energy security, at installation level, is composed of three components: "*reliability, resilience, and efficiency*". The proportion of time that energy delivery systems, including the external power grid and microgrid, can offer consistent and appropriate electricity to their clients is referred to as energy reliability. Energy resilience refers to an electrical supply's ability to anticipate, plan for, and adapt to changing events, as well as to withstand, respond to, and recover quickly from interruptions in external energy supply or power failures and outages. Energy efficiency refers to an installation's ability to reduce its energy consumption without sacrificing operational performance. The energy has been a vital component of successful warfighting in past. Energy is the catalyst for sustaining operations in any combat scenario, from fodder for horses to gasoline for jeeps and fissile material for nuclear reactors.

Our war warriors on the battlefield are increasingly relying on capabilities at domestic military installations to support crucial tasks, frequently in near real time. Numerous Armed Forces domestic stations also support a variety of sensitive research and development facilities, ranging from microelectronics and laboratories to huge installations like ports and air bases. These facilities are reliant on the commercial electric grid for power. Thus, a prolonged outage of the domestic power grid will have a considerable impact on the Armed Forces' operational mission and will have significant economic ramifications. The evolving nature of energy systems creates new options for the Armed Forces to save money on power while still meeting their energy security requirements. The Armed Forces must minimise their facilities' energy intensity, increase their use of renewable energy sources, and strengthen their energy resilience and security.

There are a variety of strategies for enhancing energy security, one of which is to upgrade the commercial electricity transmission and distribution infrastructure. This research focuses exclusively on potential enhancements within the installation's fence line.

Microgrids are energy systems made up of interconnected loads and energy supplies that, when integrated, may be disconnected from the local utility grid and operate independently. They establish a system for the Armed Forces to achieve enhanced energy security for key infrastructure, particularly in remote places, as well as cost savings through higher energy efficiency. When implemented appropriately, microgrids can also serve as a catalyst for the widespread adoption of renewable energy sources. Microgrids on military installations must be tightly connected to the broader utility grid in order to achieve long-term cost reductions.

Military organisations often control the microgrid, which can operate whether or not it is connected to an external supplier. Military sites are classified into two types: those that are connected to a public utility and those that are located on islands or other isolated regions and generate all of their own electricity. The United States Armed Forces have been implementing microgrids at various bases in order to improve energy security (March, 2013).

1.2 THE NEED

The military bases and installations in the majority of the country are connected to the grid, during outages, other interruptions, and in remote areas, the facility requires an energy source. There are many bases of the armed forces in high altitude, snow-bound areas or remote islands where grid power is not available and electricity is supplied only by diesel generator sets. As one of the largest users of energy, this research will strive to address the need to reduce demand, expand supply, and construct an energy-secure force, which will imply a military that consumes less energy, has more secure energy sources, and has the energy resources it requires to protect its forces. This will mean :-

- **Decrease dependency** on fossil fuel.
- Increase range, endurance, reliability and **energy security** of armed forces.
- Increase **energy efficiency** of operation.
- Saving lives and lowering the risk to troops by using, transporting, and storing energy.
- Reduce defence spending on energy consumption.
- **Optimal use of renewable energy resources** – transitioning to cleaner fuels lowering carbon footprints. Contributing to national goals such as lowering dependency on fossil fuels, reducing greenhouse gas emissions, and utilising renewable sources.

1.3 MOTIVATION

The motivation for the microgrid research is to overcome the current challenges in energy needs in remote areas of the Armed Forces, as well as the challenges listed below:

- Maintaining backup power generation equipment on a military post is a popular method of ensuring operational continuity during a power outage. It is customary for essential loads on installations to have dedicated backup generating sources, which have the disadvantage of being unreliable and inflexible.
- In certain cases, military infrastructure is located in isolated locations that are shut off for months at a time, necessitating the stockpiling of fuel for the essential supply of energy. Fuel storage in remote locations is a big challenge, especially for tiny bases.
- A large number of areas are in high altitude, very high snow-bound mountains or remote island locations where fuel for generators is supplied by helicopters or manually carried. Transportation or carriage of fuel to those places for daily energy supply is a logistical challenge and costs an exorbitantly high amount.
- Renewable energy sources deployed on military sites are not integrated and function in a stand-alone mode, i.e., they are not linked to the distribution system.
- The entire energy supply system in remote military bases is inefficient.
- The present system has the challenge of **ageing distribution and transmission systems**.

1.4 PROBLEM STATEMENT

There are no microgrids on any of the Indian Armed Forces facilities, and no research or effort has been made to build and integrate energy resources into a microgrid. In this case, research is being done to design and build a distant site microgrid that can keep military sites, including mission-critical facilities, running smoothly at both the component and system level. There will be a need for a reliable, efficient, and safe microgrid in order to power important buildings on a base as well as to run the base as a whole. The same will apply to forces stationed at forward operating bases and other remote locations. At present , the Armed Forces' dispersed renewable energy sources operate independently, with no plans to integrate these resources. These energy sources work independently, supplying specific tiny loads. **The research will focus on the problem of design, modelling and simulation of a specialized microgrid for remote bases of the Armed Forces and cater for their special needs. To enhance reliability, the problem of load sharing between bases will be addressed by networking**

of Microgrids including outage management. Based on the design, microgrids will be established on isolated islands to maximise power supply from multiple sources on a military base/station, including the integration of renewable energy technology. These microgrids on distant Armed Forces islands will be the first of their sort in the country.

1.5 OBJECTIVES

The main objective of this thesis is to concentrate on various technical challenges in the design of a microgrid operating in a military station or in a forward base in remote areas that facilitate the use of renewable energy technologies for the Armed Forces. The research will focus on special requirements of critical loads, power sharing when multiple power sources are connected to the grid, power quality, stability, and improving reliability by interconnecting microgrids. The ultimate objective will be to design and develop a working microgrid on a remote military base. Hence, the approach to this research involves carrying out the following objectives.

- **Identify resources and requirements of a microgrid in remote areas for Armed Forces**. This research will begin with a critical analysis of the present state of the art in microgrid research, with an emphasis on the Armed Forces and their security requirements. The resource assessment, challenges associated with building remote microgrids, and knowledge gaps associated with the use and installation of military microgrids will all be identified.

- **Modelling of components of a microgrid along with controls.** This involves the identification of each component of the microgrid, followed by designing and simulating the component for its performance parameters. Designing a complete microgrid is a typical process as it contains several different complex subsystems and synchronisation is also required between them. Hence, individual components, including sources, power electronic devices, and controls of the proposed system, are designed first, simulated for their performance in MATLAB, and thereafter the components and sub systems are integrated together.

- **Simulation of the microgrid in various operating conditions and under wide range of parameters.** A microgrid with the capacity of a military station will be built in this work with the unique requirements of the Armed Forces in mind. There will be a lot of solar energy in the design that is being proposed. The effects of bad weather and meteorological conditions on solar energy production will be looked at to see if energy storage in the form of batteries can help. Batteries store extra energy that is made by photovoltaic (PV) systems and release it when the amount of power needed exceeds the amount that the PV system can provide. Diesel generator sets will be used to power important loads, offer reliability, and provide a backup for critical operations that require power during outages, nighttime operations, or in the event of unanticipated meteorological conditions. The proposed microgrid will be designed and simulated using MATLAB. The working of the microgrid under various operating conditions will be tested for its performance, including varying metrological conditions and load conditions.

- **Networking of microgrids, stability with load sharing and simulation of outage.** Additionally, numerous small autonomous microgrids can be combined to share the load and meet the energy needs of remote military zones. Numerous self-monitored microgrids will be networked to increase the efficiency, dependability, and resilience of power systems, as well as their stability. Three remote Armed Forces sites are planned and simulated using a network of microgrids. The proposed power coordination strategy is designed in such a way that it attempts to minimise the total amount of fossil fuel consumed by generators supplying critical loads during normal operation. However, it is capable of managing an emergency scenario in the case of a power outage by immediately routing electricity to important loads from other operational bases. The complete system will be simulated and verified using MATLAB.

- **Design, implementation and system development of a microgrids for remote location of Armed Forces.** Four microgrids have been designed as part of the research work for the Armed Forces in remote bases in the Andaman and Nicobar Islands. They cater to the energy needs of the base, including critical loads, and seek to increase self-reliance by exploiting renewable energy sources. The design and specifications of the microgrid will be developed at four bases of the Armed Forces by the Military Engineering Services. The project consists of solar arrays with energy storage in battery banks connected to existing power houses with the entire distribution being controlled by the microgrid controller having the capability to switch over to energy sources as per availability and economic criteria.

The expected end result of this research is a working and implementable model for a microgrid established in remote locations of the Armed Forces. **The microgrids, the first of their kind, will serve as a model for many more such microgrids that can be established throughout our country's remote locations and vast borders.**

2 REVIEW OF LITERATURE AND GAP

2.1 INTRODUCTION

Microgrid adoption is increasing throughout the world, posing new challenges and opportunities. There are still major challenges in designing, controlling, and operating microgrids efficiently, both connected to the grid and isolated from it, and extensive research is being performed to solve these concerns. At the moment, significant research and study have been undertaken on the technical aspects of microgrids. These studies are divided into three categories: system planning and design, system operation, and system control. This chapter discusses the concept and characteristics of microgrids in general. It provides a critical overview of the literature on general microgrids and their use in remote places. The emphasis is on current research trends, needs, and extant gaps in techniques in this field.

The literature review for the research work comprised of the following areas:

- Introduction to microgrids, concept and types.
- Microgrids and distributed generation with energy storage systems.
- Challenges of microgrids.
- Distributed generation, microgrid protection, intelligent controllers and energy management.
- Interconnected microgrids and controls.
- Machine learning techniques.
- Studies on development of microgrids in Armed Forces - US Army and Indian Army.

2.2 INTRODUCTION, CONCEPTS AND TYPES OF MICROGRIDS

The power grid is a network of integrated electrical components that consists of the generation, transmission, and distribution of power. A typical power grid is a large-scale, centralised network in which power plants create high-voltage electricity that is transported and distributed to end users at a lower voltage (Zheng et al., 2018). Because of the great distances between the generation sources and the load, a significant amount of electrical energy is lost in transmission. Hence, small and isolated loads have to deal with a major problem of power loss.

Microgrids are smaller versions of power grids that can work without the dependence of other power sources and are self-sufficient. The generation centres are typically installed and positioned near the end users, and they typically include hybrid energy resources, energy storage devices, and regulated loads (Konidena et al., 2020). This eliminates power loss during transmission and is especially advantageous for isolated customers. Microgrids have been built all over the world as a way to reduce reliance on the electricity grid and distant producing units. It is also used as an opportunity to take advantage of the high penetration of renewable power while reducing greenhouse gas emissions and seeking to handle supply-demand balancing at a more local level (Lasseter, 2002).

This prevents power loss during transmission, which is especially advantageous for remote clients. Microgrids have been built worldwide to reduce reliance on the energy grid and remote power producing units. Additionally, it is utilised to maximise the usage of renewable energy while reducing greenhouse gas emissions and seeking to balance supply and demand on a more local level (Liu et al., 2018). As a result, it is critical to provide adequate power source sizing in microgrids that utilise distributed energy resources (DER) to assure the system's stability and economics (Meisen, 1998; Mohamad & Teh, 2018). Some of the power sources that can be used in a microgrid are wind turbines, photovoltaic panels, energy storage systems, and combined heat and power (CHP). ESSs are often made up of a variety of different types of energy storage (ES) devices. This results in a hybrid energy storage system (HESS) that is better at both performance and cost. There has been a lot of research done by academics on how to make microgrids more efficient in terms of how much power resources they have and where they are placed (Ghiassi-Farrokhfal et al., 2016; Mashayekh et al., 2017; Shin et al., 2018), strategy for dispatch and operation (Jin et al., 2017), strategy for energy management (Pascual et al., 2015; Zhao et al., 2015) etc.

A microgrid primarily consists of renewable energy sources, distributed energy generators, various energy storage devices, power electronics, and a control system for monitoring and regulating the generator's power supply primary grid source (grid-connected or off-grid) (Le, 2018).

The key objective is to optimise microgrid operation while also lowering the total cost of energy distributed resources, rebates, and income. The accompanying losses and emission costs are negligible. Physical limits on distributed energy resources and on the energy balance are used to illustrate restrictions. The objective function under the technical option is the system's power loss. Voltage volatility and device loading are constraints, as are the physical restrictions of distributed energy resources and energy balance.

Microgrids operate in two primary modes: on-grid and off-grid. On a large scale, the vast majority of microgrids operate in a hybrid mode (LUU, 2014). In on-grid mode, the microgrid is connected to the grid; hence, in the event of a power breakdown or shortage, electricity is drawn from the grid, ensuring that the load receives consistent power. Additionally, when power generation is high, extra power can be exported to the grid. This is not practical on smaller islands or remote places, so off-grid microgrids are deployed. Due to the fact that it is not connected to the grid, there may be issues during a power outage or scheduled maintenance. As a result, the energy storage system's capacity should be increased in proportion to the type of load that will be employed. This self-contained mode of operation is also referred to as the "island mode" or "stand-alone systems." Additionally, there are additional grid system classes based on the application of the load (M. B. Kumar, 2017). The microgrid consists of a small transmission and distribution network which efficiently makes use of distributed energy resources. Based on type of design, microgrids can be of various types as

- Campus Environment/Institutional Microgrids
- Remote "Off-Grid" Microgrids
- Military Base Microgrids
- Commercial and Industrial (C&I) Microgrids

With the rise of renewable energy sources and microgrids at military base camps, the energy storage requirement has now become particularly prominent. Energy storage systems supplement renewable energy sources by storing excess electricity during periods of low demand and/or high production. When energy demand is high and/or renewable energy generation is insufficient, the energy storage device will discharge electricity to meet the necessary energy demand (Chen et al., 2012). This greatly improves the usability of electricity that comes from renewable sources by putting it together with the real need for energy. Without a power storage network, power production from renewable sources and the need for loads must be thought of as two separate and uncontrollable inputs (Ghasemi & Enayatzare, 2018). Batteries, supercapacitors, compressed air, and thermal energy storage are all being looked at for use in distributed microgrids right now. Batteries are the most common way to store energy in microgrids. Lithium-ion batteries and lead-acid batteries are the two most popular types. Due to increased energy density and the absence of a devastating memory effect, lithium-ion is becoming the most chosen type of battery (Chen et al., 2012).

Lead-acid batteries are used when the cost of making them is important, because they are less expensive than lithium-ion batteries. There are no chemical processes in super capacitors, which are electrical storage systems that store energy in an interface between an electrode and an electrolyte that doesn't leak (Mehtab et al., 2019). In spite of that, these batteries can be charged and discharged very quickly, and they have a longer life cycle than other types of batteries. Super capacitors' drawback is that they have poor energy density, indicating their total power per weight is smaller than other batteries (B. K. Kim et al., 2015).

2.3 MICROGRIDS AND DISTRIBUTED GENERATION WITH ENERGY STORAGE SYSTEMS

Distributed generation is a method that uses smaller scale resources to generate electricity on the load side. It mostly contains diesel generators and other renewable sources that can suit the local climate. There are small, low-voltage supply networks called "microgrids" that are used to provide electricity or heat for a small settlement, like a residential colony or a remote area. These networks can also be used by academic institutions, businesses, islands, or other small settlements (Razavi et al., 2019). It is primarily a dynamic distribution network, consisting of DG systems and a diverse load mix at distribution voltage levels. Essentially, a microgrid is a collection of multiple energy storage sources. The energy generated by these sources is gathered, processed, and distributed to meet the demands of the load. When control components interface with microscale energy framing a single element, its operation necessitates the use of a control network. This type of control network is necessary to ensure adaptability and to protect the specific energy system and power quality (M. B. Kumar, 2017).

The point of fundamental coupling is the electrical circuit point at which a microgrid is connected to a fundamental grid (Moussavou, 2014). Microgrids without a Point of Common Coupling (PCC) are referred to as restricted microgrids. They are frequently used in remote locations (e.g., remote groups or remote destinations) when connecting with the primary network is not feasible due to either technical or financial constraints.

In a microgrid, the generators and micro-sources are often renewable or non-conventional. They can lead to a significant modification in the way power is generated traditionally, where the electricity is generated in a centralised location far away and then transmitted over a long distance through heavy transmission lines. It is capable of supplying electricity to remote areas with limited transmission capabilities (Zhao et al., 2018). This dispersed generation can give more reliability to rural and hilly areas in the event of power outages. Conventional power systems around the world face problems like the gradual depletion of fossil fuel resources, wasteful energy use, and environmental pollution. These problems have led to the development of new systems in which electricity is generated locally at distribution level voltages using non-traditional or renewable energy sources like wind power, biogas, natural gas, solar photovoltaic cells, combined heat and power (CHP) systems, microturbines, fuel cells, or Stirling engines, and then integrated into utilities' distribution networks. These new systems are called "distribution level systems" (Muradov, 2017). In essence, they can be called a microgrid if appropriate power sources are installed on the load side. This significantly reduces the system's maintenance and operating costs. Numerous studies have been undertaken to investigate generation concerns such as energy sources and energy storage systems (ESS), both of which are components of microgrids (S. Chowdhury et al., 2009).

Due to the variable nature of renewable energy, ESS is critical to ensuring a steady supply of electricity. Due to the microgrid's islanding nature, it also necessitates the presence of ESS for storage and power quality considerations. Better ESS efficiency enhances utility grid efficiency, resulting in lower operation costs, emissions, and increased power reliability. Using renewable energy allows variable power generation, thereby making use of the resources during their availability, and ESS allows to use of power when the sources are not being used. The utilisation of ESS would also improve the power quality issues through frequency regulation, which benefits the utility companies. These benefits may be in the form of additional revenue or a reduced cost of procuring the power (Bayne, 2000). Using ESS reduces the electricity bill and may be advantageous in the long run (Tan et al., 2013; Xu et al., 2012).

Microgrids are well-suited for distributing power to remote sections of a country where supplies from the national grid system are either difficult to access due to its topology or are frequently disrupted by harsh weather conditions or man-made disturbances. The fundamental advantage of a microgrid from a grid perspective is that it is considered a controllable entity within the electricity system. Additionally, it can be used to aggregate many loads (Cagnano et al., 2020). This offers simple control and compliance with grid rules and regulations without relying on the electrical utility's dependability and security. This offers simple control and compliance with grid rules and regulations without relying on the electrical utility's dependability and security. Microgrids benefit clients by enabling them to meet their electrical and heating requirements locally. They can provide continuous power, enhance local reliability, reduce feeder losses, and aid in local voltage regulation. Environmentally, they mitigate pollution and global warming by using low-carbon technologies.

2.4 CHALLENGES OF MICROGRIDS

Microgrids are a rapidly increasing section of the energy business that represents a paradigm change away from centralised power grids and toward more dispersed, localised generation, particularly in cities, communities, and campuses. Isolation from larger grids requires the microgrids to be more resilient to power failures and more flexible, with parallel operations permitting delivery of services that make the grid more competitive (S. Chowdhury et al., 2009).

Microgrids have their own sets of limitations when compared to conventional grids (Cagnano et al., 2020). The issues are discussed in this section with respect to the power generation system and energy storage issues (Ahmed et al., 2015). It is essential to maintain the reliability of the grid with precise synchronisation of power supply. The frequency must be maintained constantly and at par with the surrounding grid system in order to synchronise with the main grid at times of need. The power factor must also be maintained at the appropriate level. It must ideally be unity; however, it is accepted to maintain the power factor at above 90%. This is essential since having a reduced power factor will lead to higher generating costs, thereby the system will be less efficient. This is especially true for high inductive and capacitive loads like induction motors and capacitive banks, which can greatly skew the power factor. Hence, precautions must be taken to improve the power factor by utilising Power Factor Correction (PFC) devices (Gayatri et al., 2018).

Reliability is the main disadvantage in microgrids since if any fault occurs, an external grid must be made use of. Hence, it is essential to constantly monitor the power supply and usage. Two parts of power quality are generally thought to be essential: (i) transient voltage varieties and (ii) consonant twisting of the system voltage (Nobela et al., 2019). A microgrid can bring about a minor departure of transient voltage from the system if generally vast current changes amid association and disengagement of the generator are permitted. Microgrid units can possibly bring about undesirable transient voltage variations in the neighbourhood control network.

The stability of the grid is another major issue in microgrids. Stability concerns in grid-connected microgrids primarily concern the stability of specific components, such as a source or a load, including electrical motors, and their effect on the system (Farrokhabadi et al., 2020)

2.5 DISTRIBUTED GENERATION

Blake and O’Sullivan (Blake & O’Sullivan, 2018) developed a model for industrial microgrids using distributed energy resources (DERs). The developed model has been implemented in manufacturing facilities in Ireland where those facilities are connected through main electricity grids with onsite generation units. By using historical data, the load has been forecasted and evaluated for various scenarios. Lots of energy savings were observed through the distribution of load. In the future, it is planned to implement ESS for optimal sizing with charging and discharging control techniques.

Sechilariu et al., (Sechilariu et al., 2012) has proposed integrated photovoltaic (PV) isolated buildings in order to run without the requirement of the grid. The proposed Building Integrated PV (BIPV) can simultaneously supply sufficient power to the building and simultaneously supply excess power to the grid. The controller has the capability of predicting the load, cost management, and operation.

Smaller hydropower plants and wind power turbines have been planned by Litifu et al.,(Litifu et al., 2006), for isolated and hilly regions. Since solar and wind power will be less in mountainous regions, the microgrid will be created with compensation between these sources. Improvements in renewable energy will improve the energy sustainability in the microgrid and can work as the primary expansion for future expansion.

A neural network has been used to measure the optimum tilt angle of PV panels in Chatterjee and Keyhani, (Chatterjee & Keyhani, 2012) depending on the location. The amount of energy that can be generated from the PV was also estimated. It is seen that neural networks estimate the required power with high accuracy.

2.6 MICROGRID PROTECTION

The microgrid can run independently of the grid or in cooperation with it. When linked to the grid, the main grid system provides significant short-circuit current protection at the fault spot. However, when operating in islanded mode, fault currents may be created by dispersed sources installed in the microgrid, which must be mitigated. As a result, conventional overcurrent protection devices in AC and DC microgrids are rendered obsolete, and some new solutions should be devised.

In recent years, microgrids have transformed the distribution system's structure away from passive to active networks. This modification rendered over-current-based techniques ineffective in protecting new structures (Michelle et al., 2014; Mirsaeidi et al., 2017). Inverter-based DG sources can only contribute two to three times the maximum load current to a microgrid's fault current because their power electronic equipment isn't strong enough to keep the heat away from them. People who live on their own would have to wait a long time for protective devices in a microgrid powered by distributed generation through inverters to work, or they wouldn't work at all. Because of the huge difference in short circuit current between grid-connected and isolated modes, ordinary single-setting overcurrent relays can't protect dual-mode microgrids (Bui et al., 2016; Hussain et al., 2016). As a result, overcurrent protective devices cannot be utilised to protect ac microgrids and sub-grids, including those powered by inverter-based DG sources, and some novel solutions need be developed (Mirsaeidi et al., 2018).

A research by Swathika et al. (Swathika et al., 2017) demonstrated how a central protection system (CPS) can monitor and defend a microgrid adaptively. The CPS detects network faults with the use of fuzzy logic. After establishing the position and location of the fault, Boruvka's assisted Dijkstra's approach is utilised to determine the microgrid topology at each moment in time and the least weighted path connecting the faulted region to the next active source. Thus, during fault clearance, the graph algorithms can isolate the smallest possible portion of the network. The adaptive protection method based on fuzzy and graph algorithms is successfully created and verified on a reconfigurable IEEE 21-bus test microgrid system. This protection approach is easily applicable to microgrids of any size.

Hosseini et al. (Hosseini et al., 2016) underlined the need of employing offline decision-making in microgrid protection, which can compromise an otherwise powerful protection plan. This is because offline decisions may not include all possible microgrid operational topologies in the protection strategy. Alternatively, it is discovered that employing a multi-agent strategy is the only method capable of responding to microgrid structural changes with a high degree of flexibility and reliability. Using proper communication channels, this technology enables real-time analysis of all network changes and selection of the optimal protective strategy for the microgrid's architecture.

A novel strategy is laid out in (Ghisla et al., 2011) to protect DC power delivery circuits from failures and instabilities caused by negative cumulative impedance. The suggested device may work in current limiting or impedance transition mode, or it may act as a power buffer during transient upstream disturbances, depending on the system requirements. The method enables collaboration across hierarchical security layers, facilitates system reconfiguration, and enhances system stability. The controller achieves all three levels of safety automatically, focusing exclusively on local current and voltage measurements.

A protection system for ring type DC microgrid system has been proposed by Aswani and Kanakasabapathy (Aswani & Kanakasabapathy, 2016). Rather than shutting down the entire device in the event of a failure, the proposed technique isolates the malfunctioning microgrid network component. The programme finds the issue using differential current and then isolates the section using the current derivative.

Protection techniques for an isolated microgrid near a mine site has been presented by Yuan et al., (C. Yuan et al., 2015). A communication-based differential protection technique that utilises relays has been used to separate the parts with faults. An overcurrent protection relay has been used as an additional protection. MATLAB Simulink was used to simulate the microgrid's security and dependability.

Oudalov & Fidigatti, (Oudalov & Fidigatti, 2009) has presented an adaptive protection approach through advanced communication and digital relays. The protection settings have been fixed by controlling the microgrid by switching between its various operating modes. However, the integration must be more prepared to connect to the main grid. Additionally, fault computations were quite advanced for a microgrid operating in many modes. In Sortomme et al. (Sortomme et al., 2010), have shown a differential-based protection approach has been designed to safeguard against radial and looped microgrids in both modes of operation. However, the proposed solution was only effective for line security and lacked the ability to safeguard buses connected to DG units or loads. Nikkhajoei and Lasseter (Markin et al., 2015) developed a novel approach to protection based on symmetrical components. To safeguard microgrids from asymmetrical faults, the scientists used zero and negative sequence currents. The proposed technique, however, was inefficient at detecting three-phase defects, and also, the capacity of single-phase tripping was not explored. Following that, in a study conducted by Zamani et al. (Zamani et al., 2011) another protection strategy employing zero and negative-sequence components was developed to safeguard microgrids against various types of faults. Additionally, the proposed technique did not necessitate the use of any communication infrastructure. The main problem with the proposed method was that it was limited to radial microgrids, so it couldn't protect microgrids with looped feeders or transformers that were grounded. Because the strategy used zero-sequence current measurement, it couldn't protect microgrids with grounded transformers.

2.7 INTELLIGENT CONTROLLERS

Giacomoni et al., (Giacomoni et al., 2012) has developed a simulation methodology that uses sequential Monte Carlo to examine the performance of autonomous microgrids that use smart controllers to control the generation and load. The sensitivity of the microgrid to large amounts of wind generation has a negative effect on its performance. Hence, a large capacity of ESS is required in the case of a large installed capacity.

The problems faced by high capacity power sources in small and limited microgrids have been discussed by Chowdhury et al., (B. H. Chowdhury et al., 2010). In order to control the limit of generation of electricity as per the requirement, smart controllers that control the wind plant pitch angle and the rotor speed have been discussed to control the frequency regulation. It is also recommended to use a Static Synchronous Compensator (STATCOM) to stabilise the microgrid voltage at times of short-circuit faults.

A fuzzy logic control system has been utilised by Alajmi et al.,(Alajmi et al., 2010) for "*Maximum Power Point Tracking (MPPT)*" in PV systems. Hill climbing search methods were fuzzified before implementation to counter the drawbacks. The use of fuzzy logic with MPPT is seen to be effective for improving the performance of capturing solar power. Perturb and Observe (P&O) techniques have been performed by Abdelsalam et al.,(Abdelsalam et al., 2011), and compared with other MPPT algorithms, which shows that the existing algorithms have complexities in the oscillations and high computational load. A modified P&O algorithm that provides better performance than the existing MPPT algorithms. No oscillations were observed near the maximum points with the proposed method. Kamel et al.,(Kamel et al., 2015) has combined high-density storage with capacitors to maintain the power reliability in microgrids. A fuzzy logic controller was utilised to regulate the power generated by the wind turbines and to regulate the power flow during islanding mode. The proposed controller has been compared with existing pitch controllers to control the generation of wind turbines.

Yuan et al. (M. Yuan et al., 2019) has provided a hierarchical control technique for a distributed generation, energy storage, and load DC microgrid. The designed hierarchical protocol consists of two layers in order to maintain power balance and bus voltage fluctuation based on resource variation and dynamic load capabilities. The primary layer of the proposed strategy utilises an adaptive drop controller with a voltage feedback compensation circuit for energy storage system for electrical parameters with dynamic power sharing of bus voltage deviation. The next stage uses supervisory control design for exchanging power and enhancing the system stability of operation. The analysis is carried out by taking into account MPPT and drop control modes with effective bus regulation for a variety of load demands. The results have shown that the proposed strategy controls the fluctuation in bus voltage with dynamic power sharing. However, this research does not provide results for different load conditions.

Sedaghati and Shakarami (Sedaghati & Shakarami, 2019) has proposed a method for controlling and managing a grid-connected microgrid with a hybrid renewable energy system (HRES) and a three-phase load. The HRES system is comprised of a photovoltaic (PV) system, a battery storage system (BSS), a supercapacitor (SC), and a solid oxide fuel cell (SOFC) (SOFC). To ensure system reliability, the SOFC source is used to keep the BSS fully charged. The direct current (DC) voltage is then converted to alternating current (AC) using a three-phase voltage source inverter (VSI). In VSI-based HRES systems, an adaptive fractional fuzzy sliding mode control (AFFSMC) technique is described to assure power balance and proper load sharing. The controller is capable of precisely and rapidly tracking specific commands within the microgrid. The stability of the control mechanism under load fluctuation is investigated using a sliding surface with fractional order. Additionally, fuzzy sets based on fractional adaptive rules are used to accurately forecast the microgrid's unknown properties. The simulation results demonstrate the effectiveness and capacity of an AFFSMC method under a variety of fault and loading conditions. Additionally, the proposed control strategy is evaluated in comparison to a traditional proportional integral derivative controller.

2.8 ENERGY MANAGEMENT

Microgrids are classified on the basis of their arbitrage, reliability, and power quality in Paquette and Divan,(Paquette & Divan, 2012). However, all these microgrids require inverter-based installations along with ESS so that the microgrids with critical loads have good power quality that is higher than or on par with the utility grid. A control strategy has been presented by Elrayyah et al.,(Elrayyah et al., 2014) for microgrid that integrates PV source along with MPPT controller. In this work, the controller disables the MPPT controller at times when the frequency needs to be stable.

Xing et al., (Xing et al., 2019) has proposed a framework for a hierarchical energy management scheme with the utilisation of distributed model predictive control (DMPC) for grid-connected microgrids. The developed framework was performed under two scenarios with global and individual performance operations. In the first stage, internal power exchange is performed through the incorporation of DERs. In the second stage, the microgrid is installed with a local controller to solve the global cost function to retain the Parento solution.

Giaouris et al. (Giaouris et al., 2018) has developed a microgrid energy management method for control and operation of grids with consideration of multiple stochastic loads. The proposed model uses a real hybrid energy system located in Greece with the concept of space modelling of power network transformation and hybrid dynamical system of operation. To adopt load management capability, the developed model encompasses logical, structural, and temporal features. The proposed model performs multi-criteria assessment for different energy management strategies for effective mixing with the load. However, this research does not offer practical implementation of the developed model for analysis.

Esmaili et al. (Esmaili et al., 2018) has presented an energy scheduling approach in microgrids for reducing the energy loss and operating costs with flexible loads for grid connections that are utilised as network resources. Electric vehicles have been considered as a type of flexible load and simulated. Under the proposed concept, EVs serve as a distributed energy storage system (ESS) for tracking lower-cost electricity and utilising renewable energy from upstream networks. Iovine et al.,(Iovine et al., 2019) has presented a power management controller framework for DC microgrid systems that consists of storage elements, renewable energy sources and load. The output power remains constant, ensuring grid stability and power balance even with dynamically varying power sources. Moreover, the DC microgrid has also considered the constraints for the controller to balance the power and desired voltage level of the system. The efficiency of the controller was better than the traditional method.

2.9 INTERCONNECTED MICROGRIDS

Zhang et al. (Zhang et al., 2018) has presented an economic and collaborative model for integrating multiple microgrids together. Since this is difficult, a two-stage adaptive robustness algorithm has been used to optimise the power flow between the microgrids with a collaborative operation model. From the results, it is seen that the approach effectively reduces operating costs with an uncertain distribution of energy sources. However, this research fails to provide the percentage energy consumption rate of the grid model.

A hierarchical stochastic energy management system has been proposed by Bazmohammadi et al. (Bazmohammadi et al., 2019). At a lower level, a decision-making process has been implemented for the local operation management of each microgrid with different sources of uncertainty. At the highest level, the central entity is responsible for coordinating the functioning of the microgrid when many microgrids are connected. The simulation results demonstrate that the proposed strategy successfully regulates the lead between the various microgrids and minimises reliance on the main grid. It has also improved the real-time power deviations. However, the computational time is high in the proposed model that includes the control parameters and prediction due to the increase in the number of microgrids. This study also does not consider power line and communication failures; hence, there is a need for an isolated mode of operation for interconnected microgrids.

A research by Abdali et al. (Abdali et al., 2019) has proposed a DC multi-microgrid simultaneous protection and control interface, so that the controller and protection systems' performance is distinct but combined. As a result, the functioning of a DC multi microgrid remains unaffected under a variety of conditions, such as a change in the active power of DGs or a short circuit. The simulation results demonstrate that the control interface and protection method proposed for DC microgrid-connected systems are highly effective.

2.10 MACHINE LEARNING TECHNIQUES

Load forecasting is essential to appropriately generate the required electricity as per the load. Wen et al., (Wen et al., 2019) suggested a system for estimating residential hourly power consumption and PV generation using a deep recurrent neural network with long-term memory units. PV arrays, energy storage systems (ESS), domestic power loads, and electric vehicles (EVs) have all been given optimal load dispatch frameworks under various scheduling circumstances. The load dispatch model was optimised using a particle swarm optimization technique. The simulation results indicate that EVs and ESS can help shift peak load, increase solar energy utilisation, and cut daily expenditures by 8.97 percent. Optimization and forecasting models were performed separately, and there is a need to systematically explore the dynamic mechanism. Additionally, more fine-grained data is required to optimise the load dispatch in real time. Load forecasting has also been performed by Wen et al. (Wen et al., 2019) in microgrids to estimate the loads in the future. ANN has been used in this work. However, they have not considered the time dependencies in the power load profile, hence the forecasting results are not good. So, there is a need to develop a better model that performs better in feature representation, mapping, and assuming time dependencies.

Providing security to the grids from faults and power surges are necessary. Artificial Neural

Network has been presented by Almutairy & Alluhaidan, (Almutairy & Alluhaidan, 2017) for detecting the fault location in the microgrid system to protect against the effects of short-circuit faults. ANN is described for one circuit breaker which gets the information from the present module in a DC microgrid. The output of the circuit breaker is connected back to the circuit once the fault is cleared in the microgrid. The machine learning algorithm will detect when to open and close the circuit breaker based on the line parameters.

Discrete Fourier Transform (DFT) has been used by Kumar et al., (D. S. Kumar et al., 2016) explored microgrid DGs protect the relays through a relay mechanism. The issue of varying fault currents that affect the relays is addressed using the technique. Fuzzy logic has been used to embed the proposed technique in order to obtain optimum protection in the IEEE 34 system. According to the simulation results, the proposed system was able to adapt to varying currents and select the most suitable protection.

Learning-based systems have been introduced in recent years to research the topic of microgrid energy resources. Learning-based methods will alleviate the need for a specific description of the framework and a prediction to cope with the uncertainties. The system would find a near-optimal strategy based on its strategy. For example, Brida et al. (Mbuwir et al., 2017) used the batch reinforced learning (RL) technology to build a battery energy management technique for a microgrid. Kim and Lim, (S. Kim & Lim, 2018) advocated a reinforcement learning-based energy management system for a smart microgrid-like structure with low running costs.

Ganesh et al. (Venayagamoorthy et al., 2016) has suggested an evolved hierarchical adaptive programming and RL paradigm for the complex energy control of an intelligent microgrid. Elham et al. (Foruzan et al., 2018) established a multi-agent RL framework for optimal distributed energy storage within a microgrid. Many learning-based methods introduced in the foregoing works, though, suffer from the disadvantage of dimensionality and have trouble managing microgrids of high-dimensional state variables and uncertainties. Also, Deep Reinforcement Learning (DRL) in the machine learning community was suggested to address the problems. The DRL strategies tackle the problem of learning from high-dimensional state sources by exploiting deep neural networks' end-to-end learning capabilities. These algorithms have achieved better success rates in improving the energy management systems (Mnih et al., 2015; Silver et al., 2016).

2.11 MICROGRIDS IN ARMED FORCES/ MILITARY

Masrur et al.,(Masrur et al., 2017) has analysed Vehicle to Grid and Vehicle to Vehicle-based microgrids for military applications in comparison with standalone systems. This research has focused on the optimisation of microgrid performance with consideration of external loads and sources to maximise the economy of fuel. The analysis of V2G-V2V communication for military applications is based on the demand for power load involved in logistics benefits for the generation of power. From the results, it is seen that the V2G-V2V system exhibits more effective performance than standalone systems. A 30% reduction in power usage has been observed in the microgrid. However, this research has failed to provide a detailed explanation of the performance of the V2G-V2V system.

Eichenberg et al.,(Eichenberg et al., 2016) has evaluated the performance of PV systems in microgrids for reduction of risk and operational cost. To evaluate the performance of PV sources, this research has focused on the thermal efficiency along with moderate-sized forward operating bases (FOBs) PVs. The optimal selection of the units has been simulated and evaluated, and it is seen that the model significantly minimises energy and diesel consumption with an increase in generation capacity. However, this research does not measure the amount of reduction in the FOB PV system.

Kashem et al., (Kashem et al., 2018) has reviewed the microgrid technology in applications of off-grid energy generation systems for the applications of military forces. Research has also evaluated smart grid integration in recent years. It has been concluded that an optimal microgird effectively reduces the fuel cost and dependency. Microgrids can be customised based on optimization, scale, and localization.However, this research has focused on fuel consumption rates and not on the performance efficiency of the microgrid in military applications.

Anglani et al.(Anglani et al., 2016) has presented an Optimised Energy Management System (OEMS) for microgrid application for temporary military bases using diesel generators, ESS, and photovoltaic panels. Batteries can be charged by photovoltaic (PV) or diesel generators. The OEMS's power circuitry enables charging the batteries from either of these sources. As long as it is used with one of the generators, it can serve as either a source of current or voltage for the loads. In this method, special ordered sets are used to handle semicontinuous functions and do economic analyses. They take into account how big a BESS is, and how that affects its charge/discharge cycle and its life. This is how OEMs use the results of optimization. The OEMS uses this information to make sure that energy sources are coordinated and that critical and non-critical loads are met with available energy. The results showed that the proposed model effectively saves fuel at a rate of around 30%. But this research does not offer any comparative measures with existing approaches. Similar work was also performed by Anglani et al.,(Anglani et al., 2017). The life time of the battery and the fuel consumption rate have been analysed effectively. From the results, it is seen that the integration of microgrid with ESS has effectively differentiated between critical and non-critical loads. The developed approach exhibits a power saving capability of around 30%. However, the performance of individual loads was not assessed in this work.

Oriti et al.(Oriti et al., 2018) has developed a controller for military-based microgrid applications. The proposed controller design manages the current flow and avoids high costs for the supporting system when discharge happens at the minimal operation limit. Furthermore, the designed controller facilitates the selection of a low pass filter independently. However, this research does not offer any significant advantages to the proposed controller and has only designed and presented it.

Ersal et al.,(Ersal et al., 2011) has developed a microgrid model with an architecture along with the incorporation of SPIDERS ("*Smart Power Infrastructure Demonstration for Energy Reliability and Security*") specifically for military applications. The developed model considered frequency, voltage, and power for inverter usage of micro sources in a microgrid. Additionally, the charging and discharging cycles of the battery are regulated. The control parameters were controlled effectively, however, the performance was not analysed properly with mathematical models.

Bunker et al.,(Bunker et al., 2018) has adopted a multidimensional droop management system that is optimal for photovoltaic sources connected to a microgrid in military applications. The simulation illustrates that the source can produce the needed quantity of power due to the droop control relationship. This control method keeps the benefits of traditional droop control while removing the need for a communication link between system parts. It also lets you use all of the energy from the sun's photovoltaic cells, which is better than traditional droop control and high-dimensional droop control with a plane.

2.12 DEVELOPMENTS IN US ARMY

> “*In World War II, the United States consumed about a gallon of fuel per soldier per day, in the 1990-91 Persian Gulf War, about 4 gallons of fuel per soldier was consumed per day. In 2006, the US operations in Iraq and Afghanistan burned*

> *about 16 gallons of fuel per soldier on average per day, almost twice as much as the year before "* (Samaras et al., 2019)

> *"...**Amory B. Lovins**, chairman and chief scientist at the Rocky Mountain Institute, in Colorado, calculated that a typical Marine Corps combat brigade needs more than a half-million gallons of fuel per day, and much of it is for generators. A single typical 60-kilowatt generator burns 4 to 5 gallons per hour, or $700,000 per year based on an estimated fuel cost of $17.44 per gallon in Afghanistan. Fueling one base's generators might cost more than $34 million per year." (www.purepower.com)*

The US Army and Department of Defense consider reduced energy demand on the battlefield, a major military challenge across all operations in diverse locations, as the US just released its first-ever Operational Energy Strategy (March, 2013). Military microgrids that never fail to operate are pushing the envelope of distributed energy management. When the US Army and Lockheed Martin built the first grid-tied microgrid at Fort Bliss in Texas, it was a big deal for the Department of Defense. The project (*Mixed-Greens-300-Mw-of-Storage-in-Hawaii-Microgrids-in-Tx-Cigs-and-More @ Www.Greentechmedia.Com*, n.d.), began operations in 2010 and supplement the base's current backup generators with renewable energy (a 120-kilowatt solar array) and energy storage (a 300-kilowatt battery system). Additionally, with Lockheed's Intelligent Microgrid Control System, it is connected to a microgrid.(*2013-05-16-U-S-Army-and-Lockheed-Martin-Commission-Microgrid-at-Fort-Bliss @ News.Lockheedmartin.Com*, n.d.). A microgrid, alternatively referred to as an islanding grid unit, is a project that incorporates on-site energy resources such as solar, batteries, and backup generators into a self-contained, islanding grid unit. Even the military is a pioneer in microgrid technology, owing to the military's requirement for a fail-safe, always-on electricity source, particularly in the event that the larger grid fails, regardless of how expensive. The US Army is rapidly deploying microgrids for military locations, with a premium on physical and cyber security, to ensure reliable power without relying on the Macrogrid system. Military microgrids on wheels are also included in this category, as are forward operating bases in regions such as Afghanistan.

To perform the United States Armed Forces' worldwide operations on land, air, or sea, energy supply over large distances, through severe weather and topography, and frequently against determined adversaries, is required. From 2011 to the present, the US Department of Defense has made significant progress in reducing energy consumption at contingency bases, adapting their requirements and force development processes, and establishing an operational energy policy and oversight framework across the Services, Combatant Commands, and the Department of Defense as a whole. The Department of Defense developed and issued the 2016 Operational Energy Strategy to reflect both the critical role of operational energy in warfighting and the risks associated with ensuring its reliable delivery (Office of the Assistant Secretary of Defense for Energy, 2016). Building on these accomplishments, the 2016 Strategy refocuses the Department of Defense's attention on a more precise set of objectives, which include:

- Improving future warfighting capability by utilising energy in force development.
- Improve the current force's mission effectiveness through modernising equipment and improving training, exercises, and operations.
- Recognize and mitigate logistics and operational risks caused by operational energy weaknesses.

The Strategy document defines military operational energy as "the energy required for training, moving, and sustaining military forces and weapons platforms in support of military operations," while the Department of Defense defines it as "the energy consumed during military operations, in direct support of military operations, and in training that supports unit readiness for military operations," including energy consumed at contingency bases.

The study for US Army (Siritoglou et al., 2021) described a simple approach for reliably estimating the distributed energy resources of a stand-alone microgrid in order to meet the load requirements of a military, commercial, industrial, or residential location in the absence of utility power. Microgrids integrate solar photovoltaic (PV) energy with energy storage to enhance the energy security of critical-load buildings. Reasoner et al. (Reasoner, 2016) by designing an isolated microgrid, adopting a holistic approach to improving the electric power generation system for a future forward operating basis. The design approach began with an analysis of the operating base demand and demand-side management improvements, followed by an assessment of multiple generation sources and energy storage choices, followed by a HOMER discrete optimization to determine the optimal microgrid architecture. In addition, sensitivity analysis was carried out to examine the impact of changing parameters on the outcome.

In (Christopher, 2019) Christoper et al. created a technique and a novel metric for the design and validation of microgrids with the goal of achieving resiliency. According to a system engineering analysis, the microgrid's job is to provide power to assure mission completion. Microgrids enable Armed Forces facilities to continue missions by powering critical loads in the event of utility power failure. A novel technique was developed to appropriately handle mission accomplishment resiliency, which was not adequately addressed by previous research and tools for microgrid design and assessment.

2.13 DEVELOPMENTS IN INDIAN ARMED FORCES

The Ministry of New and Renewable Energy of India approved and built more than 300 MW of SPV Power Projects for the Indian Armed Forces in 2015, with the help of Rs. 750.00 Crores from the Jawaharlal Nehru National Sun Mission. The projects were to be set up under various defence establishments. The 150 MW projects were allocated to the Army, Navy, and Air Force, with the balance of 150 MW going to the Ordnance Factory Board, Defence Labs, and Defence Public Sector Undertakings. The Military Engineering Services is in the process of establishing 156 MW of solar power plants across 134 military stations of the Armed Forces. Details of projects are shown. Only a few military bases have used solar photovoltaic systems to power military operations, which means there is a lot of room for growth. Details of the Solar PV systems being installed are as given in Table 2.1 Details of Solar PV systems being installed in the Armed Forces in India

Table 2.1 Details of Solar PV systems being installed in the Armed Forces in India

SERVICE	PLANNED (MW)	NUMBER OF MILITARY STATIONS
AIR FORCE	31	36
ARMY	97	72
NAVY	28	26
TOTAL	156	134

A number of grid-connected PV systems are being installed in the Indian Armed Forces in many military stations and some remote areas. The systems are feeding into the grid, but none of them is integrated with other renewable sources or energy storage systems as a microgrid.

A large number of remote bases of the armed forces are located all along the borders in inhospitable areas where they are dependent on diesel generators and the carriage of fuel is a logistic challenge, especially for places that are in high mountains and have no roads or connectivity for months at a stretch. The energy needs of these remote areas can be met by integrating renewable sources and energy storage systems controlled by a controller as a microgrid. These microgrids have the potential to reduce energy consumption by more than 35% (Engels et al., 2014). There is no literature on microgrids for remote bases of the Indian Armed Forces.

2.14 GAP

Based on a review of the literature, it is obvious that there is a large and widespread deployment of microgrids all over the world, with the number of installations expected to increase in the future. This has resulted in more effective and efficient designs, as well as more cost-effective operation of microgrids. Microgrids are becoming popular since such systems have enormous potential to electrify remote places that are still not connected to the grid via transmission and distribution networks. The existing literature has focused on any single process of implementation, like controllers, source power improvement, power electronics components, energy sources, and load management. Some of the microgrid models reviewed above have not taken into consideration the specific needs of the user (based on field specifications) into account. However, there are very few studies that deal with the implementation of microgrids specifically for the armed forces considering their special conditions.

A literature survey indicates that the US Armed Forces are aggressively developing and investing in enhancing their energy security by implementing policies and creating microgrids. This is a result of a number of energy studies, analysis, and their experiences in various military operations. The survey indicates that India has the second largest military force in the world with a large number of remote bases on its border and has yet to address the issue of creating microgrids in remote bases to enhance energy security. Designing a microgrid for a remote base to cater to its operating conditions, critical requirements, and specific needs will be a starting point for our Armed Forces.

A review of the literature reveals that significant effort has been proposed for microgrid networking to improve economics. Additionally, coordination across several local microgrids inside any urban region has been shown to increase overall quality and customer satisfaction. However, no study has been conducted on a similar configuration of networked microgrids for use in remote places by the Armed Forces to improve dependability, load sharing efficiency, and outage management for important loads.

From the literature, it is seen that microgrids provide lots of advantages to remote areas and the Armed Forces throughout the world. There is no suggested design and specifications of commercially available equipment for developing a microgrid for the armed forces in remote areas to cater for their energy needs. The aging infrastructure of the grid and long distance to the end user causes the country's power efficiency delivery to fall below 50 percent - meaning more than half of the power utilities produce goes to waste as lost heat or as transmission losses. Alternatively, microgrids often run at 80 percent efficiency and hold steady at 66 percent efficiency.

2.15 ORGANISATION OF THE THESIS.

This thesis has been divided into seven chapters. With the introduction provided in Chapter 1, Chapter 2 presents the detailed literature survey conducted for this thesis work. This chapter provides an overview of different kinds of microgrids, along with their problems and possible solutions, provided by different researchers. The gap in literature is highlighted at the end.

Chapter 3 presents the design and simulation of individual subsystems included in the complete microgrid system. This chapter has provided a description of PV systems, energy storage systems, control algorithms for maintaining the dc-link voltage, 3-phase inverter design along with control strategy, and diesel generator sets. In other words, it can be said that this chapter forms the basic foundation of the further work done in this thesis.

Chapter 4 presents the detailed design and simulation work of the 1-MW standalone microgrid system for a remote location of armed forces. This chapter presents the algorithm for incorporating a backup system in case there is a problem with the PV and energy management systems. Simulation results obtained after testing the MATLAB model under different conditions have also been presented in this chapter.

Chapter 5 presents a system of networking of different microgrids located at three remote geographical locations. The strategy of interconnecting such microgrids for reliable load sharing has been discussed in detail in this chapter. Several simulation studies have been done and the obtained results show the satisfactory performance of the entire system. The system is simulated for outages and load sharing.

Chapter 6 presents the design, specifications, and implementation of the design and construction of four microgrids in remote bases of the Armed Forces in the Andaman and Nicobar Islands, with 1-MW microgrids at Port Blair, Shibpur, and Car Nicobar, and a 250 KW microgrid at Kamorta Island. Detailed design specifications and different schematics of the actual microgrid at Port Blair have been presented in this chapter. This chapter also highlights the dire need for microgrids in the armed forces for remote locations.

Chapter 7 concludes the work done in this thesis and also highlights the possible work that can be done in the future. Chapter 7 is followed by the references used in this thesis work.

3 METHODOLOGY : DESIGN OF MICROGRID COMPONENTS

This chapter discusses the design and simulation processes of individual subsystems included in the complete microgrid system. It provides a description of PV systems, energy storage systems, control algorithms for maintaining the dc-link voltage, 3-phase inverter design along with control strategy, and diesel generator sets. In other words, it can be said that this chapter forms the basic foundation of the further work done in this thesis.

3.1 INTRODUCTION

Designing a complete microgrid is a typical process as it contains several different complex subsystems and synchronisation is also required between them. The design of each individual component of the proposed system is modelled first, thereafter validated for its performance, and finally integrated to form the microgrid. In this thesis, a similar strategy is being used for designing the complete system. This chapter discusses the design and simulation processes of individual components of the microgrid in detail, and the performance of each component is validated.

3.2 PV SYSTEM DESIGN

The performance of a photovoltaic system totally depends on the sun's irradiance to generate electricity. The sun radiation may be fall on any place on earth due to the rotation of the Earth during the whole year and the intensity of radiation rely on many factors such as latitude (α), hour angle (ω) as well as declination for a day. The parameters applied to describe the terminal assets of a solar cell are the short circuit current I_{sc}, the fill factor FF and open circuit voltage V_{oc}. The expression for fill factor can be defined as:

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}} \tag{3.1}$$

Where V_{mp} and $I_{mp}$are the voltage as well as the current of solar cell to achieve the maximum output power. The features of the solar cells also vary based on the type of cells. Figure 3.1 VI curve of a solar cell under forward voltage bias.

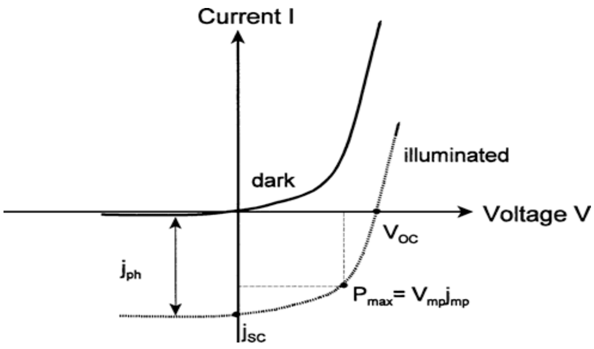


Figure 3.1 VI curve of a solar cell under forward voltage bias

3.2.1 Components of a Simple PV System

Photovoltaic energy is made by a lot of different things. Photovoltaic cells can be linked together in series or in parallel to make the panel's output voltage and current go up. Also, photovoltaic systems have diodes that are called "bypass diodes." It helps keep good, well-lit solar cells from overheating and burning out weaker or partially shaded solar cells by providing a way for current to flow around the cell that isn't good. Diodes called blocking diodes, on the other hand, are used in a different way. To move electricity around photovoltaic cells or panels, bypass diodes are used. Blocking diodes, on the other hand, are used to stop electricity from flowing back into them. The diode is usually the same, but it's in a different place and for a different reason, so blocking diodes and bypass diodes are two different things.

3.2.2 Methods of operation of a PV system

The primary distinction between grid-connected and independent solar systems is autonomy. Along with a large storage system, an isolated system should be enormous. A charge controller should be used in conjunction with the batteries to prevent them from exceeding their limits, which could result in their destruction. However, multiple backup generators are used to boost the system's reliability. When linked to the grid, power can be delivered from the grid. It is vital to monitor inverters while connecting to the grid, as the output of a solar system is direct current. The mathematical model of a photovoltaic array can be expressed in the following equations, which are obtained from the equivalent circuit of a cell, in which all cells are equal.

$$I_{PV} = n_p I_{ph} - n_p I_o \left[e\left(\frac{q\left(v_{pv} + R_S I_{PV}\right)}{AkTn_s}\right) - 1 - n_p \frac{\left(v_{pv} + R_S I_{PV}\right)}{n_s \times R_{sh}} \right] \qquad (3.2)$$

$$I_{ph} = [I_{sc} + k(T - T_r)]\frac{G}{100} \tag{3.3}$$

$$I_o = I_\pi \left[\frac{T}{T_r}\right]^3 exp\left(\frac{qV_{oc}}{AK}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \tag{3.4}$$

where v_{pv} and I_{PV} signify the output voltage as well as current of the PV array, correspondingly. R_S and $R_{sh}$are equivalent resistances of the solar cells that are connected in series and shunt. q is known as the electron charge (1.6 × 10−19 C). I_{ph} is the light produced current, I_o is the saturation current, I_π is the module reverse saturation current, A is dimensionless factor of a junction material, n_p and n_s are the quantity of solar cells that are connected in parallel and series respectively. T is the temperature measured in Kelvin. k is described as Boltzmann constant and represented by 1.38 **X** $\frac{10^{23}J}{K}$.

3.2.3 PV system specifications

Solar energy is the principal source of electricity in the proposed 1 MW islanded microgrid. To achieve the desired electrical properties, the photovoltaic system is made up of PV panels coupled in series and parallel. The photovoltaic system is constructed in such a way that a separate converter and controller are not required for "*maximum power point tracking (MPPT)*".

The proposed microgrid design incorporates a *Soltech 15TH-215*-P solar panel module. One of these solar panels produces 213.15 W and an open circuit voltage of 29V at its highest output. 23 solar panel modules are connected in series to avoid the requirement for a separate MPPT controller and converter. This leads in a maximum open circuit power point voltage of 667V, which is approximately identical to the DC link voltage necessary for a 400 V rms output phase-phase voltage. In a complete microgrid design, the battery DC-DC bidirectional converter maintains this DC link voltage, effectively eliminating the need for a separate MPPT controller for the photovoltaic system. Fig. 3.2 depicts a PV system model with a dummy load connected to the system's output. For the entire simulation, T_{ss} was chosen to be 10e^{-6}. Further RC circuit connected to the PV panel as shown in Fig. 4.1 has the following parameters: $R = 1e^{-3}$ & $C = 1000e^{-6}$.

Additionally, to create 1MW of solar energy at a 1000W/m^2 irradiance, 204 rows of such series connected PV modules are connected in parallel. Fig. 3.3 illustrates this layout graphically. The current vs. voltage and power vs. voltage curves for the full photovoltaic system are shown in Fig. 3.4.

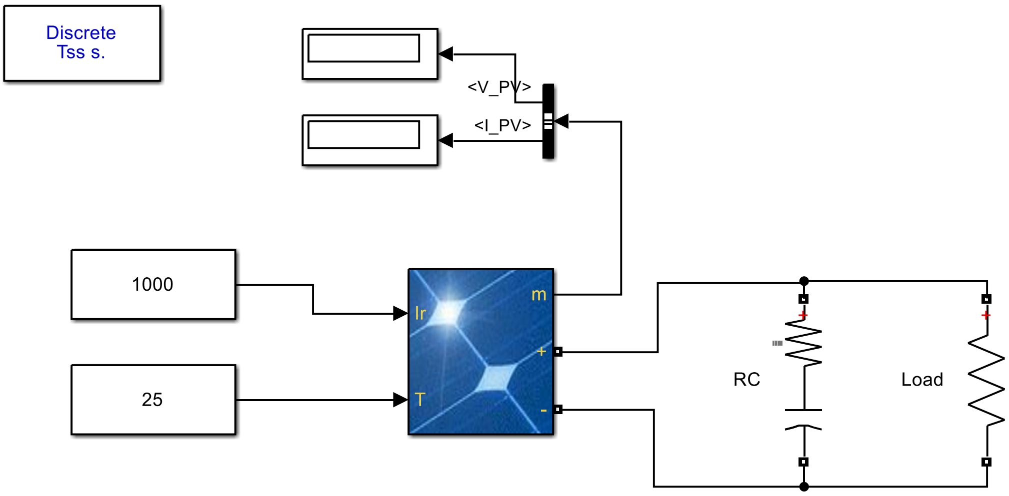


Figure 3.2: Solar Panel connected with dummy load.

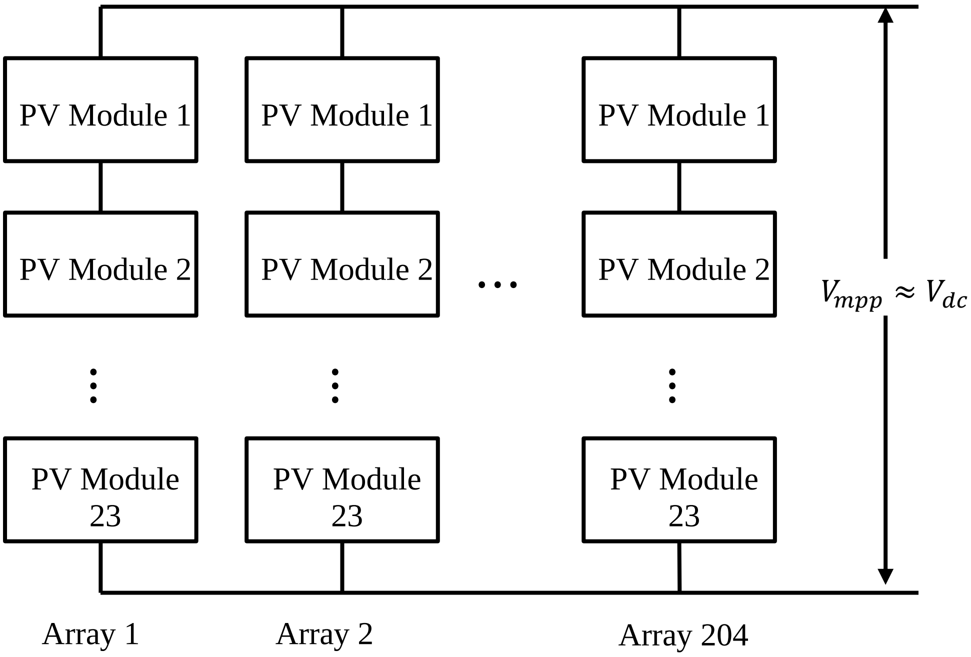


Figure 3.3 : Solar photovoltaic modules are connected in series and parallel to generate the required solar energy

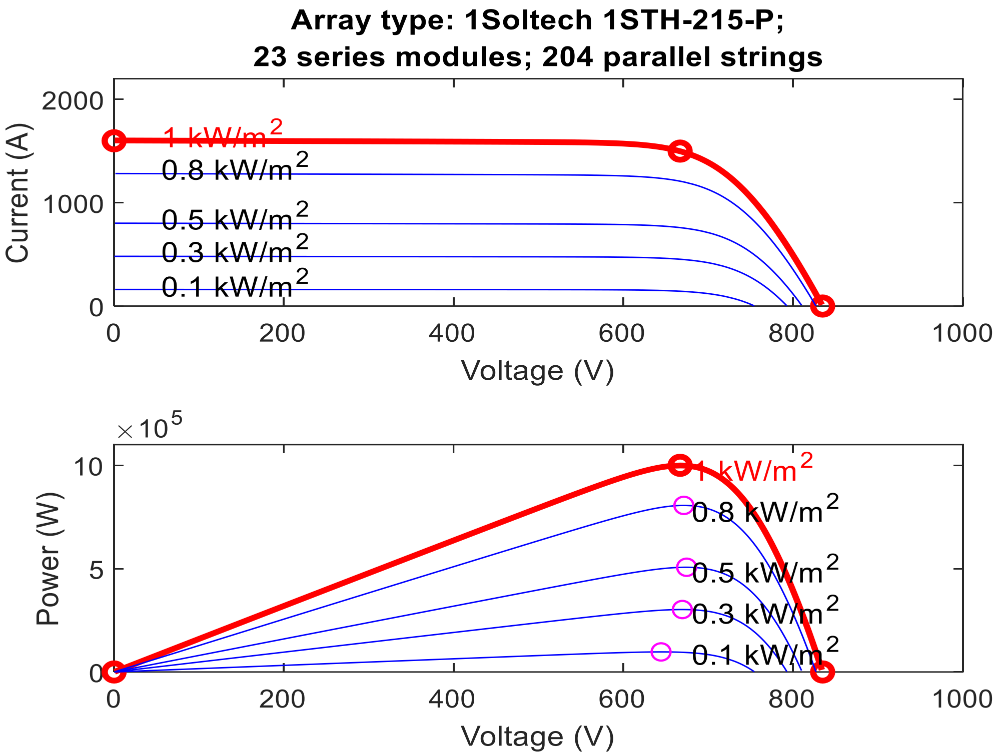


Figure 3.4: Current vs. voltage and power vs. voltage curves for a photovoltaic system with varying irradiances.

3.3 DG SET

The diesel generator is associated with the internal combustion engine, mechanical coupling, automatic voltage regulation system, speed regulator, automatic fuel injection, and fuel tank. It takes a few seconds to ten seconds to start the internal ignition engine. As the frequency and the voltage touch their respective rated values, the switch of the diesel generator is connected to the DC bus. The engine speed is kept continuous due to its speed regulator mechanism, which confirms the 50 Hz frequency of the AC voltage. The governor uses a valve mechanism to manage the fuel input to the engine, as well as the generator output power, and eventually supplies the necessary power to satisfy changes in load demand.

3.3.1 DG set specifications

Solar energy highly depends on the environmental conditions and is not consistent or reliable with its availability only during the daylight hours. In addition, during the monsoon season or on stormy days, solar energy may not be available for several days. Battery systems are generally employed along with PV panels, but they offer power for a shorter period of time and cannot provide power continuously for days. Hence, in order to avoid blackouts due to environmental conditions, diesel generator (DG) sets are integrated into the microgrid design. The chosen DG sets have the same electrical specification of 1MW so that the entire load can be shifted to the DG sets in case of an emergency.

3.3.2 Simulink model of DG set

In this section, a Simulink model of the DG set in standalone conditions has been designed and simulated. Fig. 3.5 shows the Simulink model of the DG sets with dummy 3-phase loads. Fig. 3.6 shows the inside view of the DG set used in Fig. 3.5. The DG set is simulated as a synchronous machine with different controllers connected to it. Further, the voltage and current output provided by the DG set have been shown in Fig. 3.7.

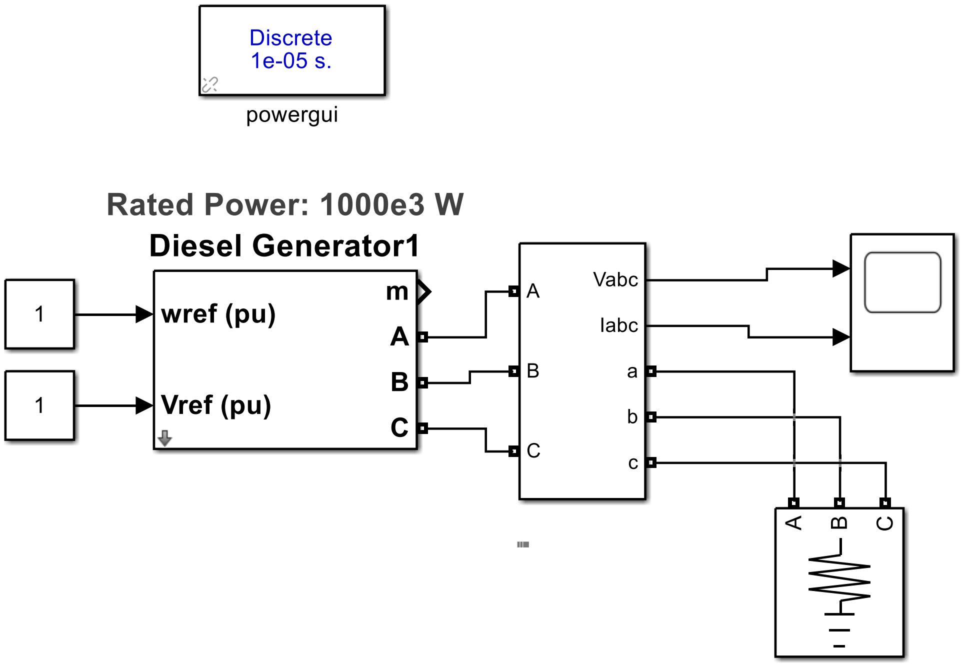


Figure 3.5: 1MW DG set model in Simulink.

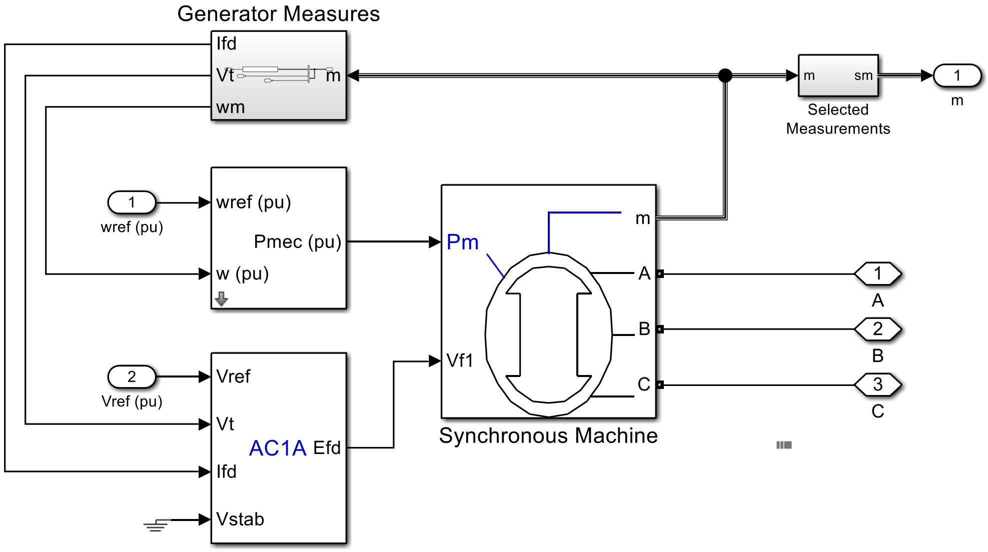


Figure 3.6: Inside view of DG set mask as shown in Fig 3.5.

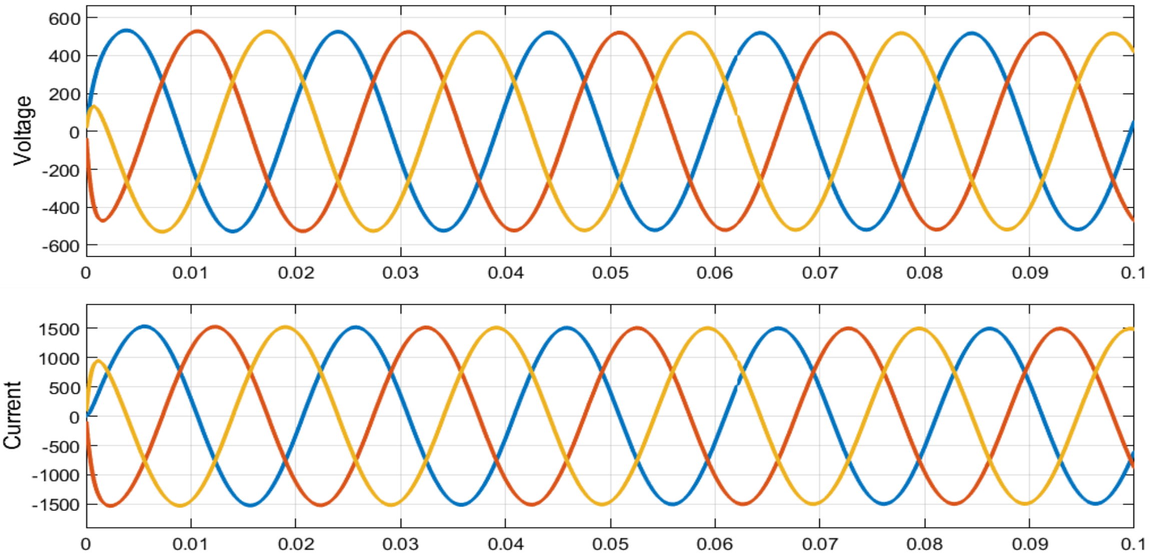


Figure 3.7: 3-Phase voltage and current curves from DG set.

3.4 ENERGY STORAGE SYSTEM

Grid power stability is a crucial requirement for the establishment of a power grid network. One of the major functions of establishing an energy storage system (ESS) is to store energy during positive power inconsistencies and discharge energy during negative power inconsistencies and hence provide stability to the grid. Energy storage methods are differentiated by different features. The choice of energy storage method depends on the following:

- Rated Power [kW]
- Efficiency [%]
- Ramp rate [kW/min or percentage of rated power/min]
- Energy Capacity [kWh]

The rated power signifies the extreme power that the equipment has the capability to achieve during the charging and discharging period. Energy capacity refers to the maximum power that can be stored in the equipment. It is significant to distinguish between the conversion and storage efficiencies when assuming the efficiency of the energy storage system. The ramp rate specifies the ability of a storage mechanism to grow or reduce the energy flow at the time of discharging as well as charging conditions and is normally represented in kW/minute. A battery storage system is an example of an ESS.

3.4.1 Battery system

A battery is an electrochemical device that implements chemical reactions to store and deliver electrical power. Mostly, a battery comprises of two half-cells, such as a positive electrode and a negative electrode, which are detached with the help of an electrolyte and also a membrane separator. Redox reactions happen inside the electrodes, and the generated ions from the reactions are transmitted with the help of an electrolyte. Figure 3.8 : Schematic diagram of battery operation and reaction. The rating power as well as the voltage level of the battery depend on the type of connections among electrochemical cells. The series connection increases the voltage of each cell, whereas the parallel connection increases the capacity by keeping the voltage at the same level. The redox reactions can be formulated as follows::

$$Negative\ electrode\colon M \rightarrow M^{n+} + ne^{-} \tag{3.5}$$

$$Positive\ electrode\colon nX + ne^{-} \rightarrow nX^{-} \tag{3.6}$$

Where e^{-} signifies electrons, M is a metal and X is an oxidising agent.

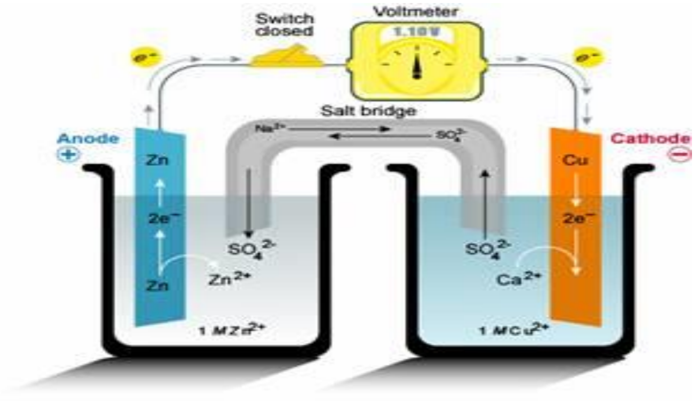


Figure 3.8 : Schematic diagram of battery operation and reaction.

3.4.2 Battery system specifications

This thesis develops an autonomous microgrid, which includes an energy storage system for the microgrid consisting of batteries with a nominal voltage of 500V and a current of 3000AH, as well as an energy management system. A single 24V 150AH battery is being considered in order to meet the demands of the battery system. Twenty parallel-connected battery arrays and twenty series-connected battery arrays are linked together, for a total of thirty-one battery arrays. Fig. 3.9 shows the battery discharging profile as per the specifications.

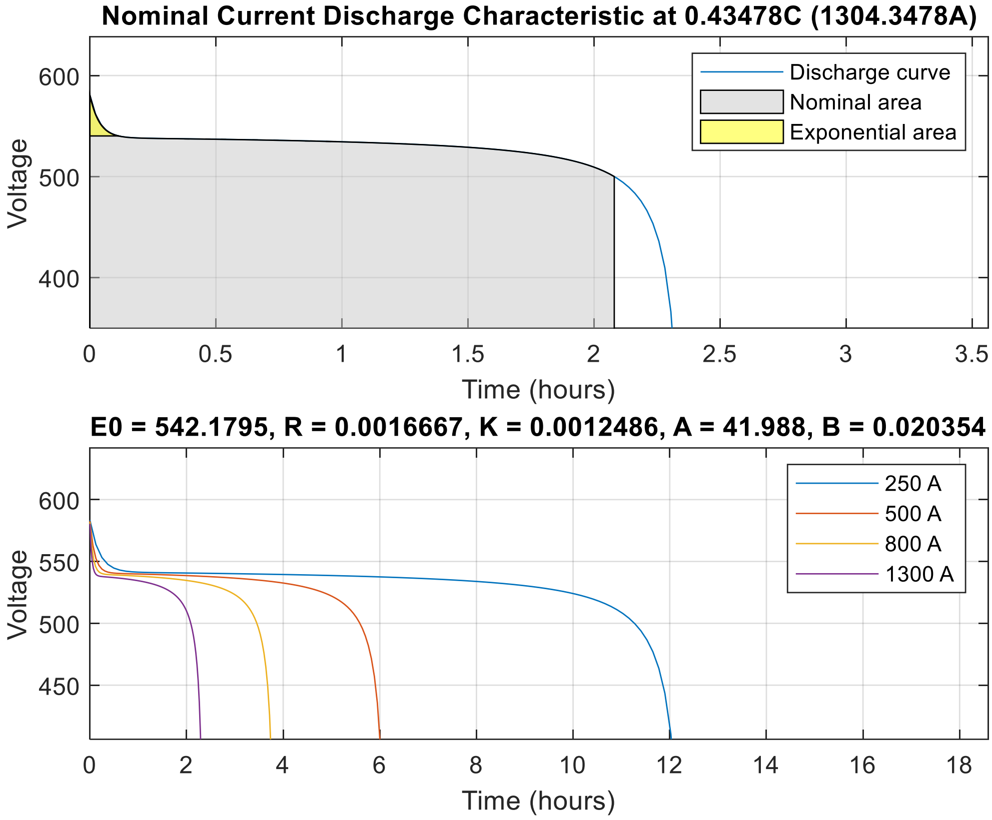


Figure 3.9 : Discharge characteristics of the battery system under nominal conditions.

3.4.3 Battery charging and discharging controller

As mentioned previously, a battery charging and discharging controller is used to maintain the DC-link voltage of the system. A DC-DC bidirectional converter is utilised to accomplish this operation. The suggested battery charging and discharging controller is depicted in Fig. 3.10. To control the operation of the DC-DC bidirectional converter, two proportional integral (PI) controllers were used. The first PI controller determines the required battery current by comparing the reference dc-link voltage to the battery unit voltage.

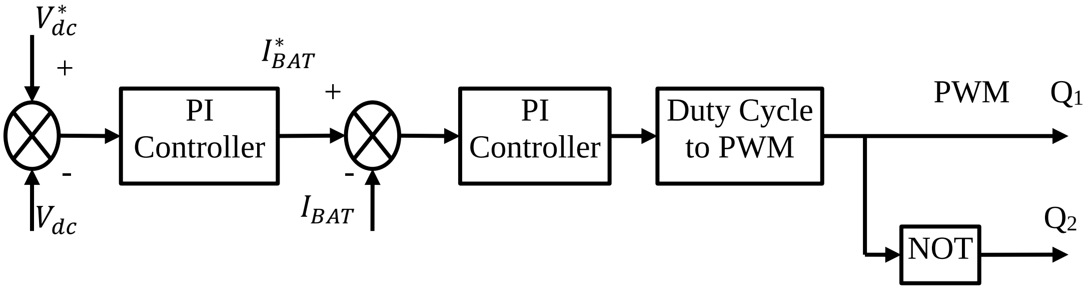


Figure 3.10 : Controller for battery charging/discharging in a bidirectional DC-DC converter.

By varying the duty cycle of the PWM signal, the second PI controller calculates and seeks to minimise the difference between the reference battery current and the actual battery current delivered. These pulse width modulation (PWM) signals are applied to the bidirectional converter's switches, which eventually control the flow of electricity to and from the battery. A restriction limit is added to the output of the first PI controller to guarantee that the required current does not exceed the battery's current parameters.

When more power is necessary and the photovoltaic system is unable to generate enough energy due to inclement weather, the battery begins discharging within its current limits. Similarly, if the load demand is minimal and the photovoltaic system provides surplus energy, the battery will begin charging according to its pre-established specifications.

3.4.4 Simulation of energy storage system

This section discusses the simulation results for the battery subsystem that was created for the microgrid model. Fig. 3.11 depicts the suggested system's Simulink model. Simulink's model also illustrates the control scheme. Further, dummy load of 2Ω was used for this simulation purpose. Numerical values of the series RL branch were taken as follows: $R = 0.05\Omega, L = 5.7610^{-4}H$. Numerical values of the parallel RC branch were taken as follows: $R = 0.001\Omega, C = 1000 \times 10^{-6}F$.

Fig. 3.12 shows the battery SOC and battery current flown from the battery during this entire simulation. Fig. 3.13 shows the battery voltage across its terminals and the variation in the voltage across the load. From these figures, it is clear that current and voltage have stabilised to their reference values in a short period of time. The results validate the effectiveness of the PI controllers in maintaining the dc-link voltage (in this case, load voltage) at their predefined values.

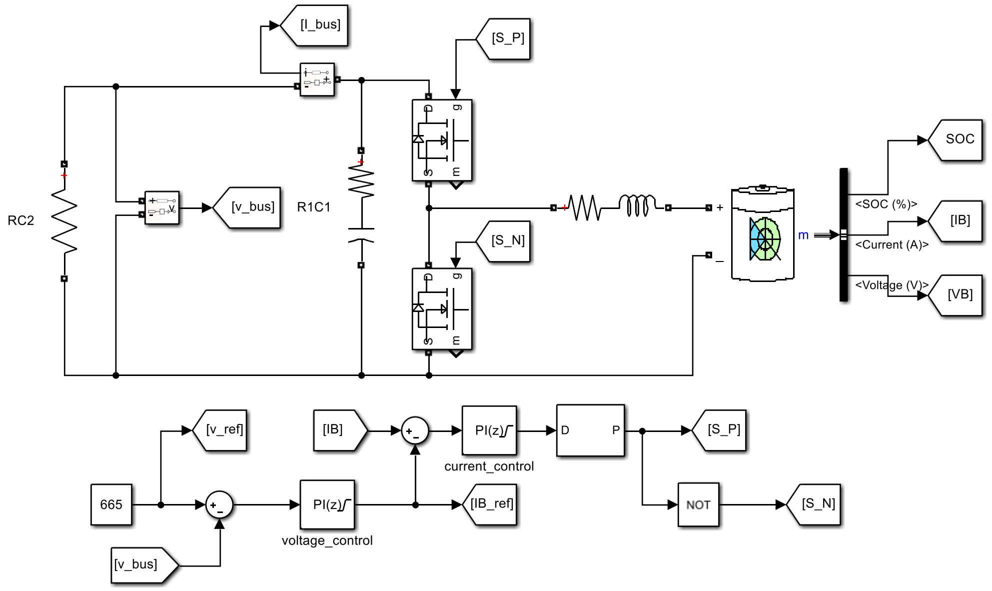


Figure 3.11 :Modelling of Battery System in Simulink.

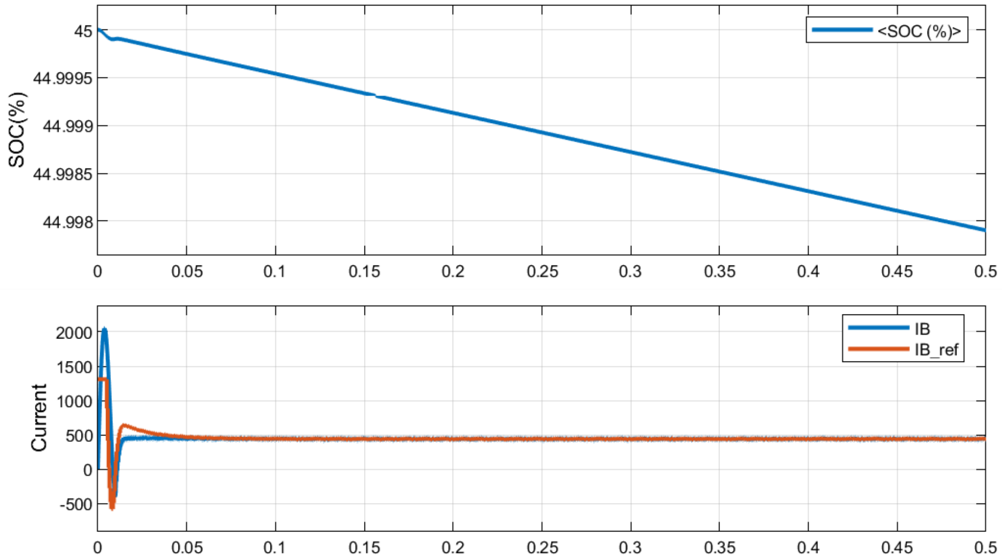


Figure 3.12 : Battery SOC (%) and currents during discharging.

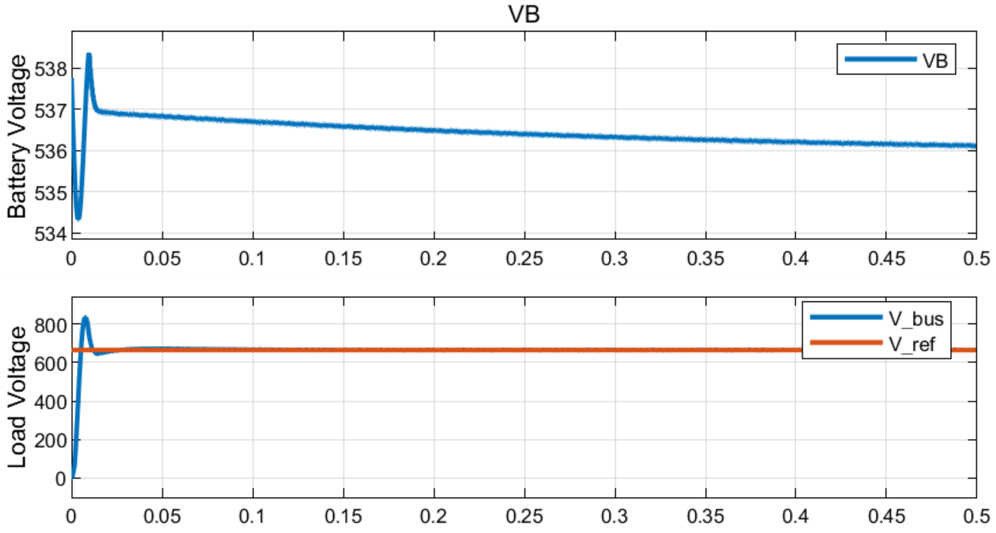


Figure 3.13 : Battery voltage and voltage profile across load.

3.5 VOLTAGE SOURCE INVERTER SYSTEM

Three-phase voltage source inverters (VSIs) are utilised in medium- to high-power applications. These topologies are designed to generate a three-phase voltage source with configurable amplitude, phase, and frequency.

Three-phase dc/ac voltage source inverters are frequently used in motor drives, active filters, and unified power flow controllers to generate controlled alternating current and frequency voltage magnitudes via various pulse width modulation (PWM) approaches. Direct current is often acquired from a single-phase or three-phase utility power supply via a diode-bridge rectifier and an LC or C filter. Fig. 3.14 illustrates the structure of a three-phase full-bridge inverter.

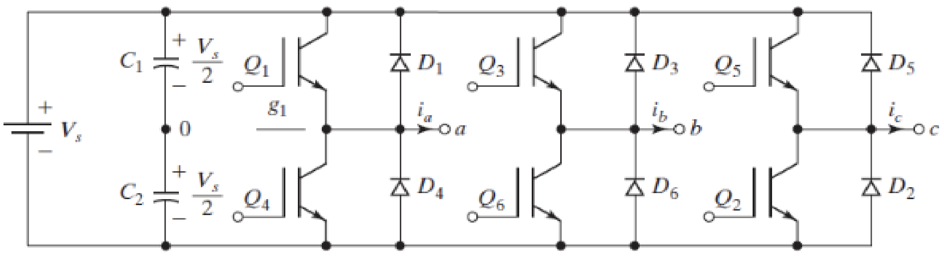


Figure 3.14 : Full-Bridge inverter circuit.

3.5.1 Sinusoidal Pulse Width Modulation (SPWM)

As stated previously, PWM is used to provide a sinusoidal output from the inverter. As with single-phase voltage source inverters, three-phase inverters can utilise the PWM technique by phase shifting three sine waves by 120° at the appropriate output voltage frequency and comparing them to a very high-frequency carrier triangle. The two signals are combined in a comparator, which outputs a high value when the sine wave is greater than the triangle and a low value when the sine wave, also known as the modulation signal, is smaller than the triangle.

Due to the discontinuous waveform of the inverter's output voltage, it is more likely that the output wave contains harmonics, which are generally undesirable since they degrade the performance of the load to which these voltages are applied. Fig. 3.15 illustrates a single-phase SPWM waveform; a three-phase waveform will be more complex.

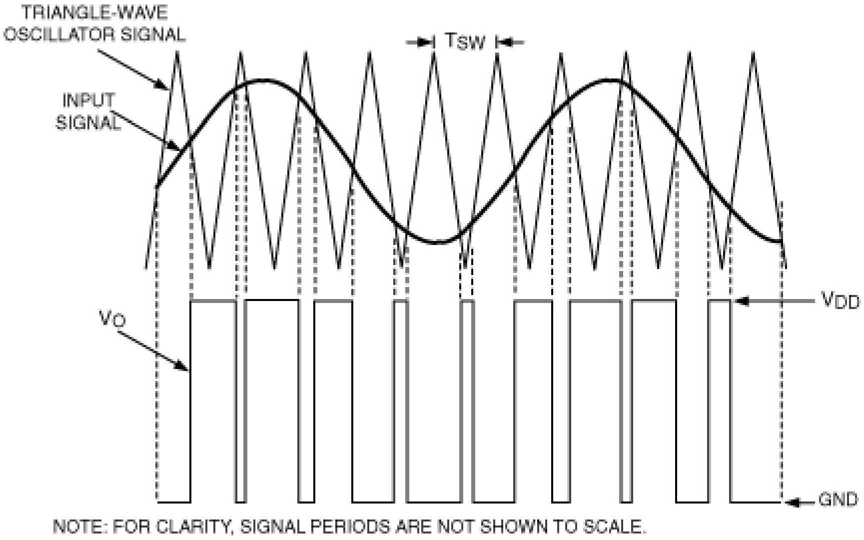


Figure 3.15 : Single phase SPWM and output waveform.

3.5.2 Simulation of designed inverter with control technique

This sub-section presents the simulation results of the proposed inverter system. In this simulation work, a 6-switch, 2-level inverter is used in the form of a universal bridge in Simulink. A PI controller has been used to generate the PWM waveform applied to the inverter. Fig. 3.16 shows the Simulink model of the system. An input voltage of 665V was applied to the inverter, which represents the DC-link voltage in the combined design. Further, at the output of the bridge, a dummy 3-phase load of 500 KW has been simulated. The VSI control scheme is depicted in Fig. 3.17 as a block diagram. This technique is used to design and tune the PI controller in such a way that the peak voltage at load is equal to the reference peak voltage. The reference phase-phase peak voltage in the proposed design is 565 V(V rms 2). As illustrated in Fig. 3.18, the load peak voltage is determined using the abc-dq transformation. The tuned PI controller output is multiplied by a three-phase sinusoidal carrier signal with a frequency of 50 Hz. This generates the reference value for the PWM generator. A three-arm, six-pulse bridge was chosen as the VSI in this work. The control strategy for this work is depicted in Figure 3.18.

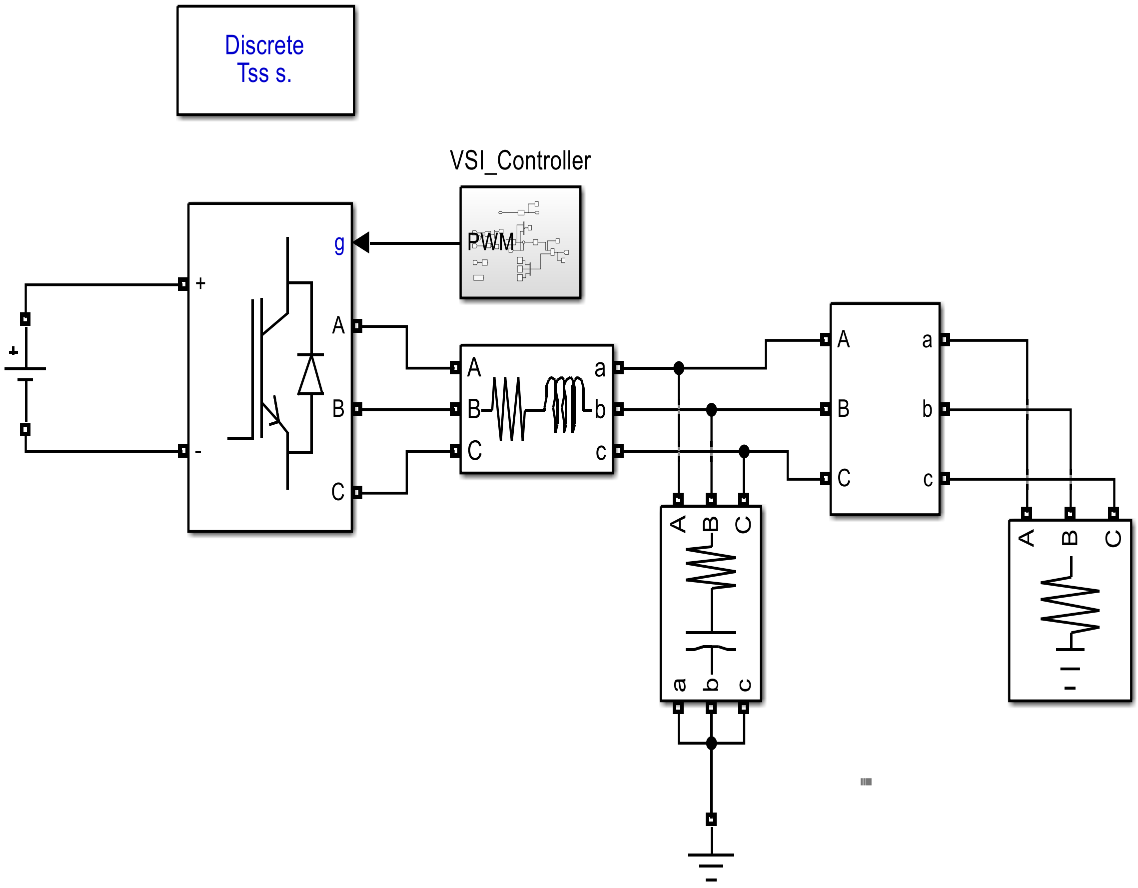


Figure 3.16 : 3-phase inverter design in Simulink.

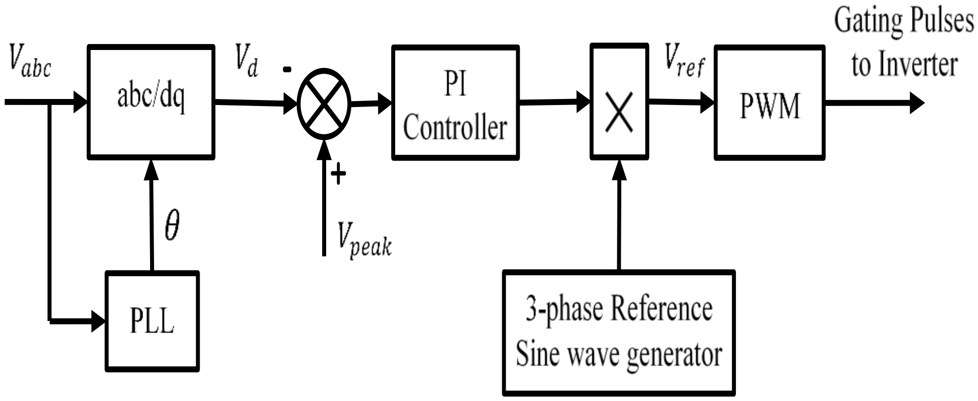


Figure 3.17 : Control scheme for VSI.

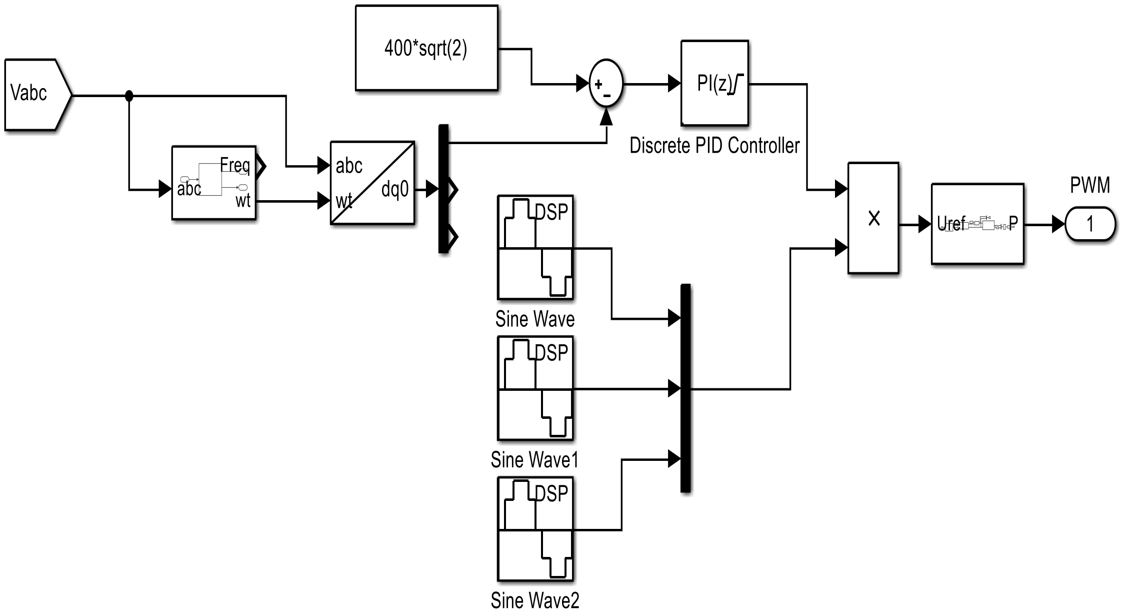


Figure 3.18 : SPWM control scheme for inverter.

Fig. 3.19 depicts the inverter bridge's output voltage and current, whereas Fig. 3.20 depicts the inverter bridge's output voltage and current waveforms under load. These figures demonstrate the effectiveness of the inverter control algorithm and filter circuit.

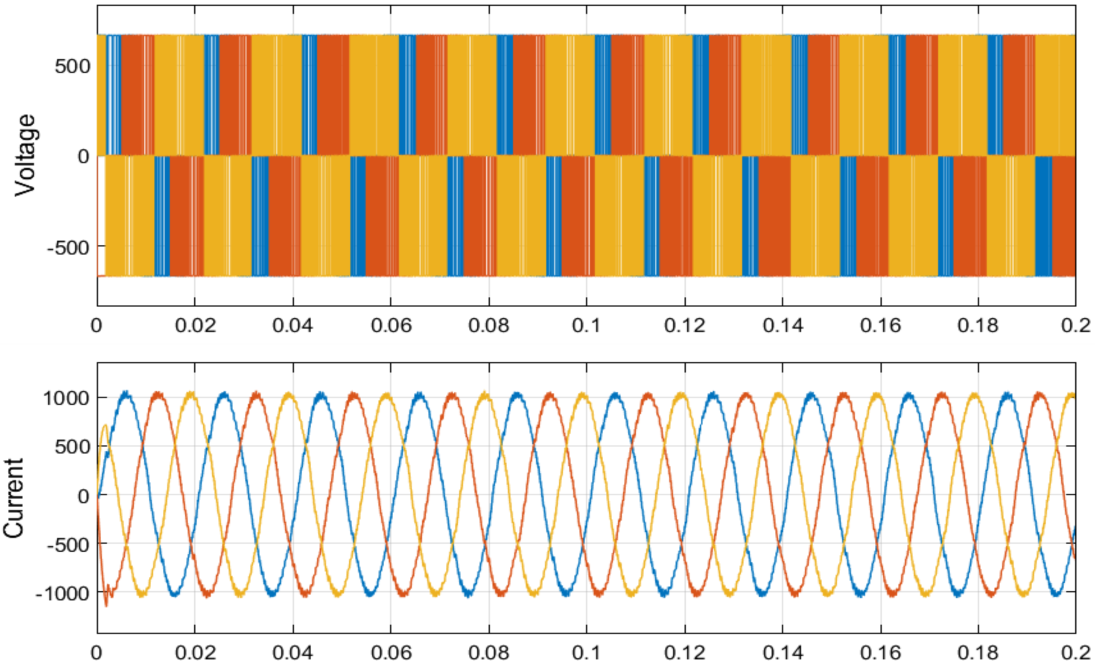


Figure 3.19 : Current and voltage waveforms prior to filter circuit.

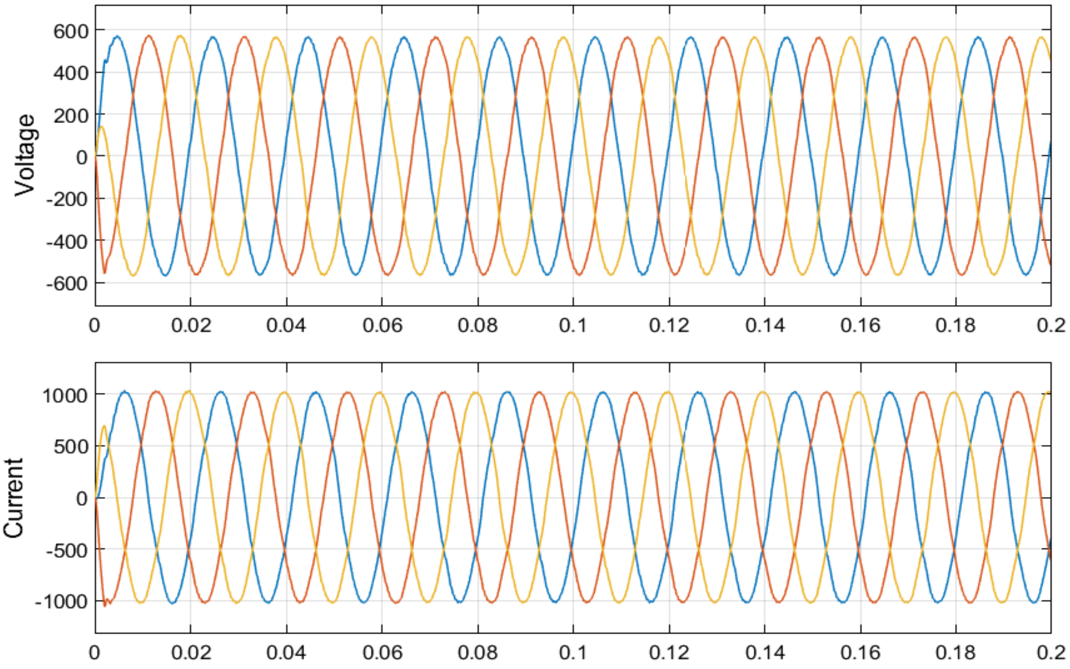


Figure 3.20 : Current and voltage waveforms across load after filter circuit.

3.6 RESULTS.

The individual components of the microgrid were simulated in Simulink based on the actual parameters which would be used for designing the microgrid in remote areas. The results of individual sub system confirmed to the theoretical results and mathematical modeling, thereby verifying our design.

4 METHODOLOGY: 1 MW MICROGRID DESIGN FOR REMOTE LOCATIONS OF ARMED FORCES

In this chapter, a microgrid with a capacity of 1 MW was created with the unique needs of the military forces in mind. Solar energy has been chosen as the principal renewable energy source in the suggested design. Additionally, an energy storage system in the form of batteries has been installed in order to counteract the negative impacts of inclement weather and severe weather conditions on the solar energy production capacity of the system. Additional applications include the powering of essential loads, the provision of reliability, and the usage of diesel generator sets as a backup for critical activities in the event of outages, nocturnal requirements, or unpredictable weather conditions. The proposed microgrid was designed and simulated using MATLAB. The microgrid's operation has also been demonstrated for varied weather and load situations. In all circumstances, the proposed design works well.

4.1 INTRODUCTION

The country's Armed Forces are stationed in military stations and bases in numerous distant areas along the borders or on islands that are far from major population centres. Many of these bases are not linked to the main power grid and rely entirely on diesel generators to provide their power requirements. These diesel generators have a negative impact on the environment due to greenhouse gas emissions and are inefficient due to logistical difficulties associated with supplying fuel to remote installations. Fuel for generators in many of these distant locales, particularly in mountainous areas, must be delivered by trucks, helicopters, boats, or manually carried to hilltops at times. The entire cost of sending armed forces to remote places rises as a result. Microgrid research has demonstrated a method for reducing dependency on large power grids in recent years, owing to developments in power electronic components and renewable energy. As a result, microgrids can be utilised to power armed troops stationed in isolated areas.

To fulfil the unique and urgent needs of armed personnel stationed in remote locations, a microgrid system with a total capacity of 1 MW was designed and simulated using MATLAB SIMULINK.

4.2 DESIGN

The proposed structure incorporates renewable energy sources such as photovoltaic solar panels and a battery-based energy storage system (BESS). The design includes a standby diesel generator set capable of managing fixed critical loads to prevent collapses or blackouts caused by unpredictability of weather conditions. A photovoltaic system generates electricity as a variable direct current voltage that varies with the weather. PI controllers are used in energy storage systems to eliminate these changes. These controllers are in charge of maintaining the DC-link voltage by managing the charging and discharging current of the battery. The BESS was designed to maintain a desired DC-link voltage and to provide energy if the photovoltaic system is unable to generate enough power due to inclement weather.

In addition, the direct current (DC) voltage across the load was converted to a three-phase alternating current (AC) signal using a three-arm, six-pulse voltage source inverter (VSI). To maintain the requisite phase-to-phase peak voltage across the load, the output voltage was regulated using a PI controller. The diesel generator set was governed by a control mechanism that was reliant on the battery system's state of charge (SOC). Additionally, as shown in Figure 4.1, the proposed microgrid design has been evaluated under a variety of weather and load demand situations. All systems, according to simulations, operate satisfactorily under these conditions. After extensive simulations, total harmonic distortion (THD) is kept well below 5%. The sections that follow describe the complete system in depth.

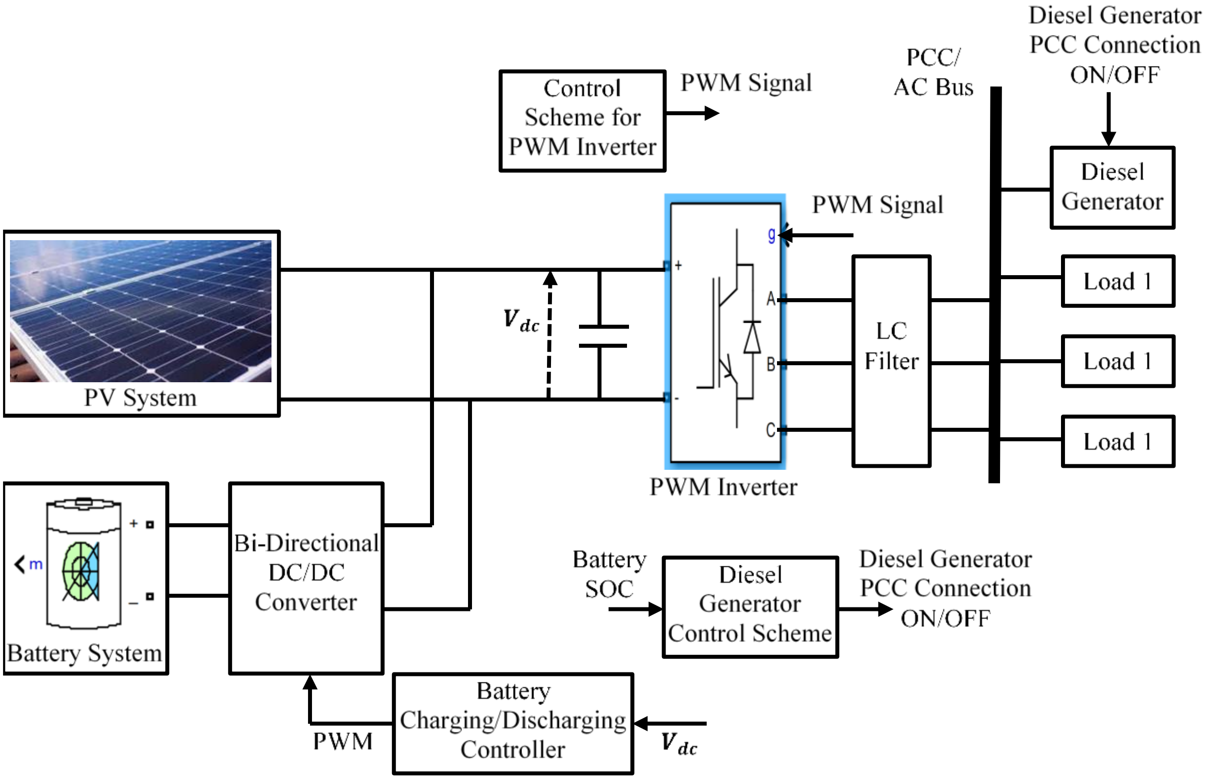


Figure 4.1 : Combined structure of the designed 1-MW microgrid.

The system is designed to deliver a phase-phase ac voltage of 400V rms. The inverter's DC link voltage must be around 665 V to keep the output AC voltage at 400 V rms (after including the voltage drop across the output LC filter). By charging and discharging the battery system via a DC-DC bidirectional converter, the control mechanism in this design will maintain the DC-link voltage at 665V. Table 4.1 summarizes the microgrid's electrical specs.

Table 4.1 : microgrid's electrical specs

Parameter	Electrical Specification
Total Power	1-MW
PV System Power	1-MW
DG Set	1-MW
DC-link Voltage	665V
Output Voltage	400 $V_{rms,ph-ph}$

4.3 SYSTEM OPERATION

The photovoltaic system is designed in such a way that it does not require an additional converter or controller for maximum power point tracking (MPPT). One of these solar panels produces 213.15 W and an open circuit voltage of 29V at its maximum output point. 23 solar panel modules are connected in series to avoid the requirement for a separate MPPT controller and converter. This results in a maximum open circuit power point voltage of 667V, which is approximately similar to the DC-link voltage required to provide a 400 V rms output phase-phase voltage. Additionally, the battery's DC-DC bidirectional converter and controller maintain this DC-link voltage, obviating the requirement for a separate PV MPPT controller.

The DC-link voltage is managed using a bidirectional DC-DC control mechanism by charging and draining the battery. If the photovoltaic system generates too much power, the battery should start charging to keep the DC-link voltage stable. If the photovoltaic system generates less power because of bad weather, the battery should start giving more power to critical loads to keep the DC-link voltage stable. When additional power is required and the photovoltaic system is unable to generate enough energy due to adverse weather conditions, the battery begins discharging within its current limitations. Similarly, if there isn't a lot of demand for electricity and the photovoltaic system has a lot of extra energy, the battery will start charging according to its pre-established specifications.

VSI sends out a PWM signal that can go from low to high. This high-frequency sound goes through the LC filter. Remove high frequency parts from the PWM signal with the low-pass filter. Then convert it to a three-phase sine wave with a fundamental frequency of 50Hz.

Additionally, the diesel generator set is utilised to provide backup power for important loads such as communication equipment, sensors, radars, and control centres at remote military locations or during periods of low solar irradiation, outages, or depleted battery capacity. An algorithm and conditions for generator start and stop have been incorporated into the design. Due to the fact that diesel generator sets run on fossil fuel and contribute to pollution, their usage in microgrids is limited to emergency situations.

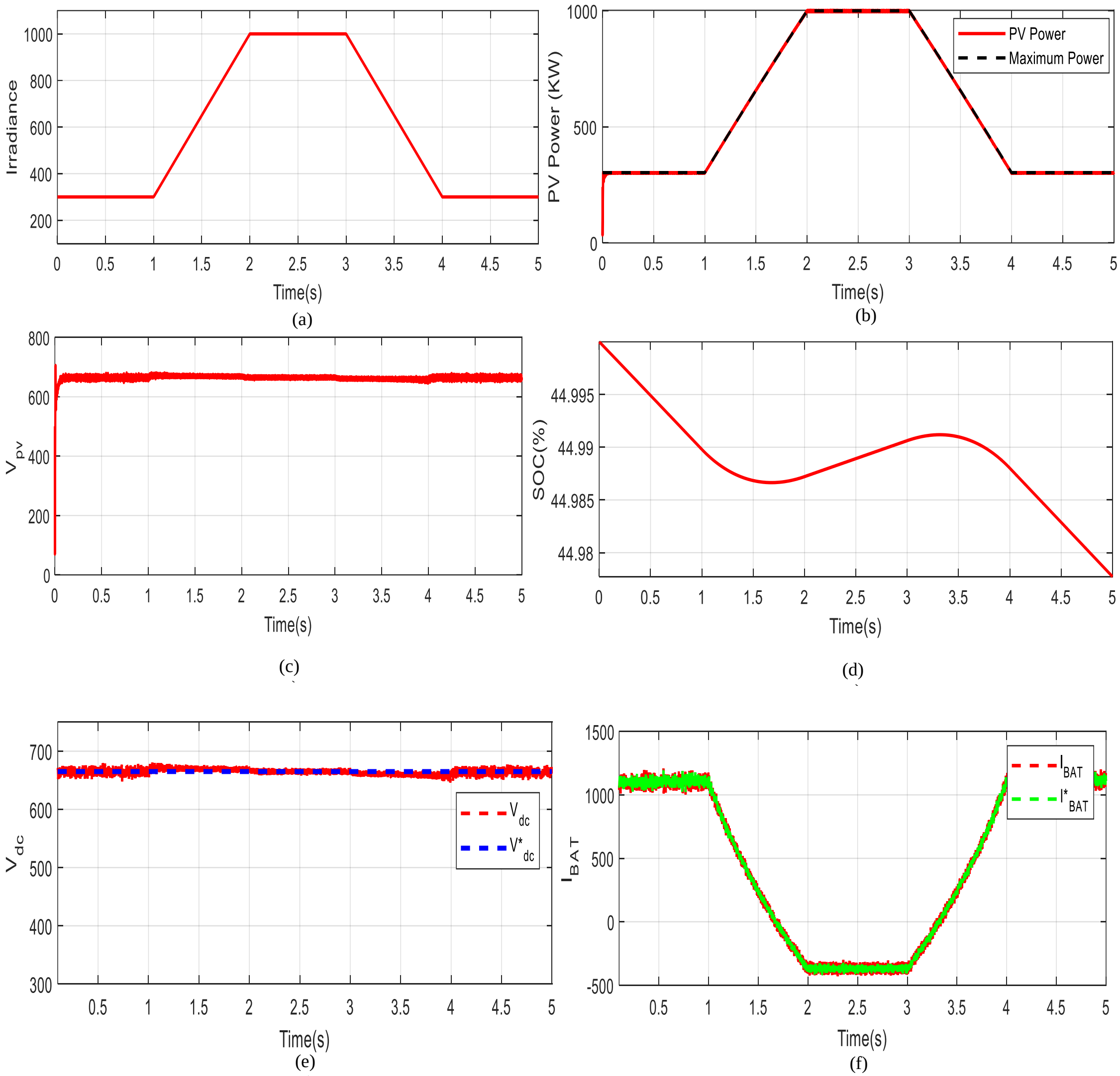
4.4 SIMULATION RESULTS

The suggested microgrid architecture has been modelled in a variety of scenarios.

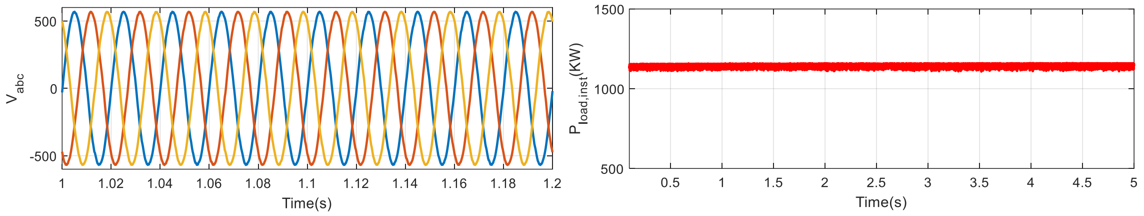
4.4.1 Varying meteorological conditions.

One of the challenges facing photovoltaic systems is weather fluctuation, which limits the quantity of electricity generated by solar panels. The study was designed to illustrate the microgrid's performance under time-varying meteorological circumstances in this scenario.

The load demand was maintained at 800 KW for this simulation investigation. We used a time-varying irradiance profile to simulate meteorological conditions on the solar panels. Solar panels generate the maximum electricity under typical conditions when exposed to 1000W/m^2 of illumination. Solar panels were lit in accordance with the irradiance profile depicted in Fig. 4.2. (a). Solar panels were exposed for one second to a 300W/m^2 irradiance, then to a 1000W/m^2 irradiance for one second, and then to a 1000W/m^2 irradiance for the next second. Following that, irradiance was immediately lowered to 300W/m^2 and sustained at that level for one second.



(a) (b) (c) (d) (e) (f)



(g)

(h)

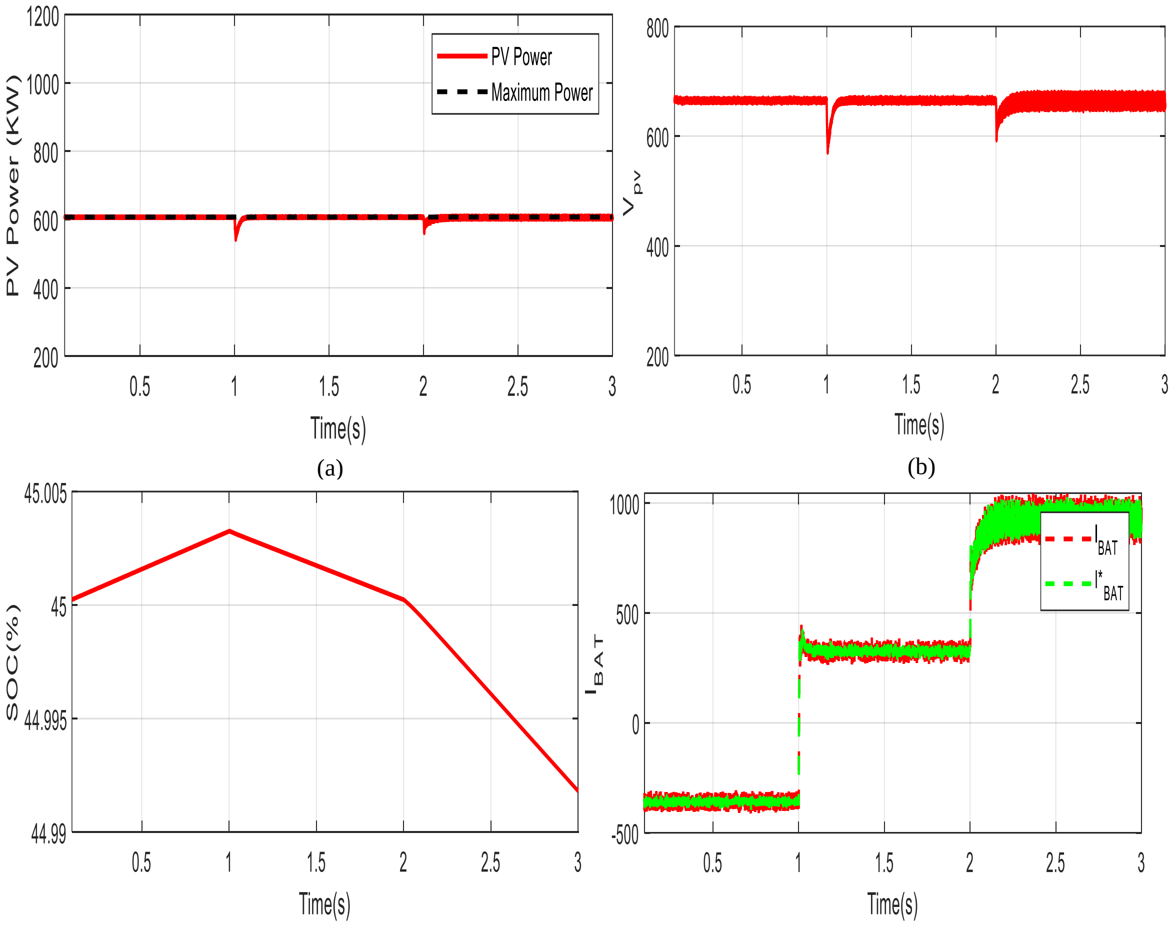
Figure 4.2 : "(a) Variation in irradiance profile, (b) Generated PV power and theoretical maximum power, (c) Voltage across PV system, (d) Battery bank SOC (%) representing charging and discharging state of battery bank, (e) DC-Link voltage, (f) Variation in current from the battery bank, (g) Three phase voltage across load, (h) Total instantaneous power to load."

Figure 4.2 (c) illustrates the voltage across the photovoltaic system, which remains constant at 665V throughout the simulation time. Fig. 4.2(d) illustrates the battery system's state of charge (SOC) and the charging and discharging controller's appropriate operation. When the irradiance is 300W/m2, the photovoltaic system's output is insufficient to power the loads, and the battery system delivers the excess power. As a result, the batteries begin to deplete, as indicated by the diminishing state of charge (SOC) curve throughout this time period. The battery state of charge begins to shift from discharging to charging during the transition phase from 300W/m^2 to 1000W/m^2, when the photovoltaic system begins to supply sufficient power to run the loads. When a solar system is illuminated with 1000W/m^2 irradiance, the PV system generates additional power; as a result, the battery system begins charging, as indicated by the increasing SOC values. The reference and dc-link voltages are shown in Fig. 4.2(e). The current drawn from the battery system is depicted in Figure 4.2(f). Positive battery current shows that the battery system is being discharged, whilst negative battery current indicates that it is being charged. Throughout the simulation period, the DC-link voltage remains constant, demonstrating the battery controllers' efficiency in maintaining the DC-link voltage. Fig. 4.2(g) illustrates the brief duration of voltage over the load. Fig. 4.2 (h) illustrates the immediate power flow to the load.

4.4.2 Varying load demand conditions including critical loads.

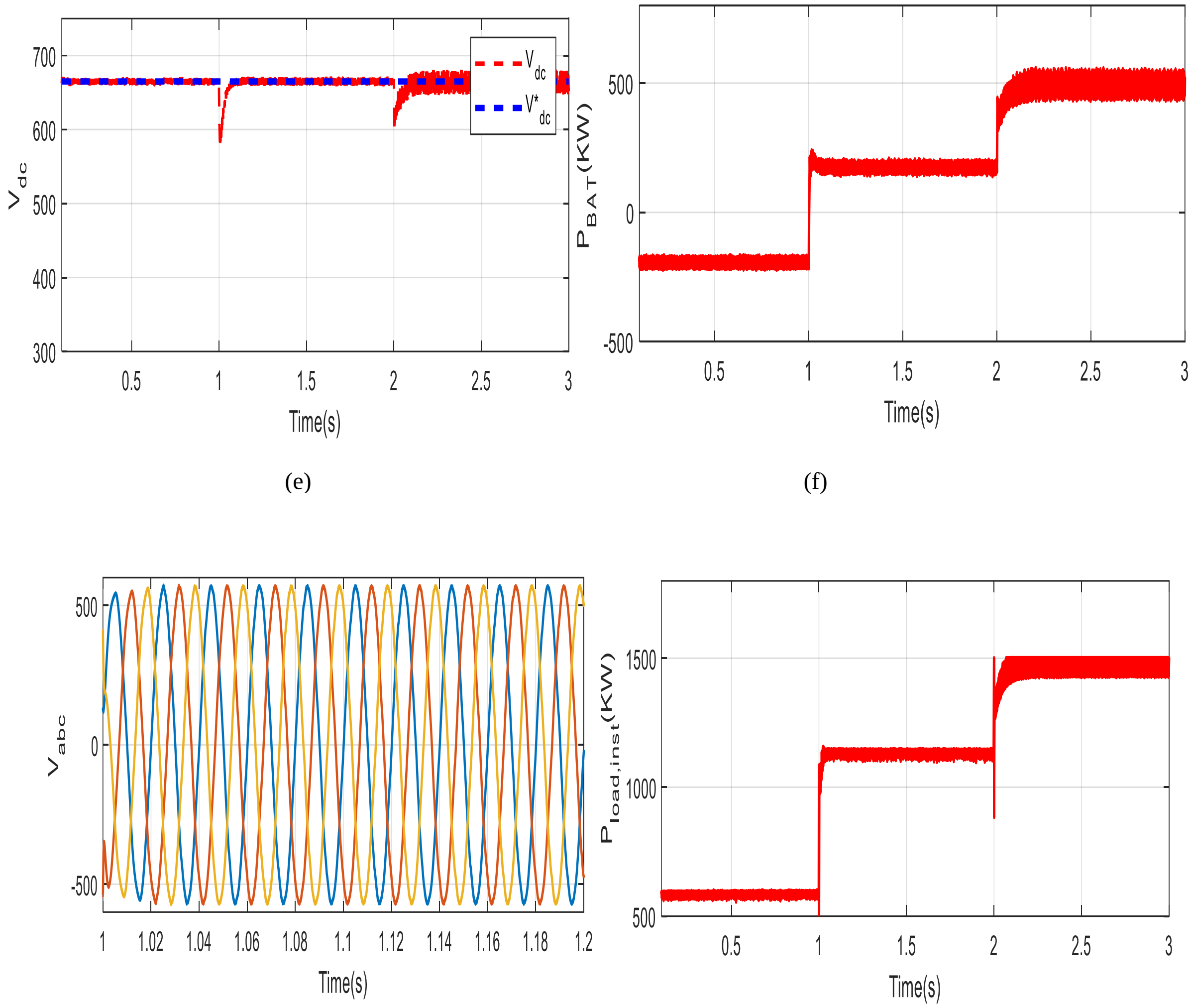
In the simulation analysis of the planned microgrid, Case 2 was used with variable loads and 60 percent of the PV system's maximum irradiance. This scenario highlights the suggested system's ability to properly absorb load variations. In this simulation study, load across the microgrid is increased by 400 KW, i.e., a 400 KW load is connected to the microgrid during the simulation time of 0–1 sec. At 1 and 2 sec instants, another 400 KW of load is added across the microgrid. Thus, the overall load across the microgrid was 800 KW during the first 1–2 seconds of the simulation, and 1.2 MW during the second and third seconds of the experiment.

Throughout the simulation time for Case 2, the irradiance value remains constant at 600W/m^2. Figure 4.3 (a) depicts the maximum power drawn from the photovoltaic system as well as the potential maximum power available from the photovoltaic system. Fig. 4.3 (b) illustrates the voltage across the photovoltaic system equal to the dc-link voltage.



(a) (b)

(c) (d)



(e) (f)

(g) (h)

Figure 4.3 : "(a) Generated PV power and theoretical maximum power, (b) Voltage across PV system, (c) Battery bank SOC (%) representing charging and discharging state of battery bank, (d) Variation in current from the battery bank, (e) DC-Link voltage, (f) Power flow profile from battery bank, (g) Three phase voltage across load, (h) Total instantaneous power to load"

A slight change in voltage occurs when the load increases abruptly at the 1 sec and 2 sec instants. As a result of the battery charging/discharging controller's action, the DC-link voltage returns to its reference value of 665V. The current drawn from the solar system stays constant as long as the photovoltaic system is continuously generating maximum power. Fig. 4.3(c) illustrates the charging and discharging rate of the battery in terms of the battery state of charge. The current obtained from the battery system is depicted in Fig. 4.3 (d), whilst the DC-link voltage is depicted in conjunction with the reference voltage in Fig. 4.3 (e). As the load on the system increases, the quantity of power required from the battery increases, as seen in Fig. 4.3. (f). Excess power was transferred to the battery when the load across the system was less than the power generated by the photovoltaic system, as demonstrated by the negative voltage during the first 0–1 seconds of the experiment. When the load exceeds the PV system's available power, the battery system kicks in to provide the additional power to the loads, as illustrated in Fig. 4.3(f) over a 1-3 second simulation time period. Fig. 4.4(g) illustrates the three-phase voltage waveform over the load. The total instantaneous power across the load is depicted in Fig. 4.3 (h). THD remained below 5% during the load fluctuation scenario. The system remained stable when simulated for longer duration of time also.

4.5 CONCLUSION

A 1 MW microgrid system operating in stand-alone mode has been constructed and modelled for a remote military base. To reduce environmental effects, the planned microgrid utilises a 1 MW photovoltaic system as the major renewable energy source. In order to keep the DC-link voltage at the required reference value of 665V, the energy storage system was built to give power to the load when the PV system is unable to generate enough electricity to power vital loads or to handle changing weather conditions. The projected microgrid's effectiveness and operation have been confirmed.

The simulation analysis demonstrates that the suggested system is capable of minimising the effect of variable irradiance and fulfilling load demand effectively. Additionally, the diesel generator was designed to provide electricity to defined important loads and as a backup power source in the event of unforeseen meteorological conditions or breakdowns. Throughout the simulation, the system was able to keep the DC-link voltage at a predefined reference value, and the THD was less than 5%.

The Technical paper with the title 'Stand Alone 1-MW Microgrid for Remote locations of Armed Forces with PV-Battery-Diesel Generator' has been published in International Journal of Engineering and Advanced Technology (IJEAT) Volume 10, Issue 1, October 20.

5 METHODOLOGY: NETWORKING OF MICROGRIDS FOR RELIABLE LOAD SHARING IN REMOTE LOCATIONS OF THE ARMED FORCES

This chapter describes a revolutionary technique for linking and networking microgrids built at several military locations as part of a larger military deployment. The bases are separated by a significant distance and are linked together. This chapter goes through the strategy for interconnecting such microgrids for reliable load sharing. A different control method will be used to regulate power sharing. Several simulation studies have been conducted, and the findings suggest that the complete system performs satisfactorily. Outages and load sharing are simulated in the system.

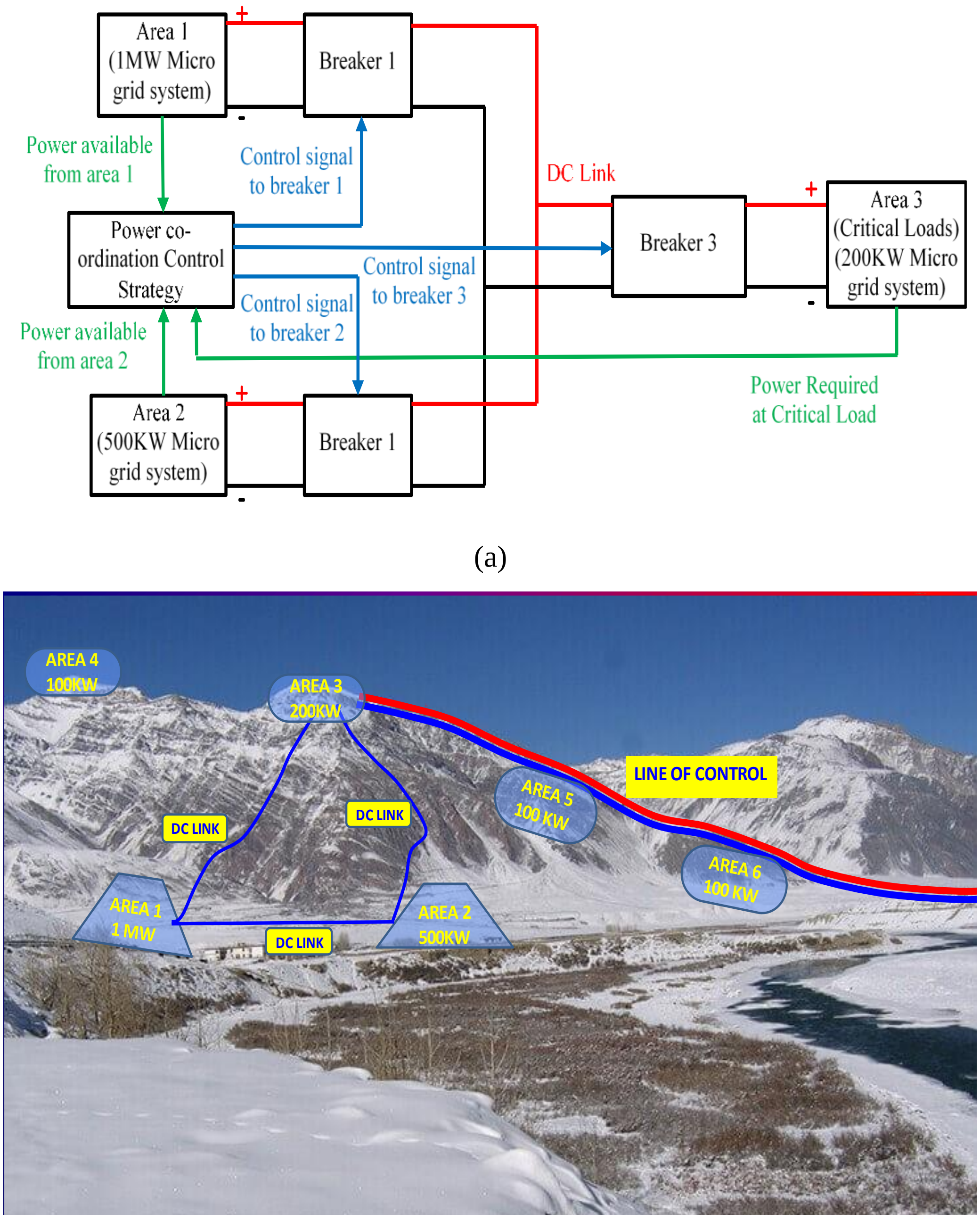
5.1 INTRODUCTION

Military microgrids should be designed in such a way that they have access to enough generation capacity within their local distributed energy resources to meet their requirements. Microgrids are widely deployed throughout the world, and their deployment is likely to increase in the future. This has resulted in more efficient and cost-effective microgrid designs, including the operation of a cluster or network of interconnected microgrids. Microgrid networks are characterised by interconnected microgrids that operate in unison. Users will profit from the networking of many microgrids since it will increase reliability and cost-effectiveness, particularly in remote locations.

The microgrid's generalised structure was addressed in Chapter 4 and is illustrated in Fig. 4.1. This chapter introduces a novel technology for connecting and networking microgrids constructed at several military locations as part of a broader military deployment. The bases are separated by a significant distance and are connected via tunnels. This study examined three distinct islanded microgrids with varying capabilities. These three microgrids will be able to interchange electricity via a shared DC connection line. To regulate power sharing, a separate control approach will be employed. The control technique determines the quantum of power sharing across these three microgrids based on the power required by each, the stated vital loads, and the available power on the other base microgrid. Numerous simulation tests were done to validate the suggested approach. These included a number of various scenarios. Additionally, an emergency situation has been studied in which all power generated by two sites' microgrids is routed to essential loads on a third site due to military action destroying the third base's power supplies.

5.2 NETWORKED MICROGRID SYSTEM DESCRIPTION

The networked microgrid is comprised of three separate bases, each having a microgrid with a capacity of 1MW, 500KW, or 200KW. The block diagram of the envisioned system is depicted in Figure 5.1. As depicted in Fig 5.1, Area 1 (Mother Base) and Area 2 are identified as operational bases in accessible deep areas with normal electricity requirements (b). Area 3 is a forward operating base in a distant location that requires a continuous 200 KW power supply for key loads such as surveillance systems, communication systems, and sensors. The network must ensure that energy is available to this forward operating base with essential loads. The same demand was satisfied using power coordination control techniques by ensuring continuous power supply to essential loads. This section contains a detailed overview of each location as well as the microgrid specifications.



(a)

(b)

Figure 5.1 : (a) Block diagram of the proposed networked microgrid and power control coordination. (b) Layout of Area 1(1 MW), Area 2 (500 KW) and Area 3 (200 KW) in the remote areas.

5.3 SYSTEM SPECIFICATIONS

Each of the three microgrids is connected to the others through a common DC connection. For the following reasons, a DC line is used to connect the microgrids:

- DC voltage is used to generate electricity from renewable sources. As a result, there is no need for a third-party converter.

- There will be no need for extra synchronisation equipment for the DC link line, and the material requirements for microgrid connectivity will consume fewer resources and costs.
- Interconnection latency will be reduced, and DC line maintenance will be simple in the event of an emergency.

The electrical specifications for microgrids at all three bases are the same. For all three bases, the DC connection voltage of the DC line remains at 665V. The load-side alternating current voltage is set to 400V rms in all three bases.The voltage at the DC connection is maintained by the battery subsystems, as indicated in Fig. 5.1 (a) and (b). The PV systems and battery storage systems at each base have been designed with the number of panels and batteries to meet their energy requirements. A DG system has been employed to provide a complete backup in case there is no solar power from the PV system and the battery system has dried up. A detailed description of the DG control scheme has been discussed in Chapter 2. Each area has a DG set with similar load specifications as that of the microgrid of that area.

5.4 MICROGRID NETWORK CONTROL SCHEME

The interconnectedness of several places is depicted in Figure 5.1. (a). The major objective of the islanded microgrid system is to run it entirely on renewable solar energy. As a result, in Areas 1 and 2, excess solar power is calculated by subtracting the power generated by the photovoltaic system from the power consumed at the load. Analytically, this can be explained by Eqs. (5.1) and (5.2) for Area 1 and Area 2, respectively.

$$P_{excess,1} = P_{pv,1} - P_{load,1} \tag{5.1}$$

$$P_{excess,2} = P_{pv,2} - P_{load,2} \tag{5.2}$$

where, P_{excess} is the surplus power from Areas 1 and 2, P_{pv} is the total amount of solar energy produced and P_{load} is a total instantaneous power consumption at load.

Area 3 is responsible for powering the forward operating base's crucial loads, and its power requirements must be supplied at all times due to the presence of important and critical equipment. To ensure the continued availability of electricity to the forward operating base in Area 3, power is rerouted to the area of the current work if solar energy generated in Area 3 is insufficient. Eq. can represent the additional solar power required by the area (5.3)

$$P_{required,3} = P_{pv,3} - P_{load,3} \tag{5.3}$$

The power coordination control approach depicted in Fig. 5.1(a) specifies the conditions under which power can be transmitted from Areas 1 and 2 to Area 3. This control technique uses $P_{required,3}$ from Area 3 has surplus power, while Area 1 has ($P_{excess,1}$) and 2 ($P_{excess,2}$). Additionally, depending on the situation, it issues control commands to each area's breakers, as illustrated in Fig. 5.1. (a).

5.4.1 Normal Mode of Operation

In normal operation, the photovoltaic system in each region generates enough energy to power the associated loads. All circuit breakers in each region remain in the OFF state during normal operation, allowing each area to operate independently as a microgrid system.

5.4.2 Power Sharing Mode

Area 3 is provided with solar energy generated in addition to the energy generated in Areas 1 and 2. As previously stated, Areas 1 and 2 are deep-water locations, whereas Area 3 is a forward operating base with limited access and a history of outages. Geographical conditions vary according to distance. If the solar photovoltaic system in Area 3 does not generate enough solar energy to meet load demand in this mode of operation, power can be diverted from Areas 1 and 2 by activating the circuit breakers in each area.

5.4.3 Emergency Mode

Forward operating sites are placed at the end of transmission systems, making them subject to outages caused by meteorological events such as landslides, avalanches, storms, and heavy rains, as well as adversary actions such as attacks. The power requirements of the technology housed at forward bases, such as weapon control systems, surveillance systems, communication systems, and sensors, must be met at all times due to the critical nature of the technology. Fueling generators is a significant resource drain at a lot of forward operating bases in distant places. To address these concerns, this article proposes a power routing technique. The power control strategy block is configured to meet Area 3's energy requirements. If there is an outage in Area 3, this algorithm will activate an emergency alarm. After the emergency alert (EMA) is activated, power from Areas 1 and 2 will be channelled to Area 3 by turning on their respective breaker panels. Non-critical loads in Areas 1 and 2 will be immediately shut down, and excess power will be used to power the forward operating base in Area 3.

Figure 5.2 depicts the suggested power coordination method in an emergency mode in a networked microgrid with forward bases.

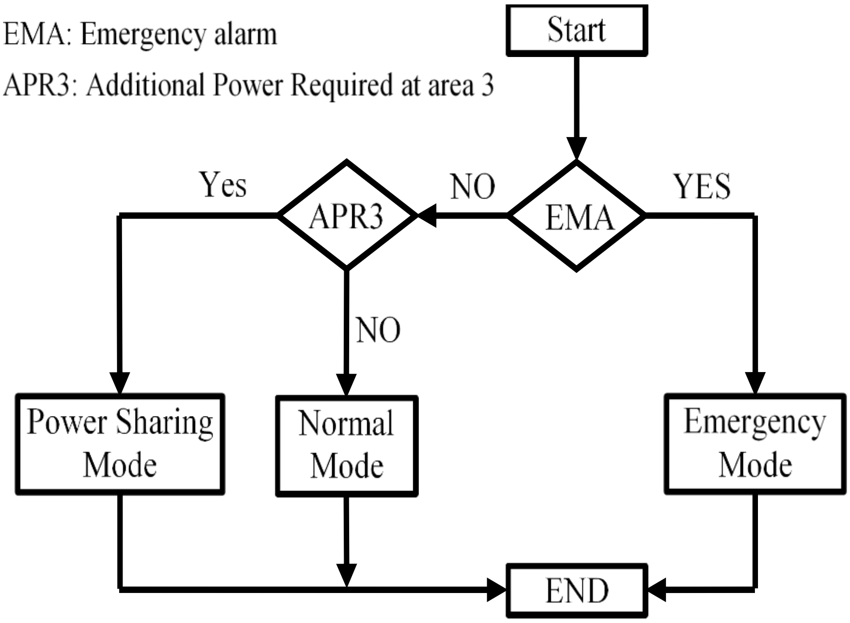


Figure 5.2 : Flow chart of control scheme for microgrid interconnections.

5.5 SIMULATION RESULTS

Fig 5.3 illustrates the proposed islanded microgrid system for army deployment in a single forward operating base constructed in MATLAB, while Fig 5.4 illustrates the complete deployment of the three sectors with interconnections in the MATLAB model. MATLAB 2018 was used to simulate and validate them. The system was simulated in each of its three operational modes: "*normal mode, power sharing mode, and emergency mode*". This section discusses the comprehensive simulation findings from the investigation.

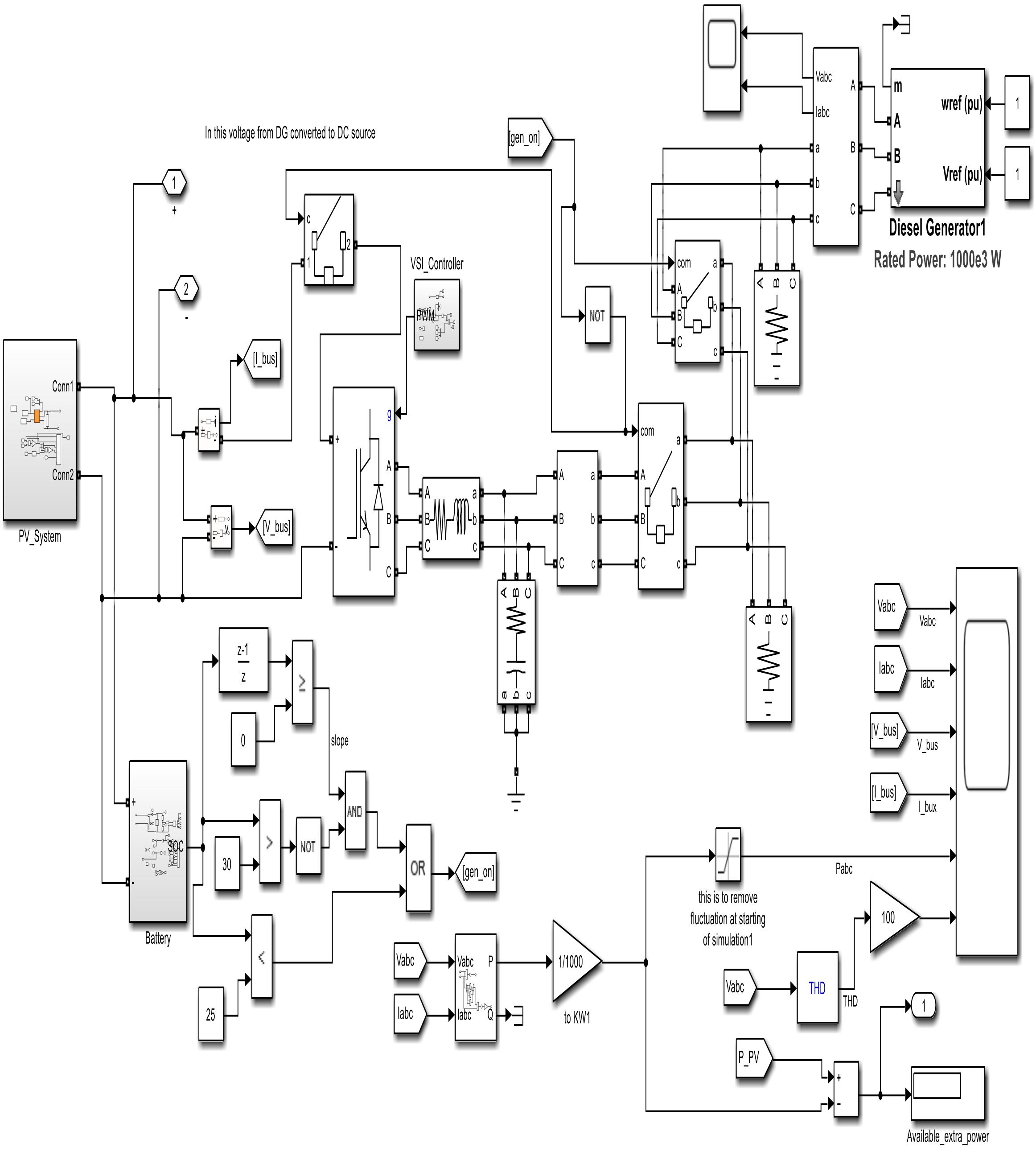


Figure 5.3 : Simulink design of one forward operating base area.

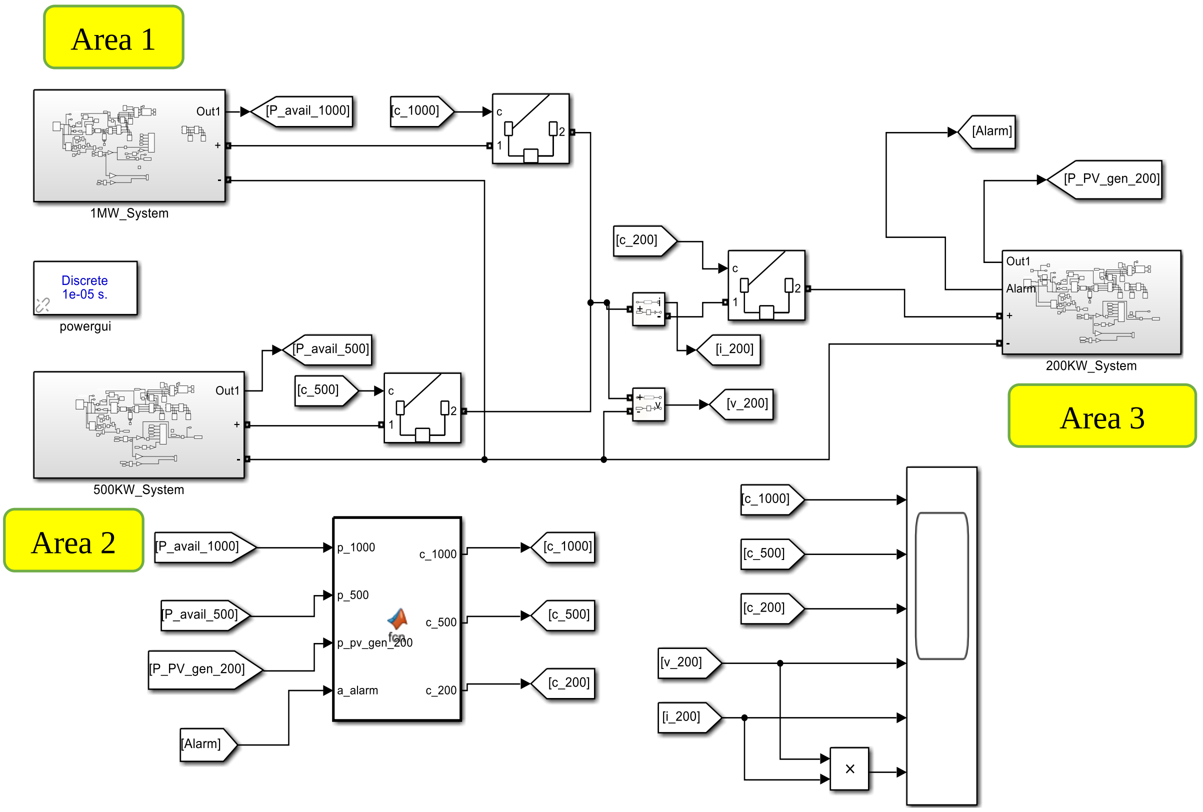
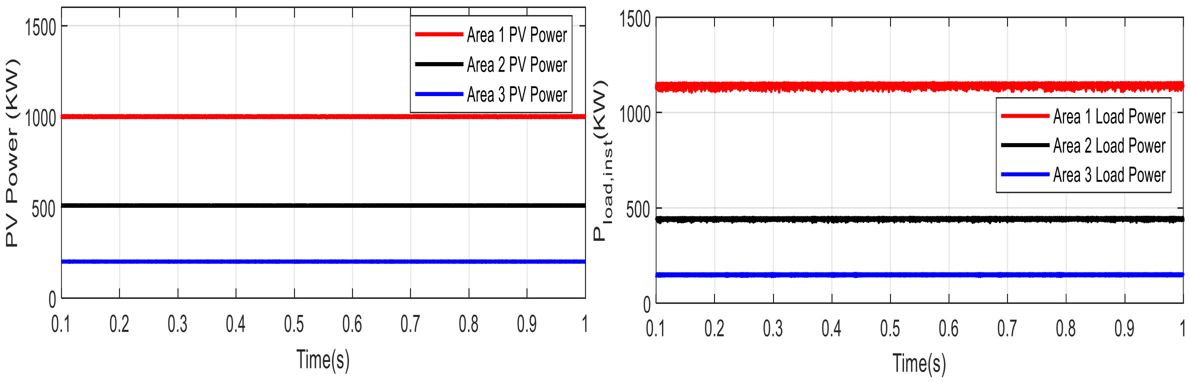


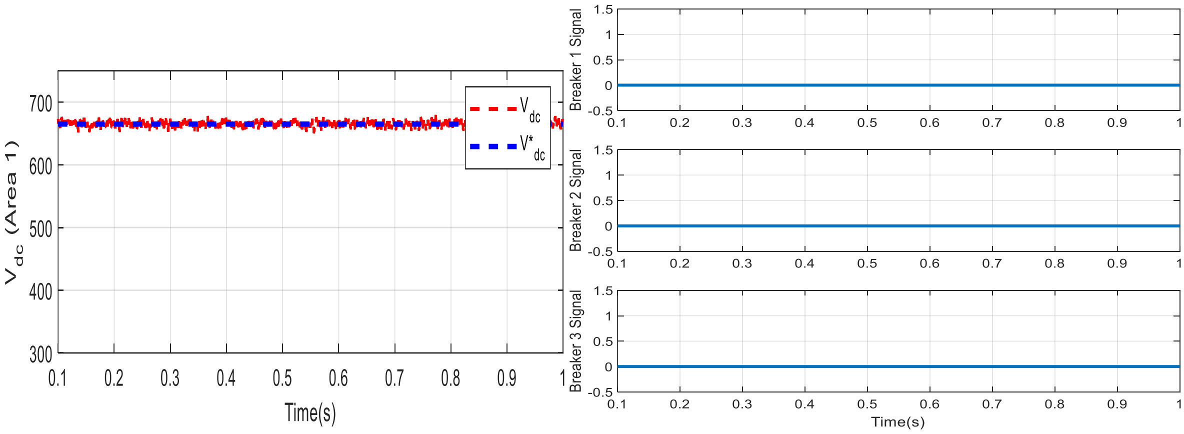
Figure 5.4 : Simulink design of networked microgrids of three operating bases.

5.5.1 Normal Mode Operation

Each of the three microgrids in Zones 1, 2, and 3 operates normally and supplies electricity to its designated area. Areas 1, 2, and 3 supplied electricity to 800KW, 300KW, and 100KW of load, respectively. Simulation of the designed interconnected microgrids was done in MATLAB and the results of the simulations confirmed the designed output. The outputs are shown in Fig 5.5.



(a) (b)



(c) (d)

Figure 5.5 : “(a) Generated PV power of each area, (b) Power delivered to the load of each area, (c) DC bus voltage of area 1 (d) Command signal generated for all three breaker”

Fig 5.5(a) illustrates the power generated at each of the three sites; as can be observed, each of the three areas operates satisfactorily in its typical mode of operation. Additionally, Fig. 5.5 (b) illustrates the amount of electricity delivered throughout the load in each area. Fig 5.5(c) illustrates the DC bus voltage in region 1. The command signal generated to engage the breakers is depicted in Figure 5.5 (d). Because Area 3 does not require more power, the power co-ordination control strategy block generates a 0 command or an OFF command.

5.5.2 Power Sharing Mode

Area 3 needs additional power in the power sharing mode, which Area 1 and Area 2 have already provided. This section summarises several of the study's findings. Solar irradiance profiles for Areas 1, 2, and 3 are depicted in Fig 5.6(a) and 5.6(b). Solar irradiation drops to 600 at 0.2 seconds in this scenario. The PV power generated is depicted in Fig. 5.6(c); as solar irradiation declines by 0.2 sec, the power given by Area 3 decreases as well, necessitating the additional power from Areas 1 and 2. Throughout this simulation, Fig. 5.6(d) depicts the instantaneous power given to the load. The DC-link voltage at each location is shown in Fig. 5.6(e)–(g) during the simulation time, demonstrating that the entire DC-link remains stable and power is shared in this mode of simulation. The commands of the breakers are depicted in Fig. 5.6(h). It is observed that all breakers activated immediately upon detecting a necessity for additional solar energy at region 3 at 0.2 sec.

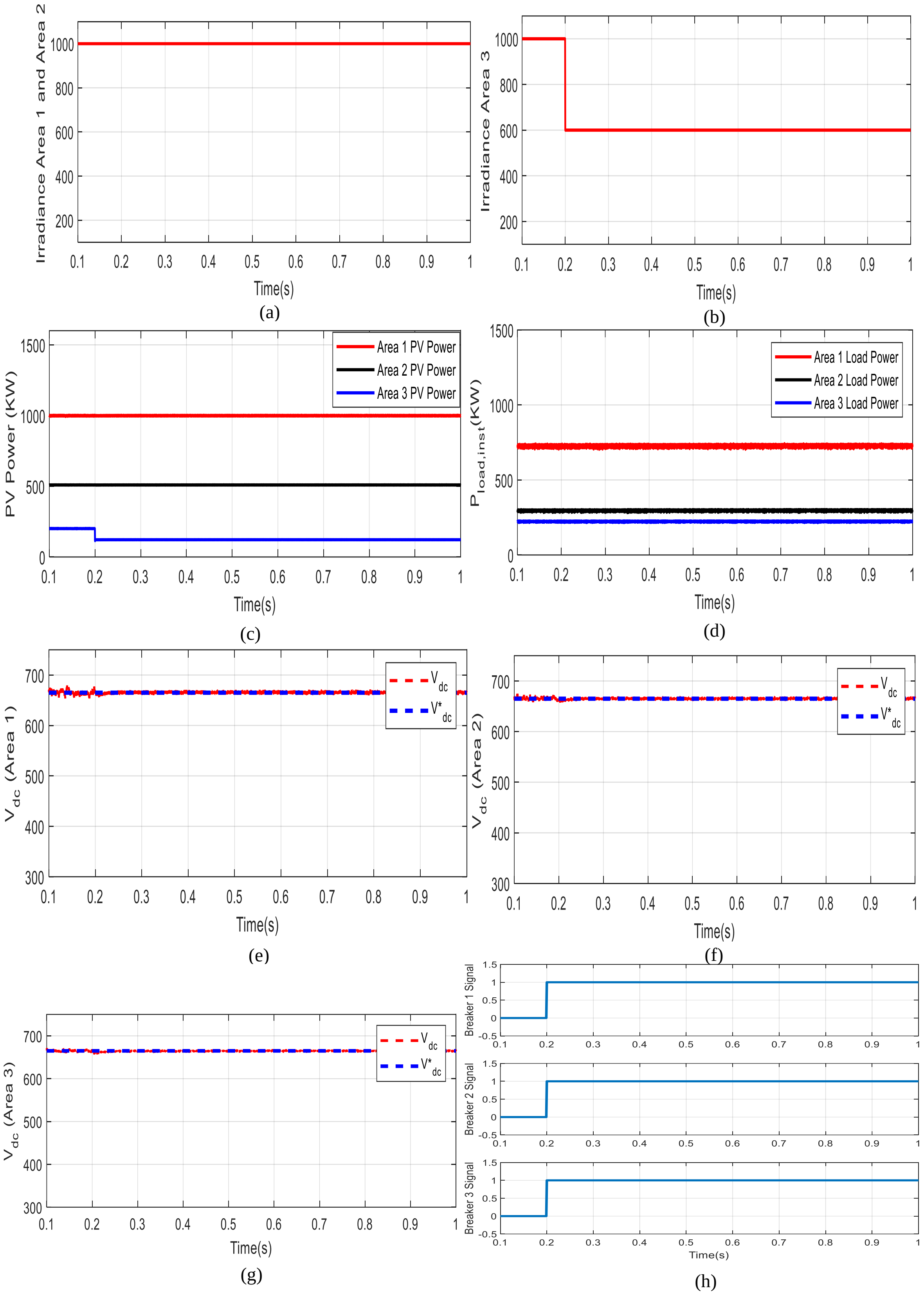
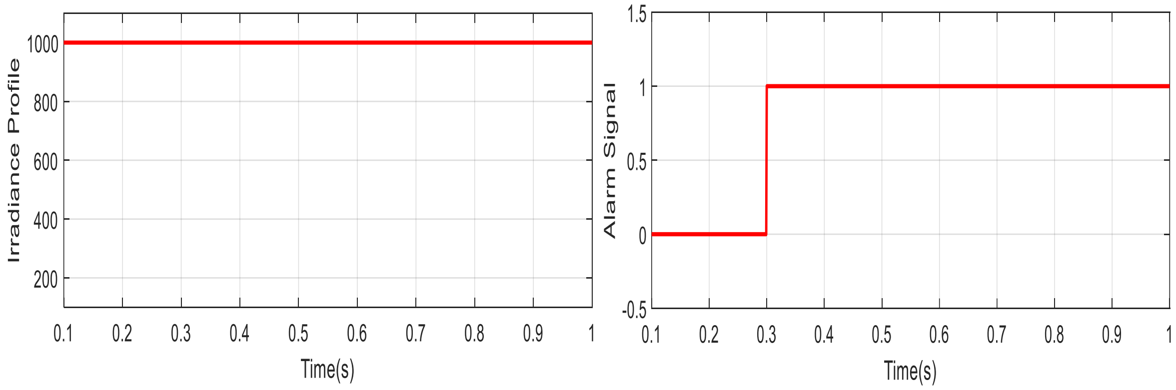


Figure 5.6 : "(a) Irradiance at area 1 and area 2, (b) Solar irradiance at area 3, (c) PV power generated at each area, (d) Instantaneous power delivered to the load at each area, (e) DC-link voltage at area 1, (f) DC-link voltage at area 2, (g) DC-link voltage at area 3, (h) Command signal generated for all three breakers."

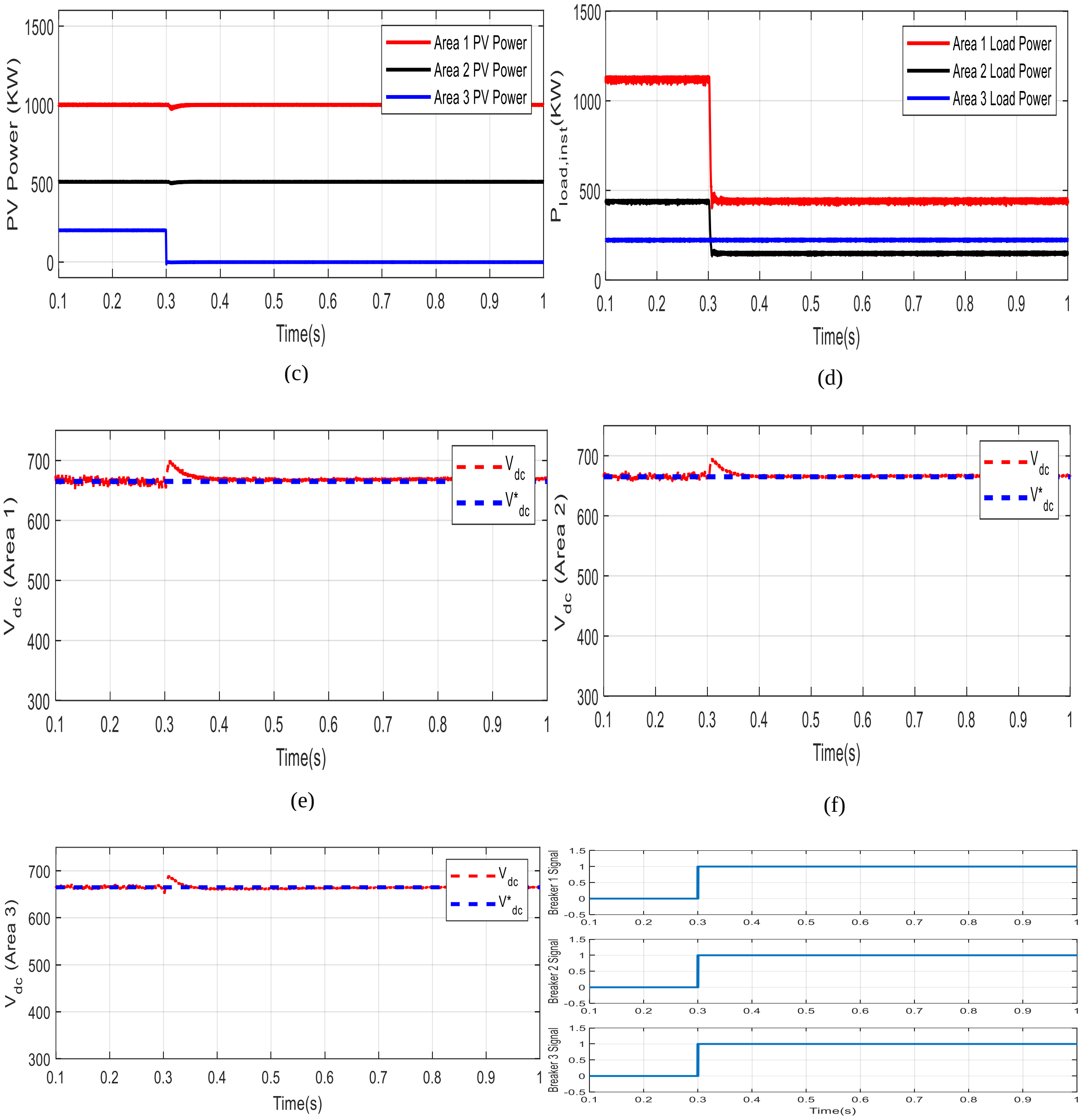
5.5.3 Emergency Mode Operation

This section summarises the emergency mode of operation's findings. As previously stated, power will be quickly channelled to Area 3's critical loads in the event of an emergency. During an emergency, all non-critical loads in Areas 1 and 2 will be disconnected, leaving only critical loads functioning. Critical loads of 300 KW and 100 KW were connected to Areas 1 and 2, respectively, in this scenario. When an outage or criticality occurs in Area 3, an emergency situation is mimicked by triggering an alarm.

Fig. 5.7 (a) illustrates the irradiance profile during the course of the experiment. The alert signal is depicted in Figure 5.7 (b). At 0.3 seconds into this simulation, an emergency situation is simulated by increasing the alarm signal to 1. The photovoltaic energy generated at each of the three locations is depicted in Fig. 5.7 (c). PV power at Area 3 is decreased to zero after 0.3 seconds due to a simulated outage caused by a natural disaster or an attack on the area's power generation. Fig. 5.7(d) illustrates the instantaneous power delivered to the load at each of the three locations. As seen in this graphic, the redundant load in Area 1 and Area 2 is disconnected immediately upon alarm activation. It manifests itself as a decrease in the instantaneous power delivered to the respective area loads. As illustrated in Fig. 5.7 (d), essential loads at Area 3 are maintained, and the area receives appropriate power throughout the simulation time. This signifies that strength from Areas 1 and 2 is channelled towards Area 3. The DC-link voltages for each location are depicted in Fig. 5.7(e)-(g) respectively. The graphs show that the DC-link maintains its stability throughout the simulated time period. FIG. 5.7 (h) depicts the command signal transmitted to each of the three breakers in accordance with the control shown in Fig. 5.2.



(a) (b)



(c) (d)

(e) (f)

(g) (h)

Figure 5.7: "(a) Irradiance profile, (b) Alarm signal, (c) PV power generated at each area, (d) Instantaneous power delivered to the load at each area, (e) DC-link voltage at area 1, (f) DC-link voltage at area 2, (g) DC-link voltage at area 3, (h) Command signal generated for all three breakers."

5.6 CONCLUSION

Three unique microgrids with varying capacities were constructed and interconnected in remote bases, and network functioning was simulated under a variety of operating situations while guaranteeing that the forward operating base's crucial power requirement is supplied via the use of a load sharing algorithm. Furthermore, the microgrids in each location were linked by a DC bus to share power with important loads in an unreachable forward base that required fuel to run generators, saving considerable resources, logistic expenses, and carbon emissions. Furthermore, simulations were done in order to ease the critical load location's emergency status by shifting electricity from the other two sectors. A simulated experiment was used to demonstrate the operation of the full system and the power coordination control technique. In the future, artificial intelligence schemes may be used to govern and monitor such networks and systems. AI tools like Neural Networks, Genetic Algorithms, Neuro fuzzy controls provides modelling and simulation for efficient use of controllers, solar inverters, battery systems and other distributed energy resources. AI removes the need for grid operators and asset managers to intervene in microgrid operations. Instead, energy is automatically delivered at the right price, place and time — without human actors making any decisions or pulling any levers. AI helps them consider the following:

- Manual vs. autonomous: For operations, controls and equipment
- Distributing and storing power
- Microgrids systems response to managing renewable variability.
- Enhancing accurate supply and demand forecasting
- Reducing energy costs
- Improving resiliency to provide optimal energy reliability if connected to the larger grid or in an island configuration

Technical paper "Networked Microgrids for Reliable Load Sharing in Remote locations of Armed Forces" published online in Turkish Journal of Computer and Mathematics Education Vol.12 No.11 (2021), 1898-1915 in May 21.

6 METHODOLOGY: DESIGN OF MICROGRIDS IN ANDAMAN AND NICOBAR ISLANDS FOR THE ARMED FORCES.

This chapter is devoted to the design of actual microgrids to be constructed in remote bases of the Armed Forces in the Andaman and Nicobar group of islands. As Chief Engineer for infrastructure development of the Armed Forces on the Islands, four microgrids have been designed as part of the research work to cater to the energy load and to increase self-reliance by exploiting the renewable energy sources. The design and specifications of these microgrid-based solar PV projects are being developed by the Military Engineering Services. The projects consist of solar arrays with battery banks connected to existing power houses, with the entire distribution being controlled by microgrid controllers having the capability to switchover to energy sources as per economic criteria and availability. Details of the design, simulation, and equipment specifications are covered in this chapter.

6.1 INTRODUCTION

The Andaman and Nicobar (A&N) islands are a group of approximately 572 islands in the Bay of Bengal, just 36 of which are inhabited. The Electricity Department of A & N (EDA & N) now has an installed capacity of roughly 113.86 MW from several generating plants. The table below summarises EDA & N's current infrastructure. Table 6.1 displays the present electric supply infrastructure in the Andaman and Nicobar Islands.

Table 6.1 : Present Electric Supply infrastructure in Andaman and Nicobar Islands

Particulars	Details
Total Installed Capacity	113 MW
Diesel Generation (Including 19.83 MW hired)	102 MW
Hydro Generation	5 MW
Solar Generation	6 MW
33 kV lines	497 km
11 kV lines	894km
LT Lines (415 V)	3,474 km
Distribution Transformer	980 Nos.
Capacity of Distribution Transformer 33kV S/S	163 MVA

The cost of supply of electricity is very high in the Andamans. The average cost of supply in the years 20-21 has been Rs 27.45/KWh. One of the key cost factors is the high cost of generation, as the Andamans are virtually totally powered by diesel generators operating on high-sulfur diesel. The small customer base and high cost of generation are the primary factors for the islands' high cost of supply.

6.2 THE CHALLENGE OF POWER SUPPLY IN REMOTE ISLANDS FOR MILITARY BASES.

The remote bases of the armed forces on the islands have limited access to electrical energy from state sources and invariably have to maintain backup generation capacity for normal and add redundancy for critical operations. During outages and other disruptions, these installations must have a reliable and sustainable supply from their own sources. The major challenges are as enumerated below:

- Maintaining backup power generation equipment on a military post is a popular method of guaranteeing operation continuity during a power outage. It is not uncommon for important loads on installations to have specific backup generating sources that are inflexible and have a low reliability rating.
- On islands, military infrastructure in isolated regions remains shut off for months, necessitating the stockpiling of fuel for energy. Natural disasters exacerbate the difficulties in these locations.
- The small renewable energy sources deployed at these remote sites are not integrated and operate in a stand-alone mode, that is, they are not connected to the distribution system.
- The present system in places has ageing generators and limited backup with very high maintenance costs.
- The whole system of energy supply in remote military installations on islands works at low efficiency with very high running costs.

6.3 ENERGY REQUIREMENT OF ARMED FORCES BASES AND MICROGRID PLANS.

The Armed Forces, comprising the Army, Air Force, Navy, and Coast Guard, are located on 11 islands, with large bases to small posts in remote locations. There are naval jetties for big ships on all islands and large infrastructure for troops on many islands. The four airfields at Port Blair, Car Nicobar, Campbell Bay, and Shibpur are larger military bases which have critical energy needs. The runways in these remote locations have to be maintained with adequate sources of power to ensure a high degree of reliability. The bases are supplied with electricity by the Electricity Department, but each base has its own backup sources of diesel generators. Even the supply through the electricity department is based on diesel generators. In some isolated bases, small solar lights and wind generators have been installed, but no major PV plant has been established for the Armed Forces. The requirement for energy at four of the bases is as given in Table 6.2.

Table 6.2 : Power requirement in the four remote military bases located in Andaman and Nicobar Islands

Base Location	Max Demand (KW)	Generating Capacity (KW)
Shibpur Base	280	610
Birchgunj Base	1200	3400
Car Nicobar Island Base	1000	3000
Kamorta Island Base	280	250

As the Chief Engineer for the development of infrastructure for the Armed Forces, to cater for the additional load and to increase self-reliance by exploiting the renewable energy sources, four microgrid based solar PV projects have been designed as a result of the research and are under construction at Birchgunj Army Base Station (Port Blair, South Andaman), Shibpur Naval Base (North Andamans), Car Nicobar Air Force Base and Kamorta Naval Base by the Military Engineering Services. The remote locations are shown in Fig. 6.1.

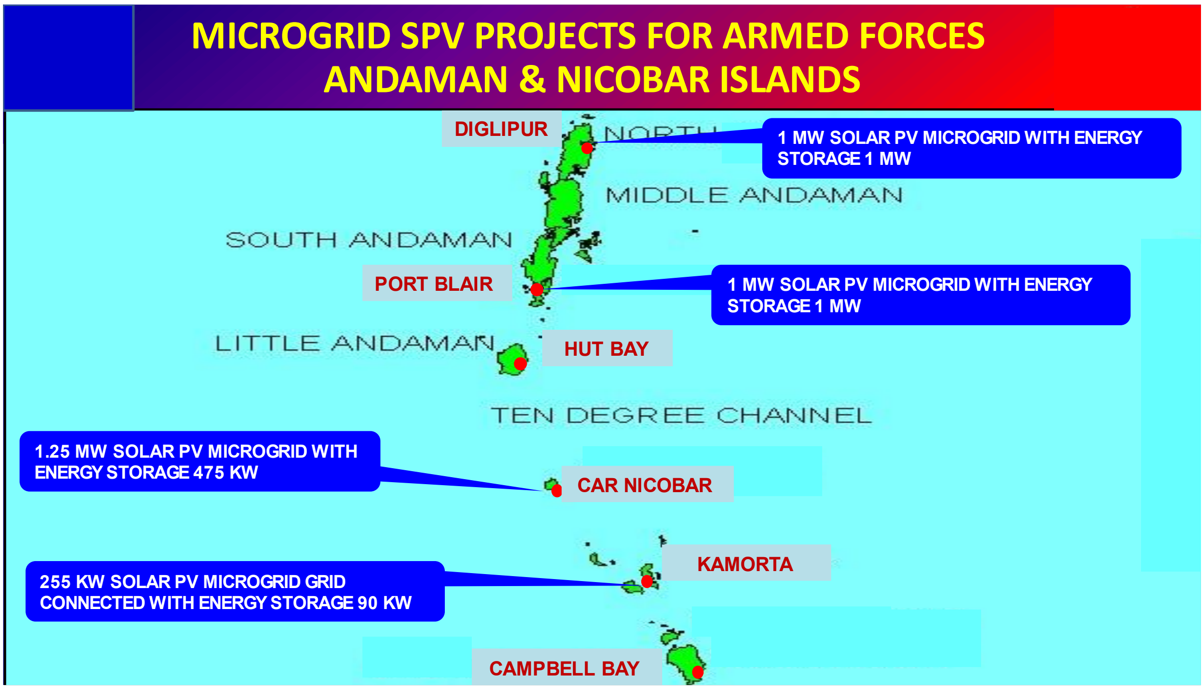


Figure 6.1:Location of four Microgrids for Armed Forces in remote areas of Andaman and Nicobar Islands.

The project consists of solar arrays with battery banks connected to existing power houses, with the entire distribution being controlled by microgrids having the capability to switchover to energy sources as per availability. **These are the first microgrids being constructed for remote military bases in the country**. The implementation will result in a significant reduction in the cost of generation from diesel generator sets running 24 hours (from Rs 27.45/KWh to Rs 8/KWh) by using solar power. Constructing these microgrids will result in huge savings for the nation and also reduce its carbon footprint by saving precious fossil fuels, including the carriage of fuel by ships from mainland India. The details of micro-grid-based Solar PV projects are as under:-

- **Birchgunj Army Base (Port Blair, South Andaman)-1 MW Solar PV Microgrid with a standby battery bank of 1 MW.**
- **Shibpur Naval Base (North Andamans)-1 MW Solar PV Microgrid with a standby battery bank of 1 MW.**
- **Carnic Air Force Base: 1.25 MW Solar PV Microgrid with a standby battery bank of 475 KW.**
- **Kamorta Naval Base-255 KW Solar PV Microgrid.**

The research and design work has been carried out across all four bases. The design of the microgrid at Birchjung Army base in Port Blair and its specifications are being highlighted in the sections.

6.3 DESIGN OF MICROGRID IN PORT BLAIR

6.3.1 PV Syst Design of Microgrid System.

The fundamental features of a solar panel are determined by the type of solar cell, the cell's temperature, and the radiation incident on it. The conversion efficiency of photovoltaic systems is a critical aspect to consider when evaluating energy-producing methods. We begin this chapter by designing and analysing the performance of the microgrid's photovoltaic system using the PV Syst software.

PV Syst is an established solar simulation software all across the world that assists in the design of a solar plant with reference to the generation of solar power by the plant per month or annually, and in some cases, we are interested in knowing how much it will produce per day. PV Syst software has the following features:

- System designing
- System sizing
- Creating a shading scene
- It generates simulations and outcomes.
- Model storage systems
- Some additional features include importing data and components and getting weather data from meteonorm.
- Simulate the ageing effect of solar modules, etc.

PV Syst software is composed of numerous components. The specs for these hardware components that act as input devices for the programme. The software collects all of the data, runs the stimulation, and produces the outcome.

Site Selection Birchjung, Port Blair, has been chosen as the location for the PV solar plant for the microgrid, with latitude 11.6° N and longitude 92.7° E at an altitude of 17 M above Mean Sea Level. This serves as an input for Meteo Data. Throughout the year, additional data like as horizontal global irradiation, horizontal diffusive irradiation, temperature, wind velocity, connected turbidity, and relative humidity can be found in the Meteonorm.

Selection of equipment. Each component and system that are commercially available and can be integrated into the present microgrid network have been identified and their specifications checked for suitability. Specifications of various components are given in the succeeding paragraphs.

PV Panels Specifications.

Make: Waaree
Module Capacity : 325Wp
Vmpp : 36.81 V
Impp : 8.83 A
Voc : 45.69 V
Isc : 9.4 A
Total No of Modules : 3080 Nos

Inverter Specifications.

Make : Dynapower EMS-250 800V

Input Specifications

DC Voltage : 580-835 V
Max DC Current : 455 A
Max voltage ripple : < 1%

Grid Connection

AC Line Voltage : 415 V AC, # Phase, ± 10 %
AC Line Frequency : 50 Hz ± 5%
Continuous AC Current : 348 A RMS
Overload AC Current : 366 A RMS
Continuous AC Power : 250 KW
Overload AC Power* : 300 KW
Power Factor : 0-1.0 Leading or lagging
Current Harmonics : IEEE 1547 Compliant, <5% TDD
Peak Efficiency : 96 %

Additional Features User Interface

Faults: AC Under Voltage, AC Over Voltage, AC Over Frequency, AC Under Frequency, AC Overload, Over-temperature, DC Over Voltage, DC Over Current.

Standards Compliance: IEEE 1547, UL 1741 SA, CA Rule 21, and HI Rule 14H

6.3.2 Simulation Using PV Syst Software

PV system performance is mostly determined through the use of PV system software when unit sizing is required. Only geographical coordinates are used to import meteorological data into the app. Furthermore, the software has a huge library for storing data on climatic conditions, components, analyses, and PV system measurements. The results can be estimated for a year's worth of generation on an hourly basis. The system's performance may be monitored on an annual basis, and then the system can be configured to produce the maximum amount of energy under the appropriate environmental conditions, temperature, and speed.

The simulation results show: PV module and inverter specifications are optimised by the PVsyst software to ensure that the grid-connected system is appropriately sized. The simulation system requirements are used to determine the system's output power and loss. The result sheets of the PV Syst software simulation are shown in Section 6.4.3. The simulations gave the following results:

Trajectories of PV modules: The Iso Shading graphic shows how the sun moves because it has different trajectories at different angles. In this graph, you can see how the angle of incidence of solar rays on photovoltaic modules changes with the angle of tilt and the direction of the sun. The tilt angle and azimuth angle of the solar panel are determined by how the solar panel is positioned on the roof. There are numerous field types to choose from. We maintained a summer tilt of 12 degrees at this site due to the sun path and geographical location, and the azimuth is 0 degrees due to the lack of elevation.

System Configuration: A grid-connected PV system for a 1000 KW power plant is modelled in the PVSyst programme. According to the simulation, 3080 modules and three inverters are required. A string of 20 PV modules is formed by connecting them in series. In total, 19 and 20 strings of 20 PV models are employed in the system. To reach the appropriate power levels, 154 strings are connected in parallel. The modules will require 5989 square metres of space. The system's maximum power point current will be around 1354 Amp. The amount of solar energy received by the photovoltaic system, as well as the ambient temperature, dictate the system's output. At 50 °C, the highest power point voltage will be 662 Vs.

Energy Production. The simulations gave following results towards energy production: -

- Annual Energy Output: 1363 MWh with a performance ratio (PR) of 75.5 percent at 50 °C, the operating temperature for photovoltaic modules. The data indicates that the highest energy production occurs in March, at 147.8 MWh, while the lowest production occurs in June.
- The primary outputs and balances are as follows: Solar panels generate 1683.5 KWh/m2 of horizontal radiation every year. The annual global energy consumption of collectors is 1721 KWh/m2. Each year, the photovoltaic array generates 1363 MWh of energy. The yearly efficiency of the approximate area attained by a photovoltaic array, referred to as E out/Array, is 13.22 percent, whereas the annual efficiency of the total system, referred to as E out/System, is 12.62 percent.
- Normalized Energy Outputs: Collection losses (LC) are 0.99 KW h/KW p/day, system losses (LS) are 0.17 KW h/KW p/day, and inverter energy production is 3.56 KW h/KW p/day on the inverter side.
- Loss Diagram: The global horizontal irradiance value is 1683 KWh/sq mtr.Effective irradiation on the collector plane is 1588 KW h/sq mtr. According to the data, the entire energy loss is 3.0 percent. As illustrated in the output's loss diagram, the PV array generates 1591 MWh of energy and has a 16.72 percent efficiency under standard test conditions. The array's virtual energy capacity is 1363 MWh, while the energy available for inverter output is 1338 MWh, for a total of 1301 MWh injected into the distribution network.

6.3.3 The PV Syst design output.

The result of the PV Syst software showing the output of the specified PV Panels and inverter are given in this section in five pages of result sheets generated by the software.

Grid-Connected System: Simulation parameters

Project :	**Grid-Connected Project at MES-Portblair**			
Geographical Site	**MES-Portblair**		Country	**India**
Situation	Latitude	11.6°N	Longitude	92.7°E
Time defined as	Legal Time	Time zone UT+5.5	Altitude	17 m
	Albedo	0.20		
Meteo data:	**MES-Portblair**	Meteonorm 7.1 (1991-2010), Sat=100% - Synthetic		

Simulation variant :	**New simulation variant**			
	Simulation date	29/08/18 16h05		

Simulation parameters

Collector Plane Orientation	Tilt	12°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Array Characteristics

PV module Si-poly	Model	**ASP 7 325 - 5BB**		
Custom parameters definition	Manufacturer	Waree		
Number of PV modules	In series	20 modules	In parallel	154 strings
Total number of PV modules	Nb. modules	3080	Unit Nom. Power	325 Wp
Array global power	Nominal (STC)	**1001 kWp**	At operating cond.	896 kWp (50°C)
Array operating characteristics (50°C)	U mpp	662 V	I mpp	1354 A
Total area	Module area	**5989 m²**	Cell area	5449 m²

Inverter	Model	**Dynapower EMS-250 800V**		
Original PVsyst database	Manufacturer	**Raychem**		
Characteristics	Operating Voltage	580-835 V	Unit Nom. Power	1000 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	1000 kWac

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	10.0 mOhm	Loss Fraction	1.8 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
LID - Light Induced Degradation			Loss Fraction	2.5 %
Module Quality Loss			Loss Fraction	1.0 %
Module Mismatch Losses			Loss Fraction	1.5 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

System loss factors

AC loss, transfo to injection	Grid Voltage	11 kV		
	Wires: 3x25.0 mm²	1306 m	Loss Fraction	0.8 % at STC
External transformer	Iron loss (24H connexion)	986 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	1227.4 mOhm	Loss Fraction	1.0 % at STC
Unavailability of the system	4.0 days, 3 periods		Time fraction	1.1 %

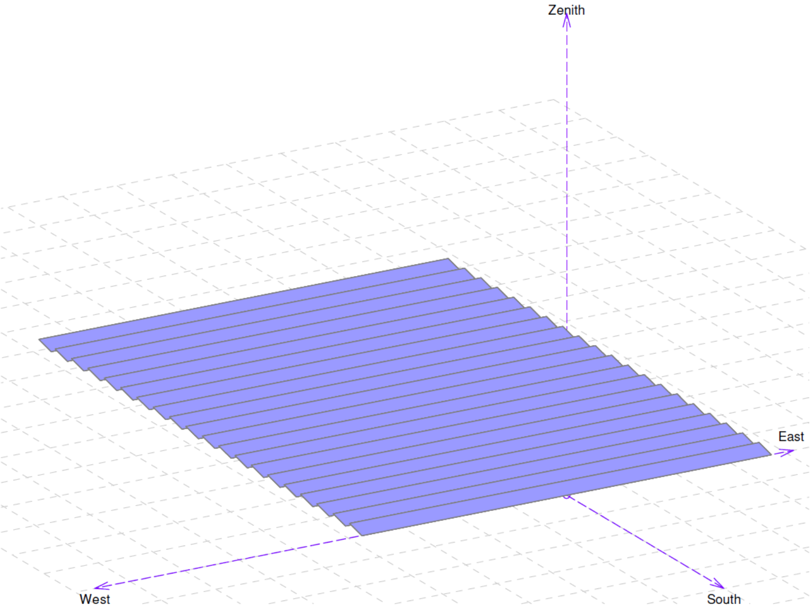
User's needs :	Unlimited load (grid)

Grid-Connected System: Near shading definition

Project : **Grid-Connected Project at MES-Portblair**
Simulation variant : **New simulation variant**

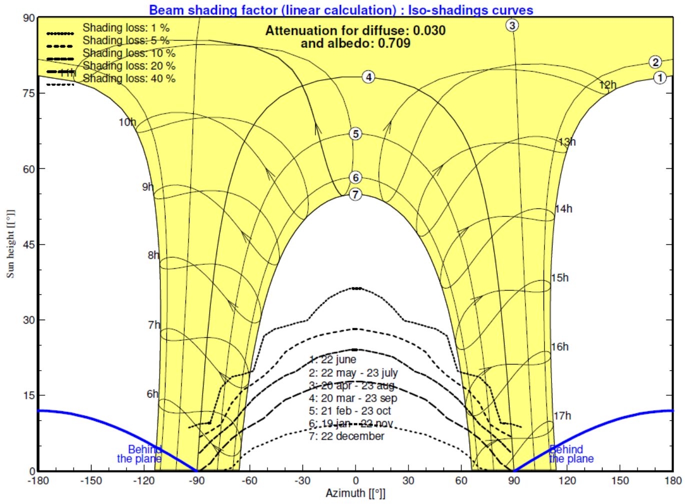
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	12°	azimuth	0°
PV modules	Model	ASP 7 325 - 5BB	Pnom	325 Wp
PV Array	Nb. of modules	3080	Pnom total	**1001 kWp**
Inverter	Model	Dynapower EMS-250 800V	Pnom	1000 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Grid-Connected Project at MESLegal Time



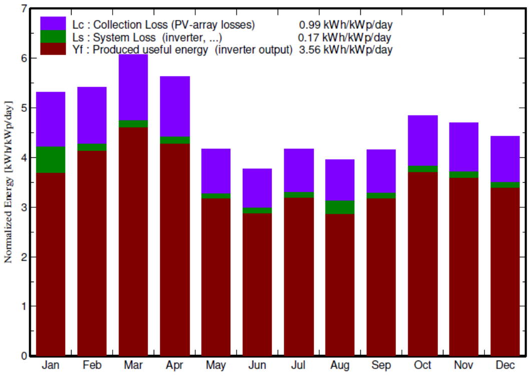
Grid-Connected System: Main results

Project : **Grid-Connected Project at MES-Portblair**
Simulation variant : **New simulation variant**

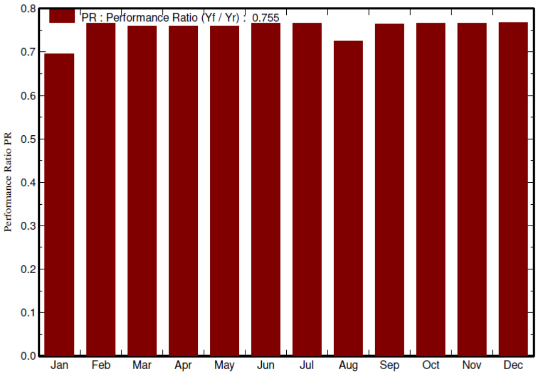
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	12°	azimuth	0°
PV modules	Model	ASP 7 325 - 5BB	Pnom	325 Wp
PV Array	Nb. of modules	3080	Pnom total	**1001 kWp**
Inverter	Model	Dynapower EMS-250 800V	Pnom	1000 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**1301 MWh/year**	Specific prod.	1299 kWh/kWp/year
	Performance Ratio PR	75.5 %		

Normalized productions (per installed kWp): Nominal power 1001 kWp



Performance Ratio PR



New simulation variant
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	148.7	26.50	164.9	152.8	131.0	114.9	13.27	11.63
February	141.9	26.80	151.5	140.3	120.0	116.2	13.22	12.80
March	183.2	27.60	188.1	175.0	147.8	143.2	13.12	12.71
April	171.5	28.10	168.9	156.3	132.7	128.5	13.12	12.70
May	135.3	27.50	129.3	118.8	102.1	98.5	13.18	12.72
June	118.9	26.70	113.1	103.2	90.0	86.7	13.29	12.81
July	135.3	27.10	129.3	118.2	102.8	99.2	13.28	12.82
August	125.4	26.90	122.6	112.3	97.2	89.0	13.24	12.12
September	124.0	26.10	124.6	114.8	98.9	95.4	13.26	12.78
October	143.9	26.80	150.4	138.9	119.3	115.3	13.25	12.81
November	130.9	27.00	141.2	130.8	112.0	108.3	13.25	12.81
December	124.5	26.99	137.5	126.8	109.3	105.6	13.28	12.83
Year	1683.5	27.01	1721.4	1588.2	1363.2	1300.8	13.22	12.62

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

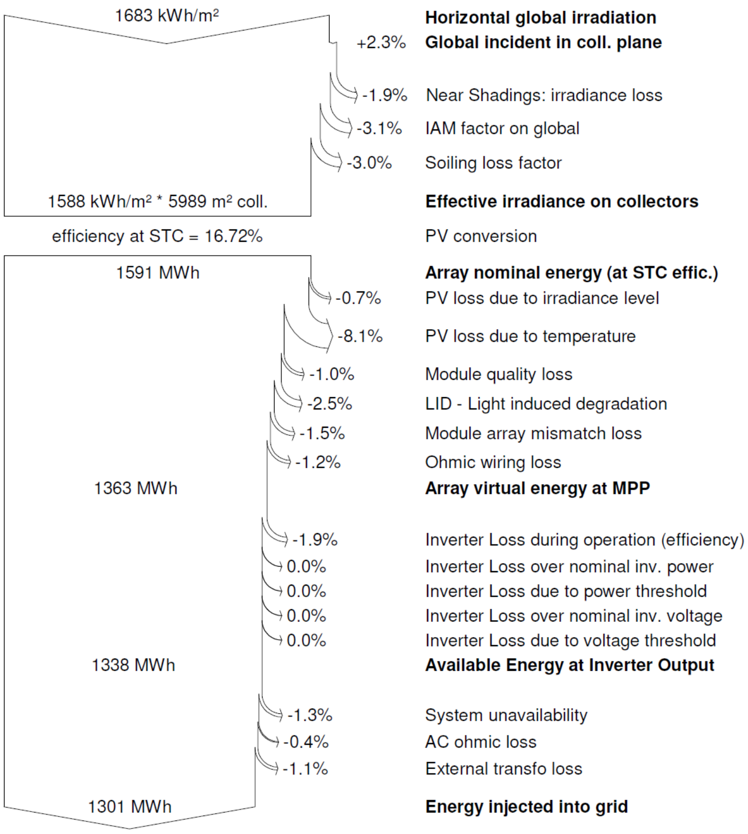
Grid-Connected System: Loss diagram

Project : **Grid-Connected Project at MES-Portblair**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	12°	azimuth	0°
PV modules	Model	ASP 7 325 - 5BB	Pnom	325 Wp
PV Array	Nb. of modules	3080	Pnom total	**1001 kWp**
Inverter	Model	Dynapower EMS-250 800V	Pnom	1000 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : **Grid-Connected Project at MES-Portblair**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	12°	azimuth	0°
PV modules	Model	ASP 7 325 - 5BB	Pnom	325 Wp
PV Array	Nb. of modules	3080	Pnom total	**1001 kWp**
Inverter	Model	Dynapower EMS-250 800V	Pnom	1000 kW ac
User's needs		Unlimited load (grid)		

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

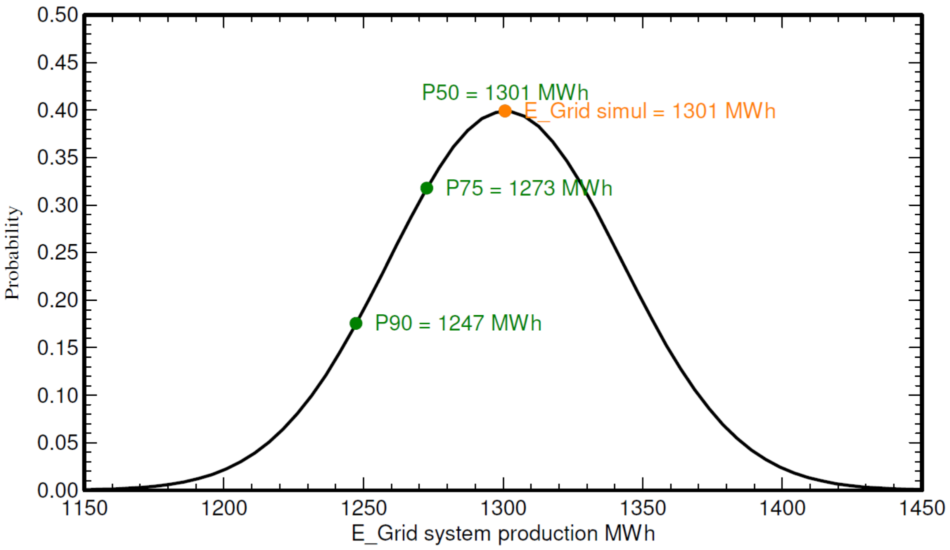
Meteo data source		Meteonorm 7.1 (1991-2010), Sat=100%		
Meteo data	Kind	Not defined	Year	1995
Specified Deviation	Year deviation from aver.	3 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	2.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	3.2 %	(quadratic sum)

Annual production probability	**Variability**	**42 MWh**
	P50	**1301 MWh**
	P90	**1247 MWh**
	P75	**1273 MWh**

Probability distribution



6.3.4 Layout of Microgrid at Port Blair base of Armed Forces.

The layout and placement of various components of the microgrid at Port Blair base of Armed Forces integrated with the existing electric distribution network is as shown in the layout diagram in Fig 6.2

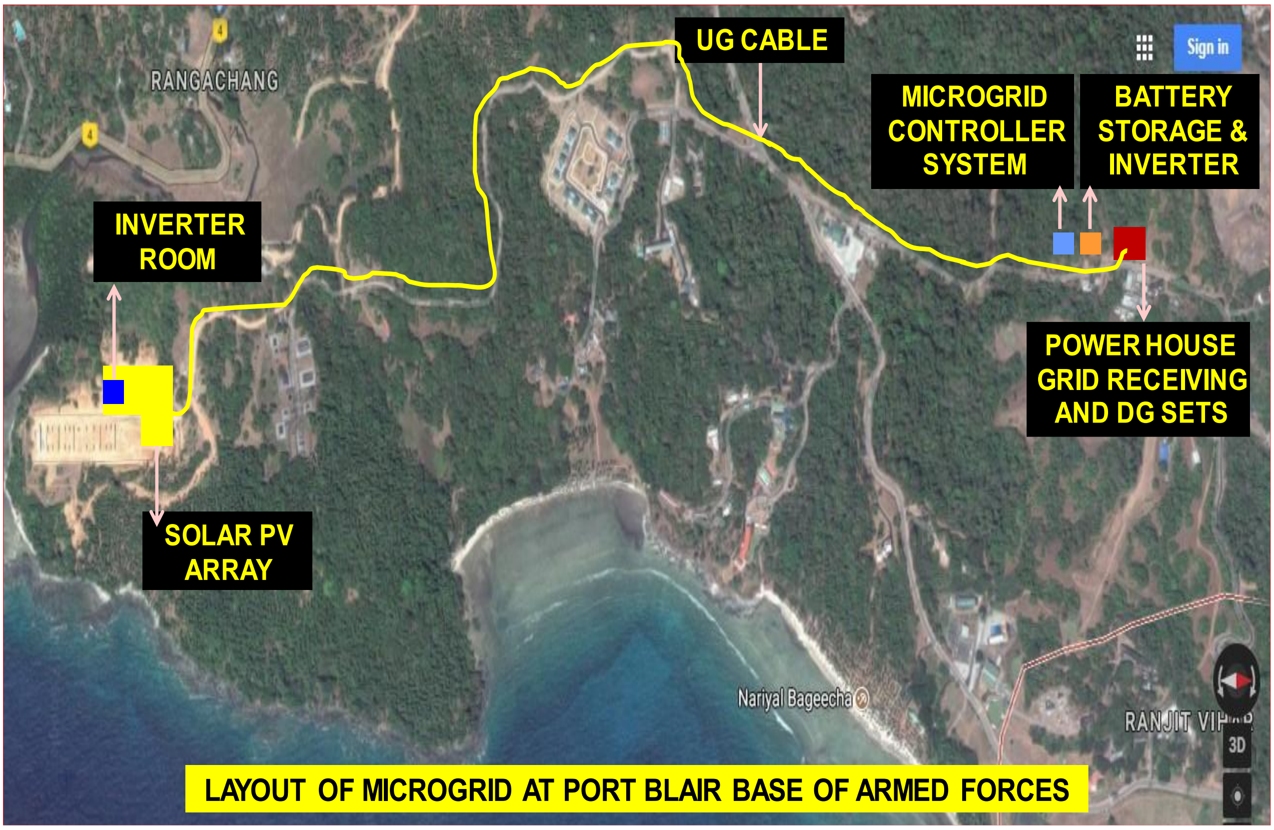
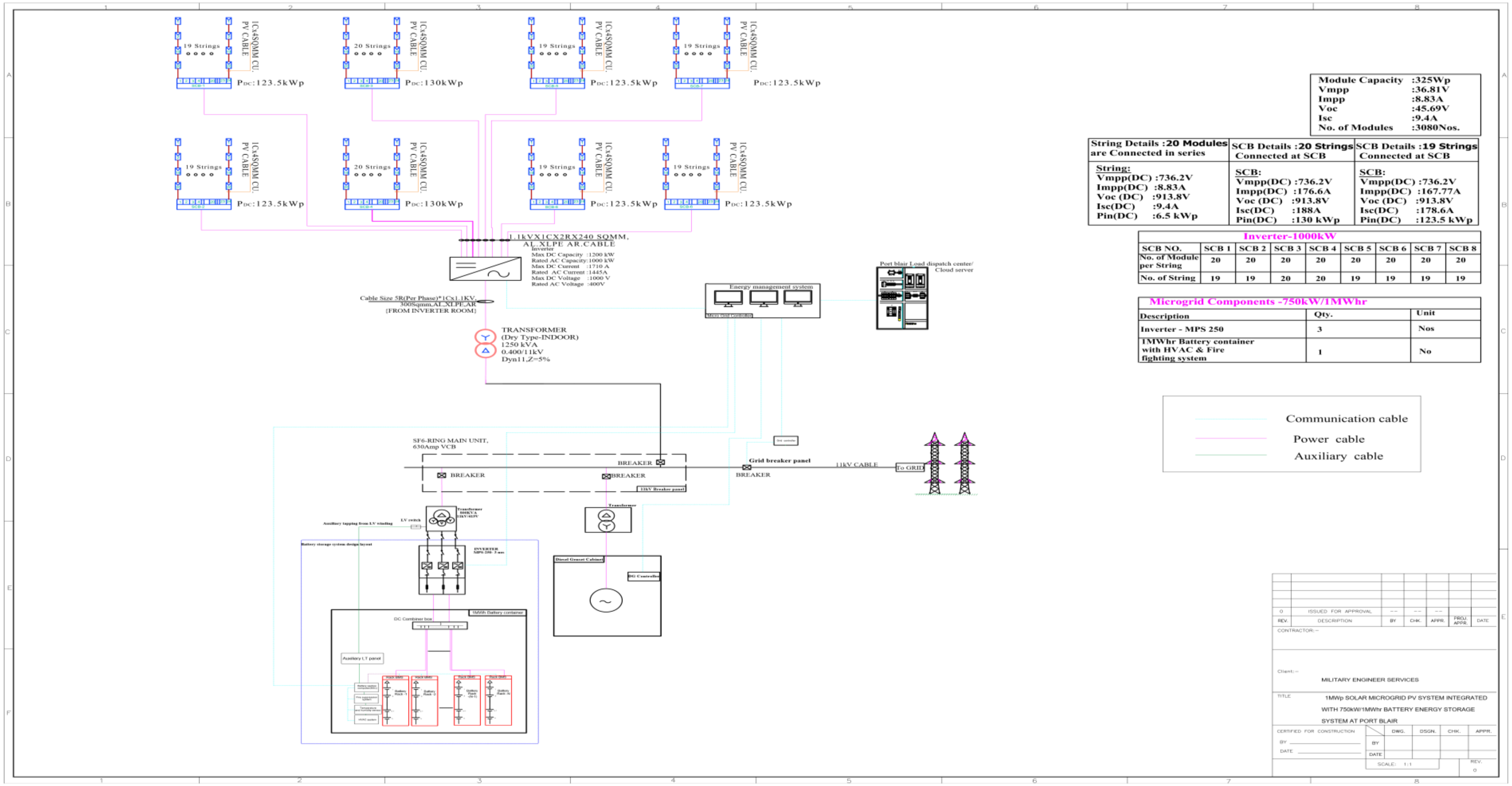


Figure 6.2:Layout diagram of Microgrid at Birchjung, Port Blair base of Armed Forces

6.3.5 Layout of Microgrid - Single Line Diagram.

The single line diagram of the Microgrid integrated with the existing electric distribution network is as shown Fig 6.3.



Module Capacity :325Wp
Vmpp :36.81V
Impp :8.83A
Voc :45.69V
Isc :9.4A
No. of Modules :3080Nos.

String Details :20 Modules are Connected in series
String:
Vmpp(DC) :736.2V
Impp(DC) :8.83A
Voc (DC) :913.8V
Isc(DC) :9.4A
Pin(DC) :6.5 kWp

SCB Details :20 Strings Connected at SCB
SCB:
Vmpp(DC) :736.2V
Impp(DC) :176.6A
Voc (DC) :913.8V
Isc(DC) :188A
Pin(DC) :130 kWp

SCB Details :19 Strings Connected at SCB
SCB:
Vmpp(DC) :736.2V
Impp(DC) :167.77A
Voc (DC) :913.8V
Isc(DC) :178.6A
Pin(DC) :123.5 kWp

Inverter-1000kW

SCB NO.	SCB 1	SCB 2	SCB 3	SCB 4	SCB 5	SCB 6	SCB 7	SCB 8
No. of Module per String	20	20	20	20	20	20	20	20
No. of String	19	19	20	20	19	19	19	19

Microgrid Components -750kW/1MWhr

Description	Qty.	Unit
Inverter - MPS 250	3	Nos
1MWhr Battery container with HVAC & Fire fighting system	1	No

REV.	DESCRIPTION	BY	CHK.	APPR.	PROJ. APPR.	DATE
0	ISSUED FOR APPROVAL	--	--	--		

CONTRACTOR:-

Client:-
MILITARY ENGINEER SERVICES

TITLE
1MWp SOLAR MICROGRID PV SYSTEM INTEGRATED
WITH 750kW/1MWhr BATTERY ENERGY STORAGE
SYSTEM AT PORT BLAIR

CERTIFIED FOR CONSTRUCTION
BY
DATE

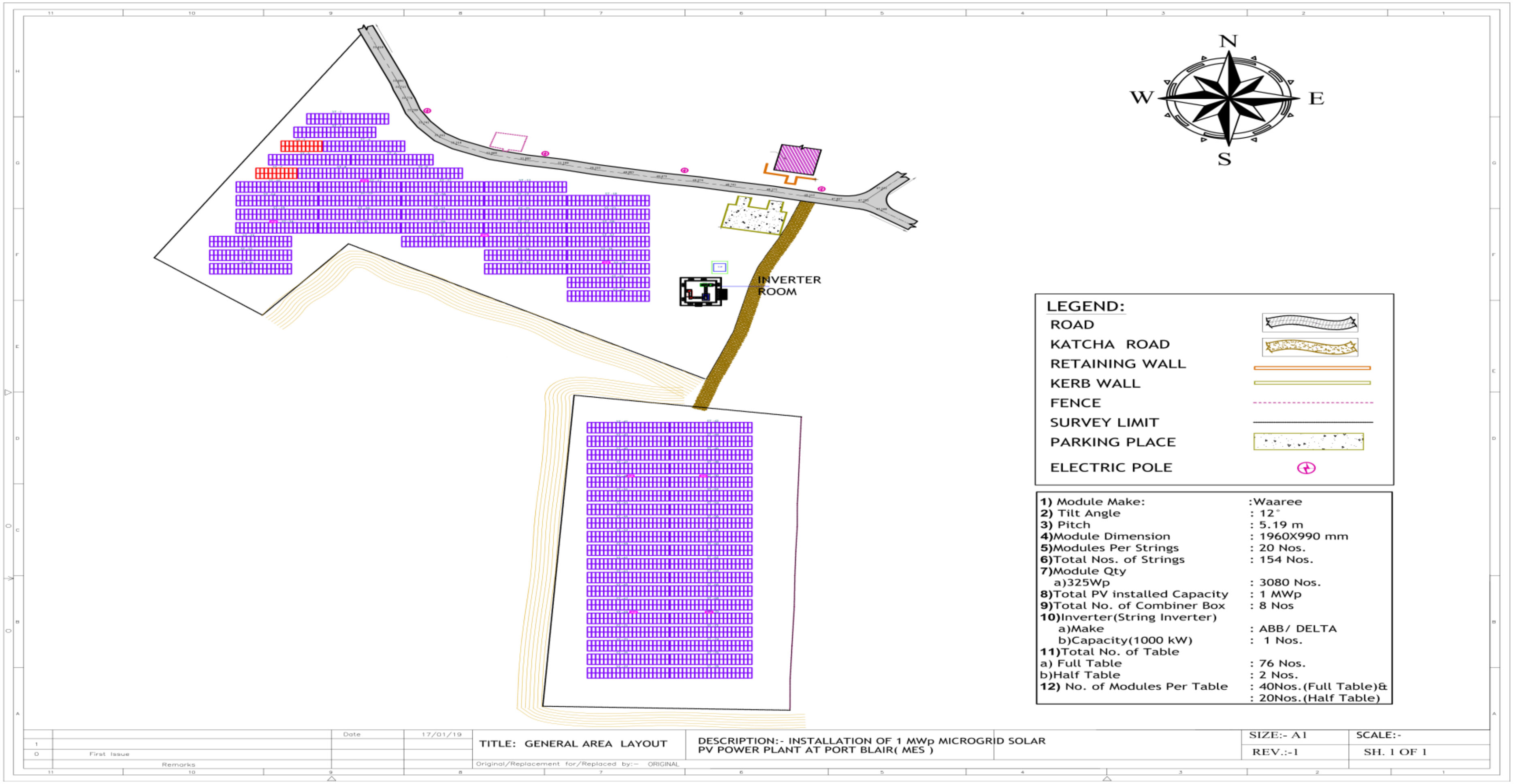
	DWG.	DSGN.	CHK.	APPR.
BY				
DATE				

SCALE: 1:1
REV. 0

Figure 6.3: The single line diagram of the Microgrid at Birchjung Military area in Port Blair

6.3.6 General Area Layout.

The general area layout and placing of the PV System with PV panels is shown in Fig 6.4

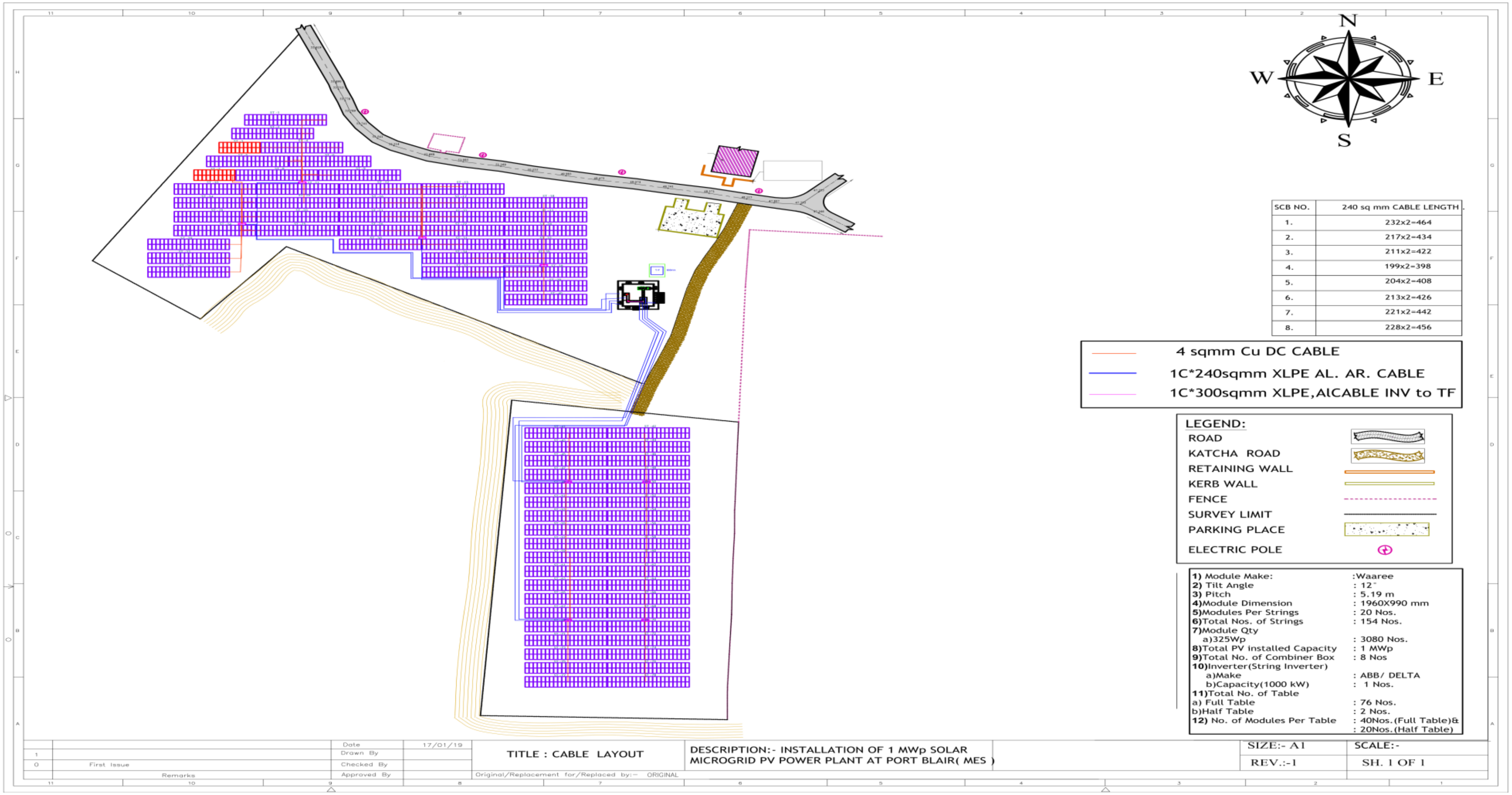


1) Module Make:	:Waaree
2) Tilt Angle	: 12°
3) Pitch	: 5.19 m
4)Module Dimension	: 1960X990 mm
5)Modules Per Strings	: 20 Nos.
6)Total Nos. of Strings	: 154 Nos.
7)Module Qty	
a)325Wp	: 3080 Nos.
8)Total PV installed Capacity	: 1 MWp
9)Total No. of Combiner Box	: 8 Nos
10) Inverter(String Inverter)	
a)Make	: ABB/ DELTA
b)Capacity(1000 kW)	: 1 Nos.
11) Total No. of Table	
a) Full Table	: 76 Nos.
b)Half Table	: 2 Nos.
12) No. of Modules Per Table	: 40Nos.(Full Table)& : 20Nos.(Half Table)

Figure 6.4:General layout of 3080 Solar PV panels in Birchjung Military area

6.3.7 Cable Layout.

The cable layout of the PV solar installation of designed sizes is as shown in the Fig 6.5.



SCB NO.	240 sq mm CABLE LENGTH
1.	232x2=464
2.	217x2=434
3.	211x2=422
4.	199x2=398
5.	204x2=408
6.	213x2=426
7.	221x2=442
8.	228x2=456

1) Module Make:	:Waaree
2) Tilt Angle	: 12°
3) Pitch	: 5.19 m
4)Module Dimension	: 1960X990 mm
5)Modules Per Strings	: 20 Nos.
6)Total Nos. of Strings	: 154 Nos.
7)Module Qty	
a)325Wp	: 3080 Nos.
8)Total PV installed Capacity	: 1 MWp
9)Total No. of Combiner Box	: 8 Nos
10) Inverter(String Inverter)	
a)Make	: ABB/ DELTA
b)Capacity(1000 kW)	: 1 Nos.
11) Total No. of Table	
a) Full Table	: 76 Nos.
b)Half Table	: 2 Nos.
12) No. of Modules Per Table	: 40Nos.(Full Table)& : 20Nos.(Half Table)

Figure 6.5:The cable layout of the PV solar installation of designed sizes

6.3.8 Earthing Layout.

The Earthing layout of the PV System has been designed and is shown in the layout drawings in Fig 6.6

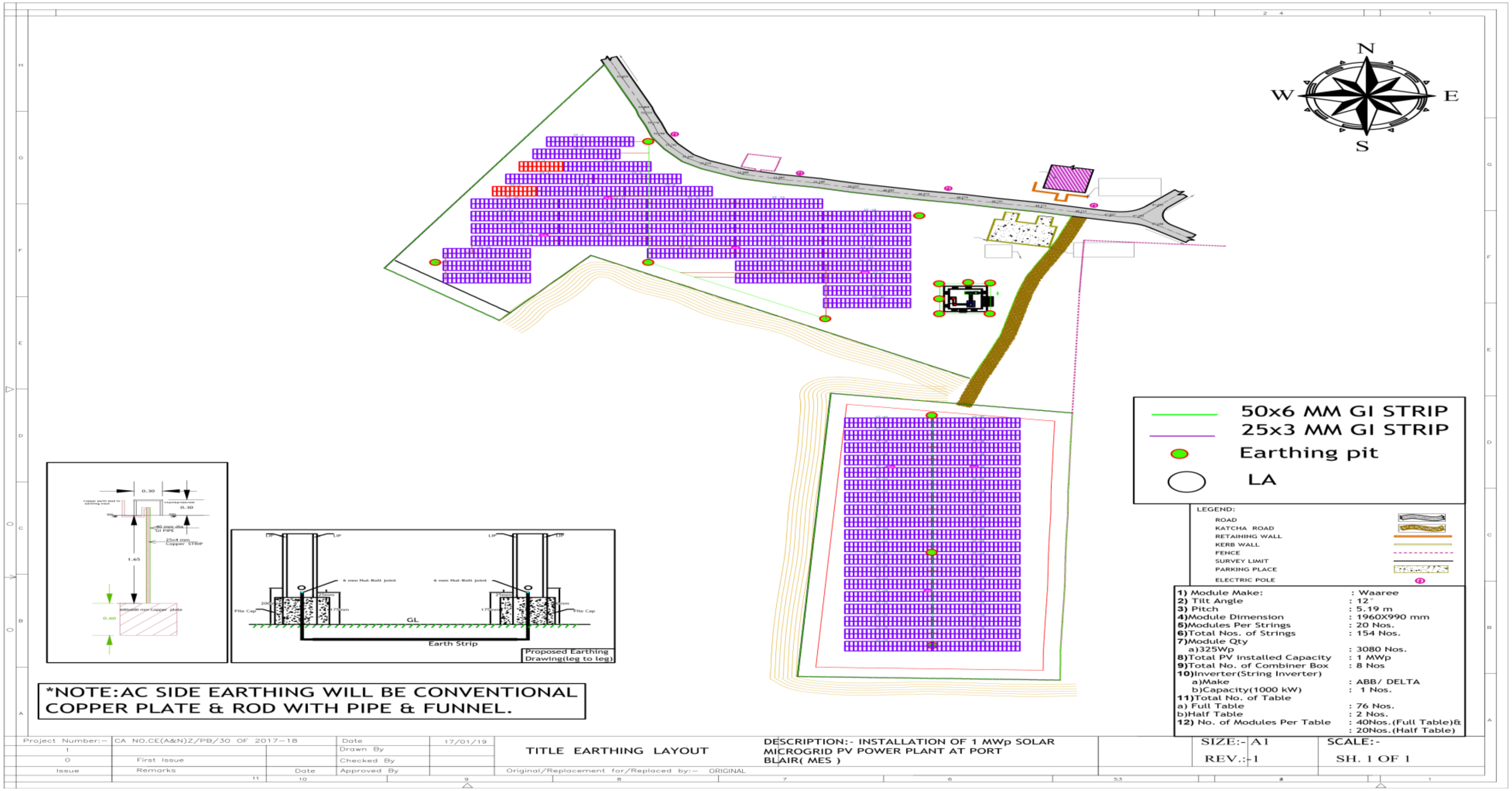
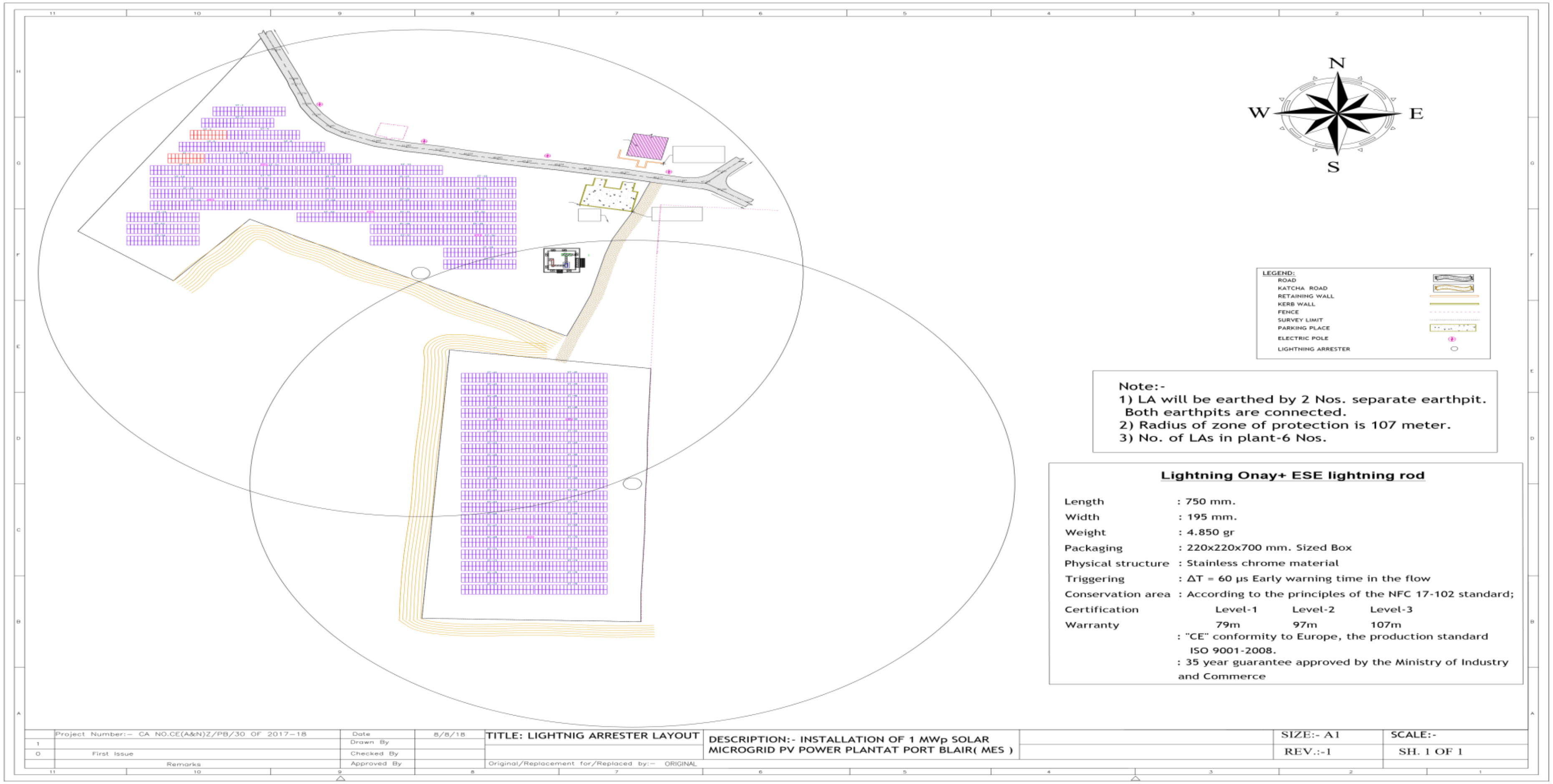


Figure 6.6:The Earthing layout of the PV System

6.3.9 Lighting Arrestor Layout.

The complete area where the PV panels are installed will be protected by lighting arrestors. Location and protection zone of the lighting arrestors is as shown in the Fig 6.7.



Note:-
1) LA will be earthed by 2 Nos. separate earthpit. Both earthpits are connected.
2) Radius of zone of protection is 107 meter.
3) No. of LAs in plant-6 Nos.

Lightning Onay+ ESE lightning rod

Length : 750 mm.
Width : 195 mm.
Weight : 4.850 gr
Packaging : 220x220x700 mm. Sized Box
Physical structure : Stainless chrome material
Triggering : ΔT = 60 µs Early warning time in the flow
Conservation area : According to the principles of the NFC 17-102 standard;

	Level-1	Level-2	Level-3
	79m	97m	107m

Certification : "CE" conformity to Europe, the production standard ISO 9001-2008.
Warranty : 35 year guarantee approved by the Ministry of Industry and Commerce

Project Number:– CA NO.CE(A&N)Z/PB/30 OF 2017–18
Date 8/8/18
1
0 First Issue
Remarks
Drawn By
Checked By
Approved By
TITLE: LIGHTNIG ARRESTER LAYOUT
Original/Replacement for/Replaced by:– ORIGINAL
DESCRIPTION:- INSTALLATION OF 1 MWp SOLAR MICROGRID PV POWER PLANTAT PORT BLAIR(MES)
SIZE:- A1
REV.:-1
SCALE:-
SH. 1 OF 1

Figure 6.7:Location and protection zone of the lighting arrestors

6.3.10 Matlab Design and Simulation of the Microgrid System.

The three major components of the microgrid system have been designed, and their performance has been simulated for their validation. The commercially available equipment that will be installed in the microgrid has been studied for its operating parameters, and similar equipment and control techniques as available in the MATLAB Simulink library have been incorporated into the design. The commercial equipment, due to propriety issues, cannot be replicated. The major components simulated are the PV system and the energy storage system with Li-ion batteries.

6.3.11 Matlab Design of Energy Storage system with Inverter.

The battery storage system with a capacity of 1 MWh with an inverter was designed with Lithium-Ion batteries, a bi-directional inverter and a charge controller. The energy storage system MATLAB design connected to the grid is shown in Fig 6.8 and the discharge characteristics of the Li-ion batteries as simulated are shown in Fig 6.9.

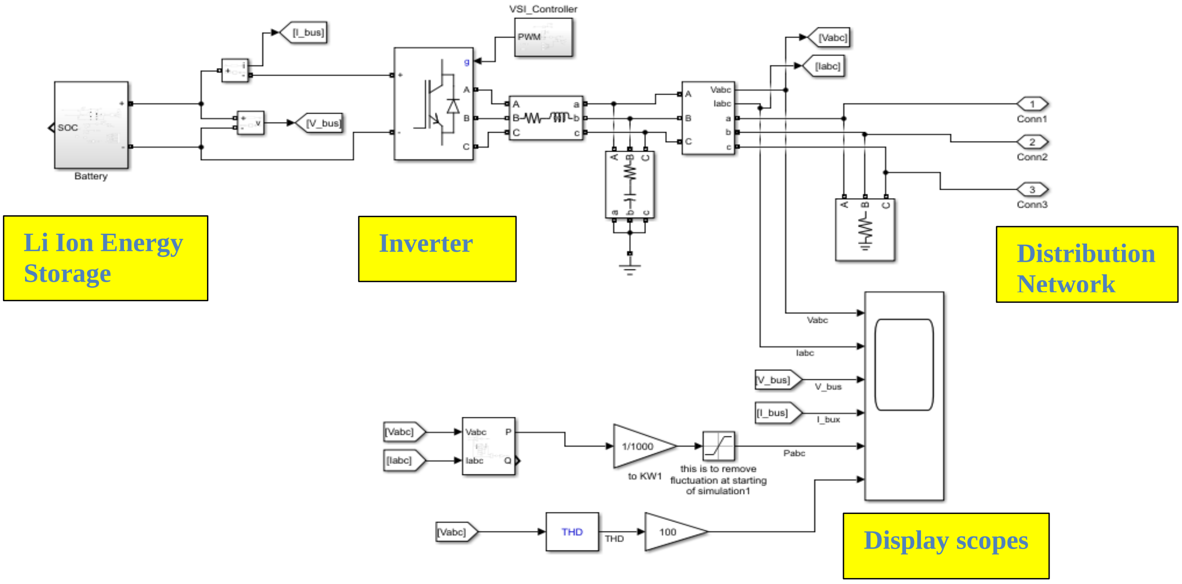


Figure 6.8:Energy Storage sub system design with inverter and Li Ion batteries.

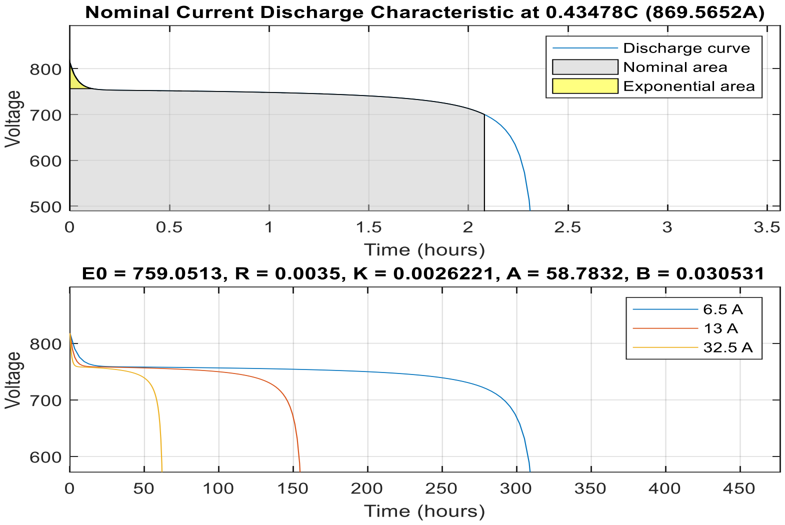
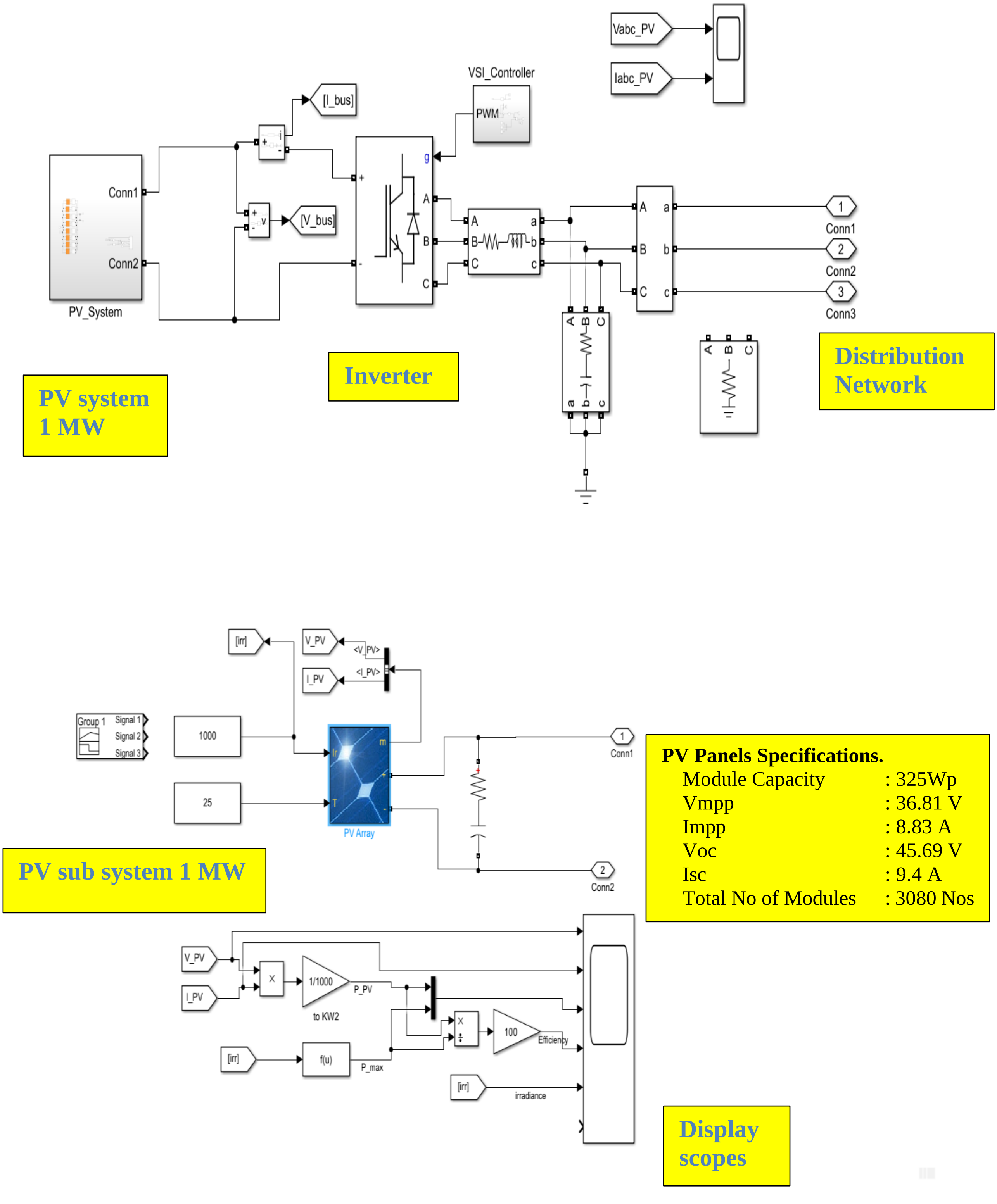


Figure 6.9: Under normal operating conditions, the battery system's discharge characteristics

6.3.12 Matlab Design of PV System with Inverter.

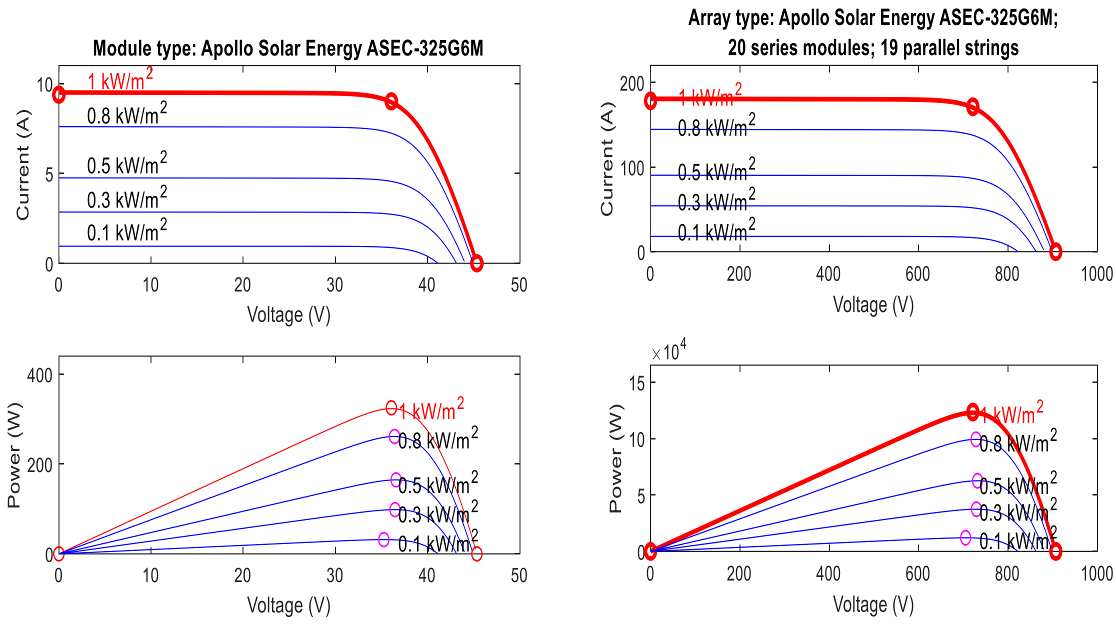
The PV system with a capacity of 1 MW is made up of 3080 panels in total. Each panel has a 325 Wp capacity. A string of 20 modules is connected in series to produce a Vmpp of 736.2 V, and 19/20 strings are connected in parallel to produce 1000 KW of electricity. The system is connected to the distribution network and is modelled in Matlab with an inverter. The PV system's operation is simulated and validated. Figure 6.10 depicts the PV subsystem diagram. The operation of a single module and a string is validated and the results of current versus voltage and PV curves of a module and a string are shown in Fig 6.11, and PV curve variation with temperature is seen in Fig 6.12.



PV Panels Specifications.

Module Capacity	: 325Wp
Vmpp	: 36.81 V
Impp	: 8.83 A
Voc	: 45.69 V
Isc	: 9.4 A
Total No of Modules	: 3080 Nos

Figure 6.10:PV System design with 3080 panels arranged in 20 modules of 19/20 strings connected to the distribution network through an inverter.



PV Curve for single module

PV curve for one array

Figure 6.11: “Current v/s voltage and power v/s voltage curve of the PV system for different amount of irradiances for one module and for an array”

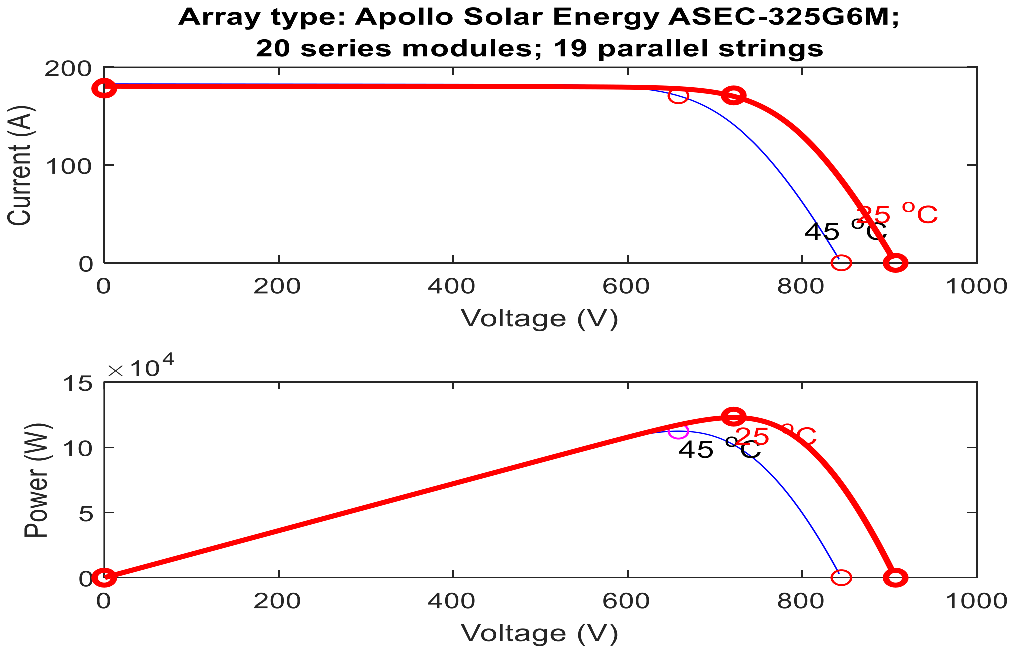


Figure 6.12: PV curve variation with respect to temperature (for one array)

6.3.13 MATLAB Design and Modelling of the complete Microgrid System.

The MATLAB design of the microgrid system integrating the PV sub system, energy storage sub system, diesel generator sub system, and the grid incoming is simulated to validate the functioning and operation of the microgrid designed in Port Blair. The modelling has been completed, keeping the parameters and specifications similar to the actual equipment available commercially. However, all parameters cannot be replicated due to propriety constraints by the vendor. Validation has been done with various sources supplying energy to the distribution network. Figure 6.13 depicts the MATLAB model for simulating the microgrid. The model is similar and based on the layout of the microgrid layout at Port Blair.

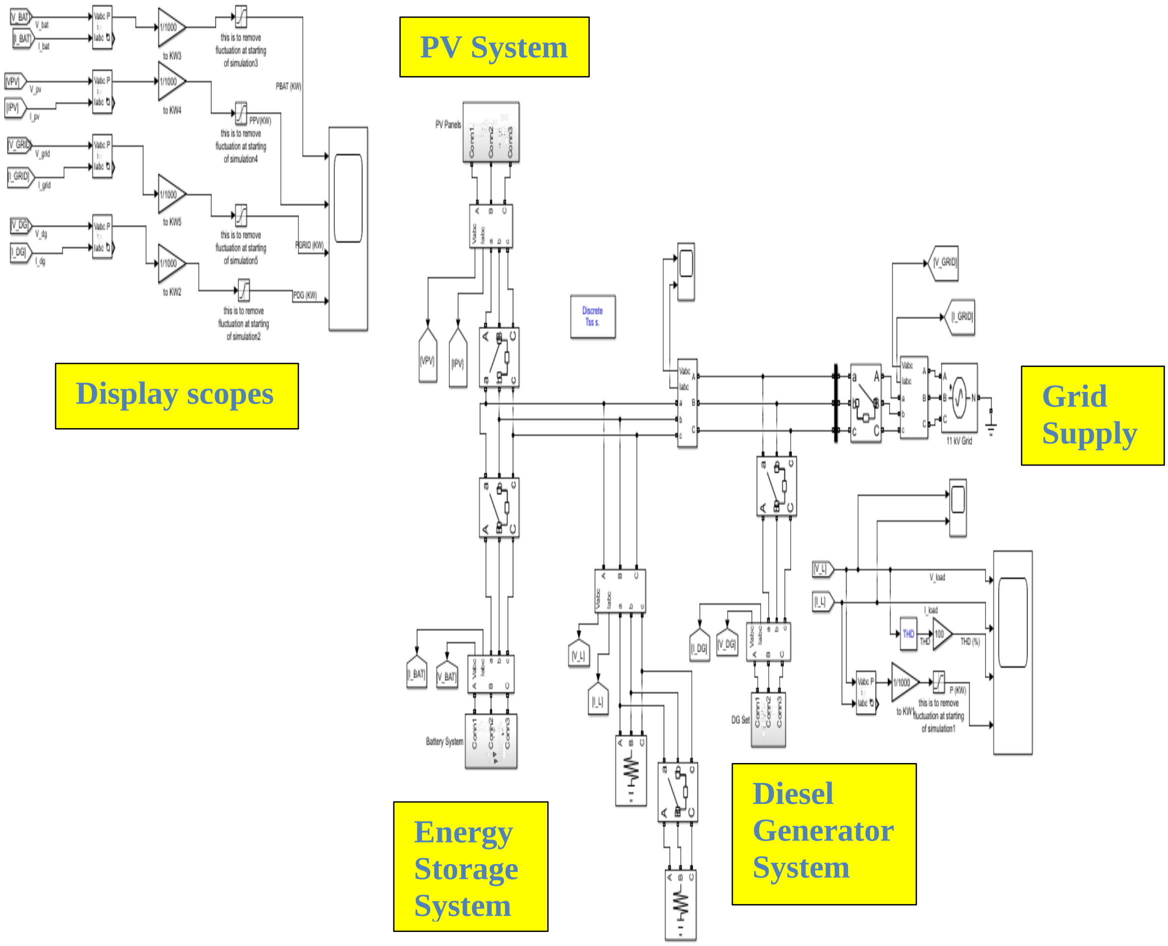
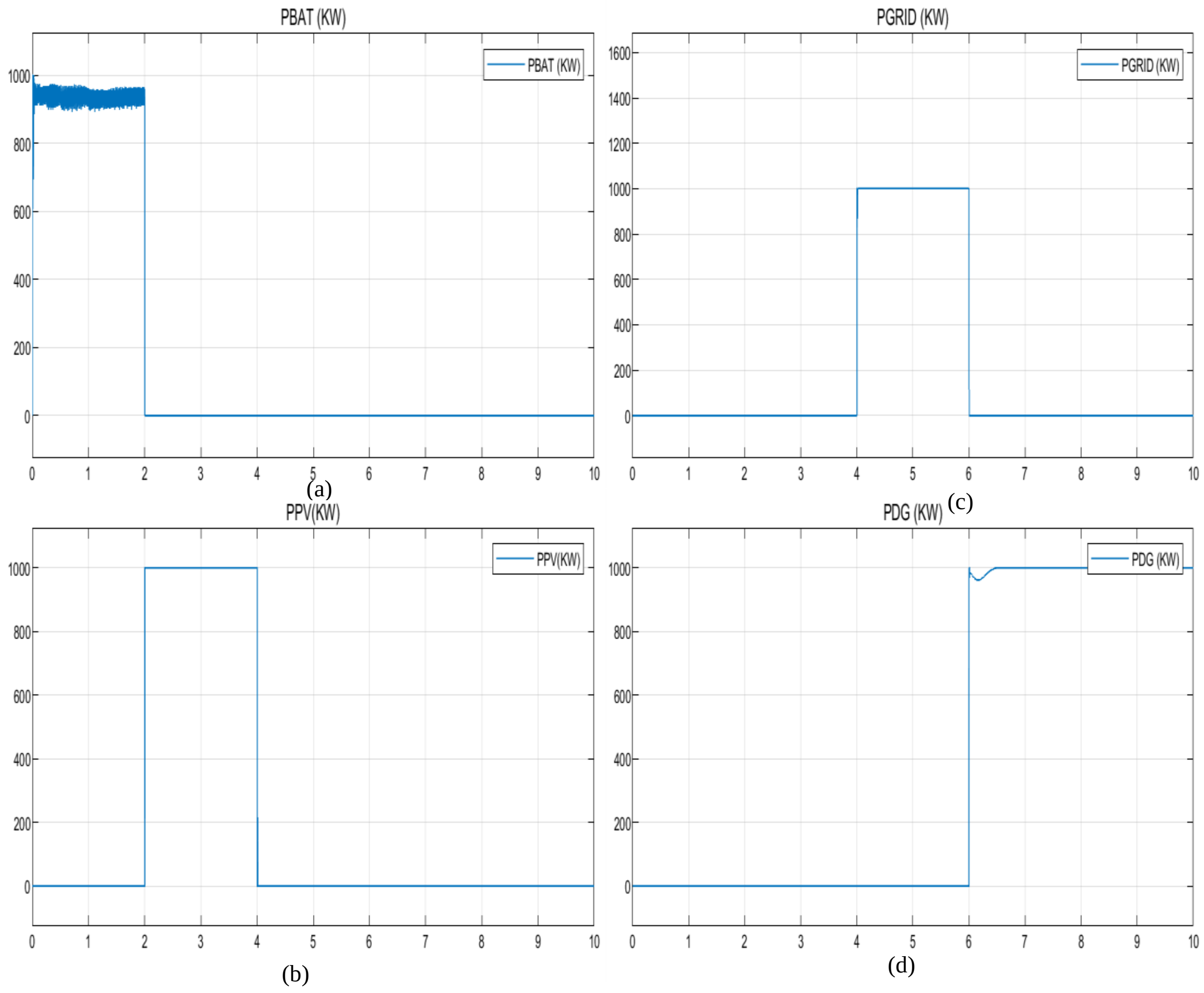


Figure 6.13:Matlab model of the microgrid system at Port Blair integrating the PV system, energy storage system, DG sets and grid supply.

6.3.14 Simulation Under Varying Operating Conditions.

Simulation has been done to validate the performance of the microgrid during various operating conditions. The load is kept constant at its maximum value of 1000 KW. The batteries are fully charged and, initially, the distribution network is connected to the batteries for 0–2 secs, and the operational condition depicted is early morning at sunrise. As the sun rises and adequate power is generated by the PV system, the controller switches the distribution network to solar power for 2-4 seconds. As the sun goes down or around sunset, the supply from the grid is switched on and energy is supplied to the distribution network through the grid every 4-6 secs. In the event of a grid failure, the generators are switched on and power is supplied to normal loads through the distribution network for 6–8 seconds. Additional critical loads are loaded into the system and simulated every 8 sec. to 10 sec. to see the response, stability, and behaviour of the microgrid. The switching is timed and is simulated as controlled by the microgrid controller. System health, voltage, and current levels/forms are observed and measured. The switching of various energy sources sequentially taking the load is seen in Fig 6.14.

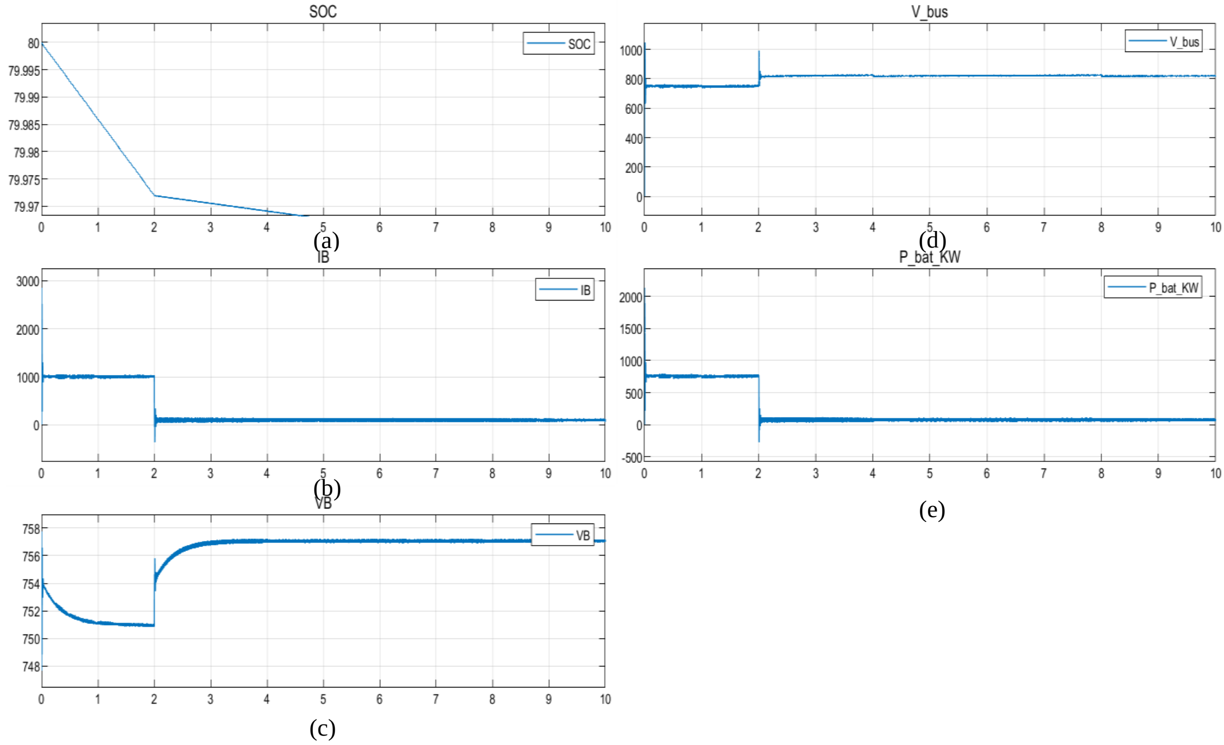


(a) (c)

(b) (d)

Figure 6.14:Shows load taken by various energy sources connected to the microgrid. (a) Li ion batteries from 0-2 secs. (b) PV system from 2 to 4 secs. (c) Grid power source from 4 to 6 secs and (d) Diesel generator set from 6 to 10 secs and the critical load connected at 8 secs with complete load taken by the Generators.

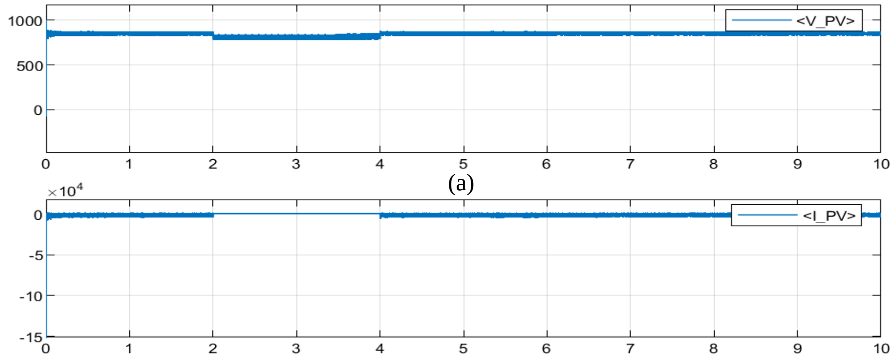
Performance of Energy Storage System. The simulation commences with the energy storage source taking the complete load of 700 KW from 0 to 2 secs. The battery parameters are checked to validate the performance characteristics. The SOC of the battery is kept at 80% and as energy is consumed at the load, the SOC curve conforms to the standard results. Fig 6.15 shows the battery current (IB) flowing in the distribution system and the voltage (VB) across its terminals. The voltage at the load (V bus) is stable, and the power supplied at the load is also stable. The plots show the effectiveness of the controllers in maintaining the power requirement at the load.



(a) (d) (b) (e) (c)

Figure 6.15:Shows the performance of the energy storage system in the microgrid. (a) SOC of the battery system. (b) Battery current IB supplied for 2 secs to the load. (c) Voltage across the battery (VB). (d) Bus voltage across the load V Bus. (e) Power supplied to the load.

Performance of PV System. The load is switched to the solar PV system for 2-4 sec. The load is kept at 700 KW and the performance of the PV system is seen. The PV system, designed with a 1000 KW capacity and a Vmpp of 736 V, is able to take the load without any imbalances in the microgrid. As seen in Fig 6.16, the PV voltage (V PV) and current (I PV) are stable.

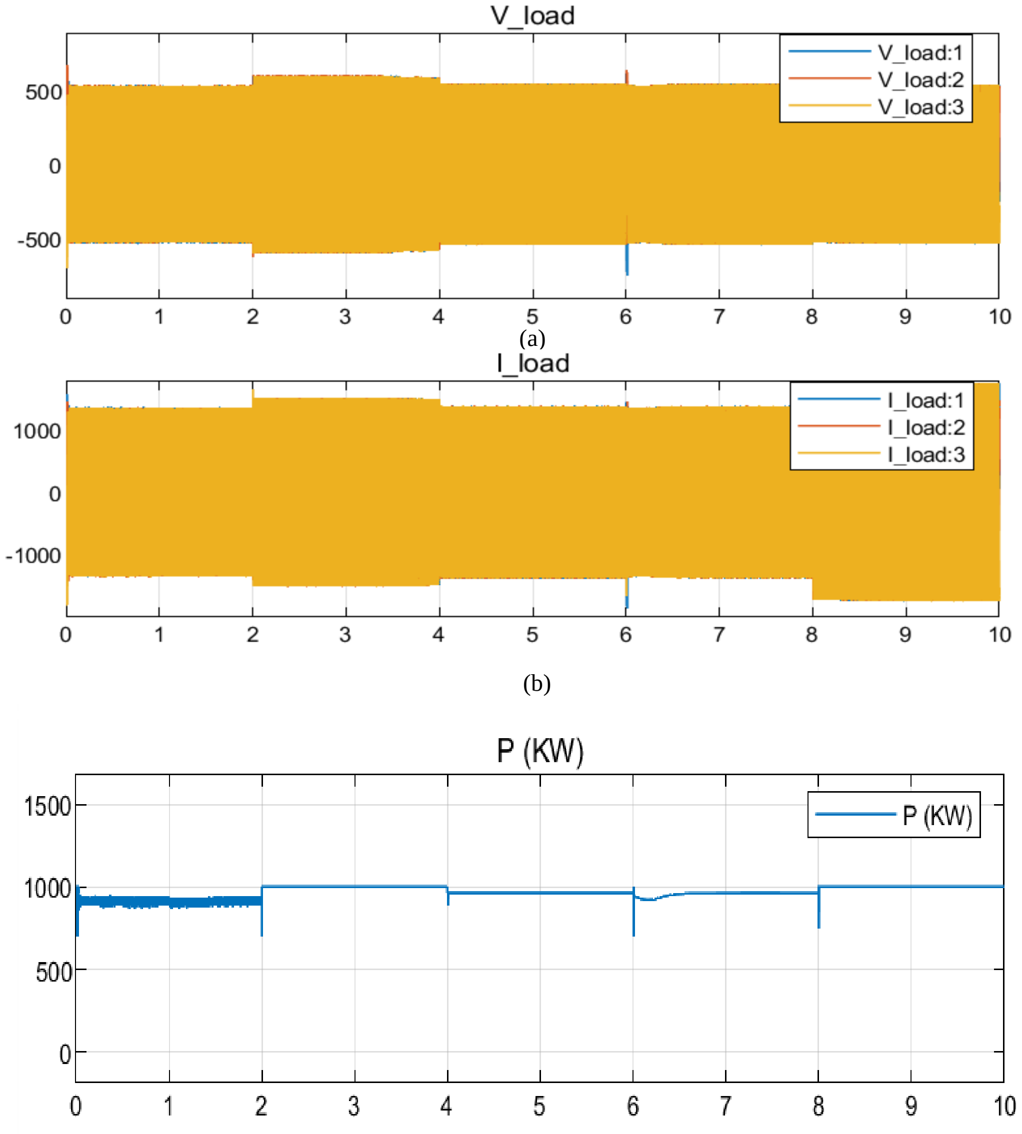


(a)

(b)

Figure 6.16 (a) and (b) Shows the performance of 1000 KW PV system connected to the microgrid. The output voltage (V PV) and current (I PV) are stable. The PV system is without any imbalances.

System performance under varying operating conditions. The microgrid is simulated with the load switched to the grid from 4 to 6 secs and thereafter to the diesel generator set from 6 to 10 secs. The load is increased from 700 KW to 900 KW to simulate critical loads connected from 8 to 10 secs. The complete simulation from 0–10 secs is validated for the stability of the microgrid and its performance. Fig 6.17 shows the performance of the microgrid. The load voltage (V load) and load current (I load) are stable and change as per the increase in demand. The power P at the load is maintained at constant levels.



(a)

(b)

(c)

Figure 6.17:Simulation of the microgrid from 0 to 10 secs with energy storage system, PV system, grid and Diesel generators supplying power (a) voltage and (b) current at the load. (c) Power across the load is maintained at constant levels.

Analysis of voltage and current wave forms at the load. The voltage and current waveforms were analysed and validated to guarantee the quality and reliability of the power delivered. The waveforms were as per the designed quality without any distortions. Fig 6.18 to Fig 6.20 show the quality of the voltage and current waveforms of all the energy sources when supplying energy to the load.

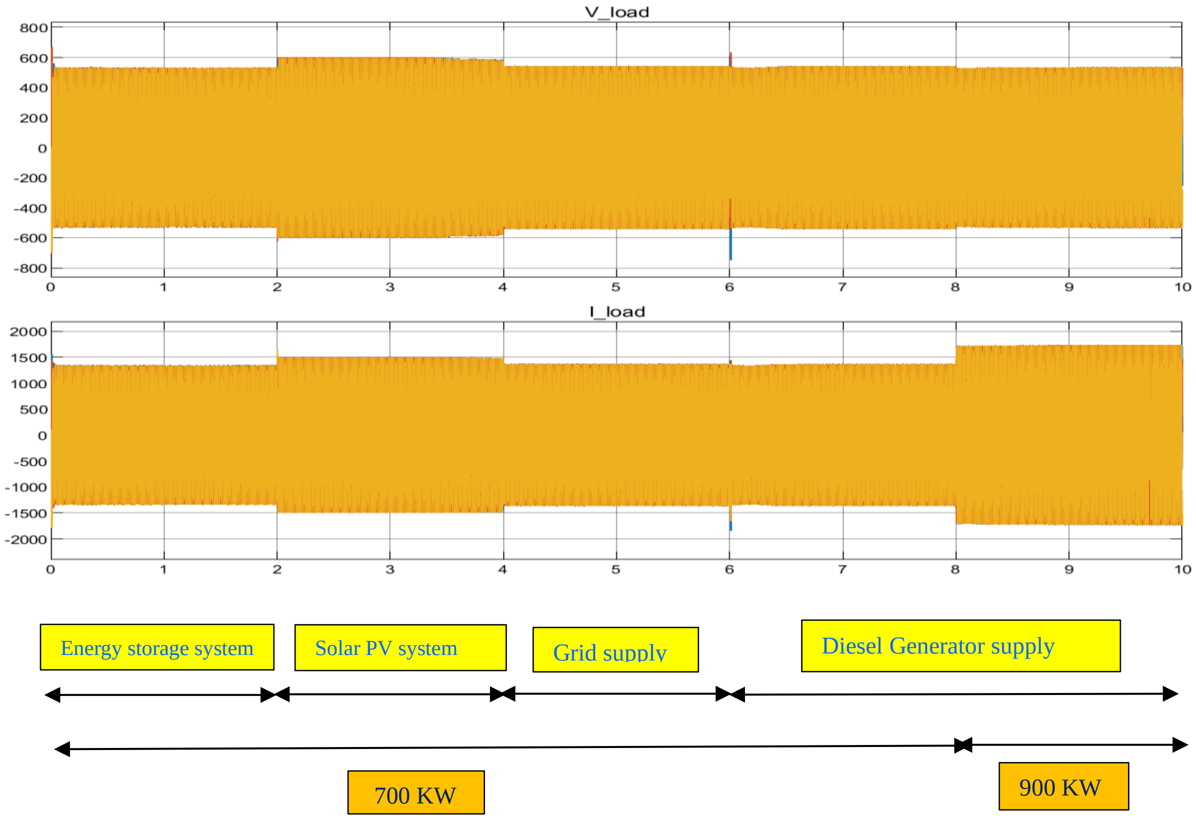
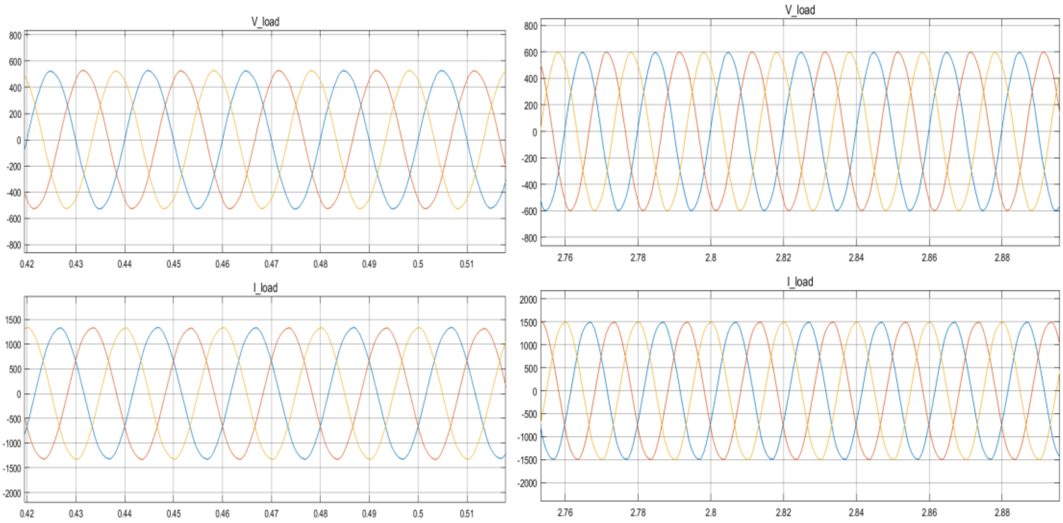
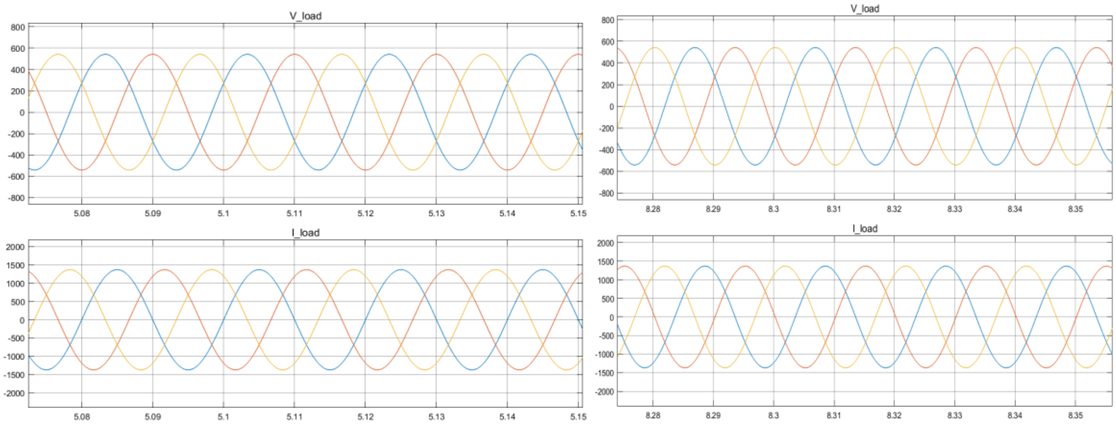


Figure 6.18:Voltage and Current waveform with different sources and different loads



(a) (b)

Figure 6.19:(a) and (c): Voltage and current waveforms (b)between 0 sec onwards when Energy storage system supplies power. (c) After 2 secs and when PV system supplies power to the microgrid



(a) (b)

Figure 6.20:(a) and (b): Voltage and current waveforms (a) 5 sec onwards when Grid supplies power. (b) After 8 secs, when generator system supplies power to the microgrid.

Results. The microgrid being installed in Port Blair is designed in MATLAB and simulated for various operating conditions. Parameters as close to the actual system are incorporated. The simulations and results validate the performance and stability of the system.

6.3.15 Microgrid: Project Introduction

The existing electrical distribution system and equipment of the four military stations were studied in detail for their specifications, ratings, and performance. Detailed research of the new commercially available microgrid equipment was done to identify the most suited and efficient systems that could be incorporated into the present electrical network. The design of the microgrid was made by incorporating the existing electrical network and the commercially available microgrid systems. The specifications of the microgrid controllers, energy storage system controllers, DG set controllers, and inverter controllers along with the connections were designed. Specifications and functions of each type of controller are described in the sections ahead. A containerized expandable lithium-ion battery energy storage system (BESS), a grid-tied ground-mounted solar photovoltaic (SPV) power plant, Energy Storage Control System (ESCS) for regulating the BESS and SPV system are all part of the Microgrid project. The microgrids are in the process of being constructed by the Military Engineering Services and have been designed by the research scholar.

Battery Energy Storage System (BESS)

BESSs can be used for capacity firming and voltage support, in addition to providing frequency regulation to aid in the integration of fluctuating renewable energy sources into the grid. Due to the intermittent nature of solar photovoltaic energy and the displacement of traditional producing units that provide ancillary services such as rapid response to power loss and system load, the rising penetration of renewable energy causes grid management difficulties.

The primary goals of implementing BESS are to:

- Assist in maintaining 50 Hz by providing a secondary source of energy for system frequency management by absorbing or discharging energy.
- During the recovery phase after a sudden loss of generating, supply electricity for 15 minutes at the point of common coupling until a quick-start producing unit can be brought online, avoiding the requirement for load shedding.
- Assist generation resources in meeting system demand fluctuations induced by renewable energy's unpredictability in terms of wind and solar availability.
- Assemble an inertial reaction.

- Give the grid operational flexibility necessary to handle scattered, intermittent generation in conjunction with the island's electrical load.

Grid tie Ground Mount Solar Photovoltaic (SPV) Power Plant

Grid-tied ground-mount solar photovoltaic (SPV) power plants are composed of an SPV array, a Power Conditioning Unit (PCU) that includes a Maximum Power Point Tracker (MPPT), the PV Module Mounting Structure, inverters, controls and protections, interconnect cables, junction boxes, distribution boxes, and switches.

Grid-connected SPV systems incorporate critical elements that enable them to supplement grid electricity during the day. Components and equipment used in solar photovoltaic (SPV) power plants, including as photovoltaic modules, cables, junction boxes, mounting frames, switches, and power conversion units (PCUs), that conform to BIS, IEC, or international standards. Solar photovoltaic systems are comprised of the following equipment and components:

- Solar photovoltaic modules are comprised of a specified number of crystalline photovoltaic cells.
- Grid-connected power conditioning unit with remote monitoring system
- Frames and structures for mounting
- junction boxes.
- protection against earthing and lightning.
- IR and UV-protected PVC cables, pipelines, and accessories

Energy Storage Control System (ESCS)

The microgrid control system is a modular and scalable design that allows renewable energy sources to be added to microgrids. This allows them to be used. Using the microgrid control system should be possible for both microgrids that are connected to the grid and microgrids that aren't. It should also be able to do the following things:

- preset modular and scalable controllers

- Employs a distributed system architecture: There will be various generation sources and loads in a microgrid setting, each with their own generating and consumption characteristics. As a result, having total access over the entire power network via decentralised controllers is critical. All system components, including solar PV, diesel generators, grid connection point, and battery/ESS system, should have their own controllers. A single controller failure should not have a catastrophic effect due to the rapid availability of replacement capacity enabled by a decentralised control system architecture. There will be no such thing as a master controller or master slave. Local to various electrical devices (generators, loads, and grids, for example), the control system will operate autonomously. The network of peers that represents the entire power system will be built by all of the nodes working together.

- maximising fuel savings by employing renewable energy sources and implementing intelligent control systems and algorithms.

- Reduce diesel generator running hours by utilising storage, loads, and the capacity of renewable energy firms to supply spinning reserves and step loads. Support is distributed I/O.

- It features an Ethernet-based communication system that enables it to be integrated into the power system's network at any moment.
- It is built on a distributed system architecture.
- Is built on a plant-independent control system platform.
- It is suitable for use in both isolated and grid-connected applications.

6.3.16 Detailed Design Specifications: Battery Energy Storage System of Li-Ion Technology of Containerized Expandable Type 1MW (AC) for an Energy Rating of 1200 KWH

The techniques and materials in the technical standard are intended to offer the very minimum criteria for commercially available equipment. Major equipment parts include a battery, a battery management system (BMS), a power conversion system (PCS), a central supervisory system control (SSC), an output/isolation transformer, and a supervisory control and data acquisition (SCADA).

The BESS must be compliant with IEEE 1547 ("*Standard for Interconnecting Distributed Resources with Electric Power Systems*"), which is an international standard. Additionally, the BESS's design should take resonance and ferro-resonance into account.

All components should be painted, coated, or otherwise protected against the Port Blair climate for a minimum of 25 years. Priority should be given to corrosion avoidance at interfaces between materials such as aluminium and steel and steel and concrete. All structures and foundations are designed to endure the harsh climate of Port Blair.

Fire Protection System

Fire protection systems should be developed according to generally accepted engineering practises. The fire prevention system and associated alarms should be designed with the knowledge that the BESS will be unattended. When building an appropriate fire prevention system, the procedure should calculate and account for the heat content of the battery cell components. Separate fire protection systems for the battery, PCS, and control spaces may be used. It is not recommended to utilise halon or other chlorofluorocarbons. The BESS should incorporate features that allow local firefighters to put out inner container fires without having to open the main container doors.

BESS: Operational Functionality

Frequency Regulation

- Absorbs and injects energy into the grid to keep frequency within permissible limits.
- Capable of both real and reactive power generation and absorption in isochronous and droop modes.
- Operate in all four quadrants, absorbing and producing reactive and active power independently of one another.
- Instantaneously (less than 20ms) provide power (MW) with a rapid disruption to assist in arresting system frequency degradation.
- Capable of providing capacity (MWh) during the recovery phase following a power loss, allowing for the ramp-up of a quickstart generator to compensate for temporary generation shortfalls.
- Assemble an inertial reaction.

Capacity Firming

- To counteract the rapid voltage and frequency variations produced by fluctuating renewable energy generation, be capable of smoothing the output and managing the ramp rate.

- Be able to operate independently in all four quadrants, absorbing and creating reactive and active power.

Voltage Support

By injecting or absorbing both actual and reactive power, the BESS should be able to support voltage at the PCC to which it is linked (VARs). During a power discharge or charge, whether active or standby, this technique should be possible. Dynamic operation (constantly altering reactive or actual power output) or static operation (constantly varying reactive or actual power output) (operation at a fixed power factor). In this case, the system's human controller should be able to specify the operation's priority and/or the desired amount of reactive power support, including distinct levels for leading and trailing VARs, as well as whether reactive power is prioritised over real power or real power is prioritised over reactive power. It should be allowed to prioritise either real or reactive power as long as the BESS's nameplate VA rating is not exceeded. The BESS in this application should be able to respond to both real-time control signals.

Automatic scheduling

To maximise its quick response time, the BESS should be capable of ramping to a pre-programmed output level by a remote signal from the user's SCADA system or by programming a ramp rate into the BESS HMI.

Selectable output level and ramp rate, as well as programmable output level, are available through a continuous real-time remote input from the SCADA system. Once activated, the BESS shall continue to function at the specified output until it is stopped by a remote signal or reaches its rated discharge limit.

Grid compliance

IEEE 1547 specifications must be met by the microgrid.

Black Start Capability

Black start capabilities must adhere to certain specifications. Without the presence of utility voltage, the PCS shall be capable of starting and working. The use of the black start capability must never result in the accidental energization of the substation busbar.

Control Systems

The control system should be capable of and developed in such a way that it can operate the BESS automatically and without human intervention in any of the functionality supplied. The control system design should incorporate monitoring, manual operation on-site, and remote operation via the users' SCADA system or a dedicated workstation. The control system shall be programmable in order to define or modify any parameters, set points, or limitations required for effective operation in any of the defined operation modes.

The control system should enable users to alter all operational, monitoring, and management settings for the BESS's numerous functionalities.

Standards Requirements

BESS and other equipment should adhere to applicable international standards.

Batteries and Secondary Cells Safety Requirements for Large-Scale Industrial Applications (IEC 61427).

IEC 62619 Safety Requirements for Large-Scale Industrial Applications (for lithium cells)

62281 IEC (for Lithium-Ion Battery)

IEC 62620 Secondary cells and batteries with alkaline or other non-acid electrolytes: transport safety

ANSI/IEC 60664-1 Coordination of insulation for equipment installed in low-voltage systems

IEC 62103 Electronic equipment for use in power transmission and distribution systems

IEC 61140 Shock protection

ISO/IEC 60364 UL 1642 - Electrical installations for buildings Lithium-ion battery safety standard

6.3.17 Detail Design Specifications: 1MW (AC / 1.1MWP (DC) Grid Tie Ground Mount Solar Photo Voltaic (SPV) Power Plant

Solar Photovoltaic Modules.

The solar photovoltaic modules that are being designed should have a cumulative capacity of 1.1 megawatts per photovoltaic module. Photovoltaic modules must conform to the most recent edition of the IEC photovoltaic module qualification test or a BIS standard that is equivalent. Modules of Crystalline Silicon Solar Cells IS14286/IEC 61215. Additionally, the modules must conform to IEC 61730 Part 1 – Construction standards and Part 2 – Testing and safety qualification criteria, or a comparable international standard.

- Throughout their lifetime, the photovoltaic modules will be exposed to a highly corrosive environment, and they must comply with IEC 61701.

- Solar photovoltaic arrays shall be built of solar crystalline modules with a minimum of 72 cells and a maximum power output of 320 Wp.

- The PV modules should have been tested and approved by one of the IEC-authorized test facilities.

- Corrosion-resistant materials, preferably anodized aluminium, should be used to construct the module frame.

- Performance: It is anticipated that electrical deterioration of generated power will be no greater than 20% of the lowest rated power over a 25-year period, and no greater than 10% after ten years of full rated beginning output.

6.3.18 Inverter and Power Conditioning Unit (PCU)

At an ambient temperature of 50 degrees Celsius, the cumulative AC output power will be 1 MW. The Power Conditioning Unit (PCU) should be set up as a string/central inverter, with an electronic inverter and components for control, protection, and data logging. Control, protection, and data logging devices, as well as hardware and software for remote monitoring, should be included with all PCUs. In Europe, the inverter's efficiency should be at least 96 percent, as determined by the IEC 61683 efficiency standard. Inverters should have a minimum protection level of IP 65 (outdoor) or IP 21 (indoor) and Protection Class II.

Negative Grounding – PID Effect. To counteract the PID Effect, the PV Modules must be negatively grounded, and this must be a built-in function of the Inverter.

6.3.19 Protection

As a result, the system should have all necessary protections, including earthing, lightning protection, and grid islanding:

Lightning Protection

SPV power plants should be equipped with lightning and overvoltage protection. The major goal of this protection should be to keep the overvoltage within a reasonable range before it damages the solar array or other subsystem components. Over voltage can be caused by lightning, atmospheric disturbances, etc. An adequate number of lightning arcs conforming to IEC 62305 should be planned and designed to protect the entire area occupied by the PV array. Metal oxide varistors (MOVs) should be utilised to protect against induced high-voltage conditions and appropriate earthing should be employed to ensure that induced transients find an alternate path to earth.

Surge Protection

Surge-arrestors of SPD type I, II, or I+II connected to earth via the +ve and –ve terminals should be used for internal surge protection (via Y arrangement).

Earthing Protection

According to IS: 3043-1987, each photovoltaic array structure shall be correctly grounded or earthed. Additionally, lighting arresters and masts should be earthed within the field of the photovoltaic array. The earth resistance should be less than 5 ohms when all earthing points are linked together and at the same potential.

Anti Islanding

It is vital that any independent power-generating inverters connected to the grid turn down immediately in the event of a grid failure. This precludes DC-to-AC inverters from supplying power to smaller grid portions, termed "islands." Charged islands present a risk to personnel who may feel they are working in an unpowered region; this can also harm grid-connected components. Solar PV systems should be protected from islanding. Apart from disconnecting from the grid as a result of islanding protection, disconnection from the grid should also be designed for under and over voltage conditions.

6.3.20 Energy Storage Control System (ESCS) for Controlling the BESS and SPV System Functions - General Function of Microgrid System Controller

- **Step Load Capacity Calculation**

A microgrid is composed of two components: those that regulate frequency and voltage and those that support frequency and voltage control. A microgrid controller, in conjunction with energy storage, acts as a frequency and voltage support component, injecting or absorbing actual and reactive power to keep the grid stable. Step-load capacity is required in isolated power systems to accommodate a sudden or immediate rise in load. This can happen because of an unexpected power plant failure, such as a generator or ESS trip, or because of a renewable feeder trip. Conventional generators, such as diesel generators and energy storage components, can often handle step loads. The microgrid control system should determine the extent to which the ESS can provide step-load support. The ability of an ESS to accommodate step loads refers to the largest instantaneous increase in power output of the ESS. The step load capability of the ESS is combined with the step load capability of the frequency control components to determine the overall system step load capacity online. This final figure should be enough to compensate for the loss of any generator (whether fossil-fueled or renewable) or storage device while maintaining an acceptable degree of power quality.

- **Spinning Reserve Capacity Calculation**

To handle incremental demand increases, isolated power systems require a spinning reserve. A spinning reserve is the additional power that a generator or ESS can provide in addition to its current output but is not required to provide immediately; it is typically equal to the rated output minus the current output.

The quantity of spinning reserve that the linked ESS is capable of delivering should be determined by the microgrid control system. The power station's overall spinning reserve is derived by aggregating the individual spinning reserves of all ESSs and generators. The total power system's spinning reserve value influences generator scheduling, resulting in the system switching to higher or lower generator configurations.

- **Battery Management**

• The SOC control limits the operation of the ESS in order to maintain defined parameters for the energy storage. This will be performed by limiting the microgrid controller's power setpoint value sent to the ESS when the SOC is approaching full or empty.

• State of Charge Calculation: The ESS will have a Battery Management System (BMS) that will calculate the ESS's state of charge (SOC).

• Automatic recharge: The ESS injects or drains energy from the network for a variety of purposes, including increased network stability, aiding overburdened generators, and according to external set directions. The ESS deviates from its predefined ideal SOC as a result of such events. The automated recharge will return the ESS to its optimal state of charge (SOC) without putting the network under undue strain.

• ESS Scheduling: Automatic selection of online generation configurations. In order to select the optimal design (from a number of configurations), characteristics such as prime power rating, generator availability, spinning reserve, and minimum run-time are taken into consideration (of individual engines and configuration).

Grid-Connected Functions

Even when linked to the grid, the ESS will support the microgrid. This assistance will take the form of permitting a variety of grid-connected voltage/reactive power modes in addition to a single frequency/real power mode. This section explores certain modes in greater detail.

Correction of the power factor

The microgrid will maintain a minimum power factor at the Network Reference Point by injecting reactive power from energy storage systems/generators (grid connection point).

The system should be sufficiently adaptable that the operator can alter the power factor limit using a graphical user interface. Grid-side controllers, load feeders, renewable energy generators, and diesel generators will all report to the microgrid the amount of active and reactive power they supply. This information is used by the microgrid control system to determine whether the reactive load on the network exceeds the reactive limits and, if so, by how much. To maintain the power factor of the network feeder above the power factor limit, reactive power is injected via ESS and diesel generators, with reactive power values shared according to the sharing processes.

Microgrid Peak Elimination

Microgrid Peak Lopping limits the network feeder's maximum active power consumption, as measured at the Network Reference Point (grid connection point). This function enables the use of a network connection that may be incapable of supplying the microgrid's whole energy consumption without requiring costly line or infrastructure improvements.

The system should be sufficiently adaptable to permit the operator to set the maximum available active power at the network feeder (grid connection point). The network's active power will be communicated through grid-side controllers, load feeders, renewable energy generators, and diesel generators. Additional power will be required if the aggregated microgrid demand exceeds the maximum power rating of the network feeder. To begin, renewable energy generators' output will be increased to the maximum extent practicable. If this is insufficient, energy storage and/or diesel generators are used to generate the required electricity.

Switching Off Anti-Islanding Protection

This function prevents the microgrid from becoming islanded and operating in island mode inadvertently. This may occur as a result of a line failure or operator switching, or as a result of the opening of an upstream macrogrid circuit breaker or fuse. To ensure that the microgrid does not operate in the absence of adequate anti-islanding protections, However, in order for the microgrid to operate in island mode when necessary (as judged by the operator), this protection must be deactivated; otherwise, erroneous anti-island tripping would occur. The microgrid control system will include a digital output that will enable the system's anti-islanding protection to be activated and deactivated.

- **Functions – Islanded**

Frequency Support

The basic function of frequency support is to keep the grid stable. Its goal is to reduce grid frequency fluctuations caused by variations in load or generation. Support for frequency will be dependent on both the actual frequency and the rate of change of the frequency (active inertia). When in Frequency Support mode, the ESS system injects real power into the grid during periods of low demand and pulls real power from it during periods of high demand. The Frequency Support technique makes reference to the frequency set-point. Around this reference frequency, a dead band is added. If the grid's real frequency is within this dead band, the ESS output is zero kW. If the output power set-point is not in the dead band, it grows linearly as frequency reduces and decreases linearly as frequency increases. To sustain the frequency shift rate, the ESS will inject power proportional to the frequency change rate of the grid, acting as inertia.

Voltage Support

The voltage support system's principal function is grid stabilisation. In voltage support mode, the microgrid control system monitors the positive sequence grid voltage and either injects reactive power or absorbs reactive power when the grid voltage is low or high. There will be a voltage setpoint as a centre voltage. A dead ring surrounds this central voltage. If the real grid voltage is inside this dead range, the ESS output is zero kVAr. If the output reactive power setpoint is not in the dead band, it grows linearly as the voltage lowers and reduces linearly as the voltage increases. The voltage deviation outside the deadband divided by the reactive power gives the operator control over the voltage support gain.

Generator Overload Support

If the load on the generators exceeds their capacity, the ESS will provide enough power to relieve the generator overload (up to the real power rating of the ESS). This allows the microgrid to continue operating without causing the generators to trip due to an abnormal load. When an overload condition is recognised, the Microgrid System will maximise the output of any renewable sources and, if necessary, start the next generator. The ESS serves as an energy supply and buffer during the transition to the next generation.

7 FUTURE WORK AND CONCLUSION

7.1 OVERVIEW AND CONCLUSION

Since the outbreak of warfare, the need for energy by combat fighters has been constantly increasing. Success on the battlefield now, more than ever, is contingent upon the rapid availability of energy. Without sufficient energy resources and manufacturing capacity, any modern war machine comes to a grinding halt. The study presented in this thesis resulted in the construction of an optimised microgrid model for scheduling power generation and distribution in the Armed Forces' remote sites. **The model and installation developed in this research work make the most efficient use of the energy sources available to a military base, including renewable energy, and they have the potential to reduce the quantum of energy required for its operation by 30–40 percent. Networking of small microgrids can be used to enhance the reliability and security of remote bases by load sharing. This installation will be the first of its kind for the Armed Forces in the country.**

Microgrids on military installations improve the military infrastructure's ability to respond to security emergencies while also increasing the nation's overall resilience through interconnection with local community load capacity. This increased resilience benefits the Armed Forces in and of itself, but also aids in deterring attacks. In the near future, the country's extraordinarily resilient power systems will be comprised of a combination of large-scale generation, distributed generation, storage, and interconnected microgrids, all of which will be supported by a regional transmission grid.

Microgrid capability development on military installations does not require a substantial investment; rather, it comprises improving the installation's existing energy infrastructure and controllers to enable the system to operate as a microgrid. For instance, by modifying the base power distribution system to incorporate a renewable generation capability (a solar array, a combined heat and power system, or a wind turbine coupled to a computer server), the interfaces required to establish a microgrid could be added at little additional cost. These would include connections that would facilitate future interconnection when the base renovates its own distribution infrastructure.

The majority of military stations, including some remote bases, remain connected to the national grid, posing a serious threat to national security due to the vulnerability of personnel, weapons, sensors, daily operations, and critical equipment during a power outage. The Armed Forces incur large annual energy expenses under the existing electrical system paradigm. The Armed Forces can transition to a more robust system by investing in one-time, up-front charges for decentralised automated microgrids powered mostly by solar photovoltaic (PV) energy. This cost can be amortised over the course of a deployment's many years. If this is accomplished, the cost of solar photovoltaic (PV) system adoption will be reduced due to the aggressive and protracted nature of the PV learning curve. Renewable energy integration into the electric power grid is currently limited to parallel operation, leaving critical mission facilities without power during a commercial power outage. This problem can be solved using the research and design outlined here. By connecting various energy systems, a scalable intelligent power grid, or microgrid, can be created. Improvements in energy storage technologies have resulted in the development of unique microgrid designs and economic models. Microgrids have developed as a potential new approach for integrating various distributed energy resources (DERs) with intelligent load control strategies in order to increase the resiliency, security, flexibility, and efficiency of military stations and remote military bases' mission-important sectors. The capability of the Indian Armed Forces to generate and integrate energy resources into a microgrid must be strengthened.

7.2 PAY OFFS

The installed microgrid in the remote island bases will result in a significant reduction in the cost of generation from diesel generator sets running 24 hours (from Rs 27.45/KWh to Rs 8/KWh) by using solar power and energy storage with an intelligent controller. The designed system will result in:

- It facilitates the integration of renewable energy resources with traditional fossil-fueled generators.
- optimises the usage of distributed energy resources (DERs) to minimise total energy and microgrid operation costs.
- ensures a secure and dependable power supply for mission-critical loads running in "islanded" mode.
- It increases the usage of renewable assets to reduce GHG emissions and environmental effects.

Against this background, **this research has achieved its main objective of developing and installing sustainable microgrids for remote location of the Armed**

Forces that is specifically based on solar PV technology and energy storage and to address the energy security concerns in the proposed microgrid model.

7.3 FUTURE WORK – WAY AHEAD

Renewable energy resource deployment has accelerated globally over the previous decade, owing to the technology's environmental benefits and recent cost reductions in development and deployment. Renewable production, on the other hand, has created new issues for supply-load balancing, owing to its intermittent, unpredictable, and volatile generation characteristics. The dissertation proposes and investigates the use of microgrids to capture the variability of distributed renewable generation in distribution networks for the Armed Forces as a novel method for mitigating the negative impacts of renewable generation deployment. Utilizing the available flexibility of microgrids is a potential local solution that results in lower investment costs for electric utilities to increase their flexibility and provide more reserved power. Further advancement, including research and development on microgrids for the Armed Forces in remote areas, could include the following aspects as explained.

7.3.1 Expand solar installations to microgrids.

The present research work is the first design and implementation of a microgrid for the Indian Armed Forces. Detail work is required at each location to establish the best option for each military station, particularly those located in distant places. This approach must include available solar gathering areas, present and future demand profiles in tiny time increments, and the possibility for load reduction through energy efficiency retrofits. On a wider scale, more exact and reliable cost estimates for solar-powered microgrid systems are required. Careful scaling up could result in templated designs that could be repeated at a fraction of the cost of the initial installation. Additionally, because this analysis focuses exclusively on a remote military base, it should be expanded to include larger military bases. Future research must look at the feasibility of shifting energy generation to a renewable solar source to meet the needs of vital infrastructures other than military bases.

7.3.2 Design.

In this investigation, the models examined only the active power. The investigation of reactive power and the provision of reactive power control to the utility grid via microgrids could also be the next stage in this effort, which could also provide voltage control to utility grids as another ancillary service. Additionally, cost-benefit analysis is critical for microgrid owners as a deciding element in their participation in grid support. This problem was briefly discussed in this paper but requires additional research to develop an accurate and comprehensive cost-benefit analysis model.

7.3.3 Policy formulation and implementation.

The Armed Forces' renewable energy initiative is still in its infancy. An Armed Forces Operational Energy Policy must be designed with the goal of guiding the Armed Forces in making the best use of energy resources to meet their energy needs and the national energy security goals. At the Department of Defence, an Energy Task Force must be established to act as a focal point and advisory body for the implementation of cost-effective, large-scale renewable energy projects. The task force may include projects in collaboration with the Ministry of Natural Resources and the private sector, particularly in new military installations and stations, to develop renewable energy technology in order to reduce costs, increase energy security and reliability, and ensure compliance with national mandates.

7.3.4 New Technologies.

The future of the Armed Forces is one of a more efficient and effective military that is also more environmentally friendly. The Armed Forces have begun considerable expenditures on component technologies that enable energy saving and efficiency. New technologies and systems in power electronics, intelligent controls, and energy storage like hydrogen fuel cells and aluminium-air batteries must be absorbed and incorporated into the present power networks, making them more efficient and reliable. Mobile tactical microgrids are another area where mobile small-scale microgrids can be developed, which could be based on containers, trailers, or towed.

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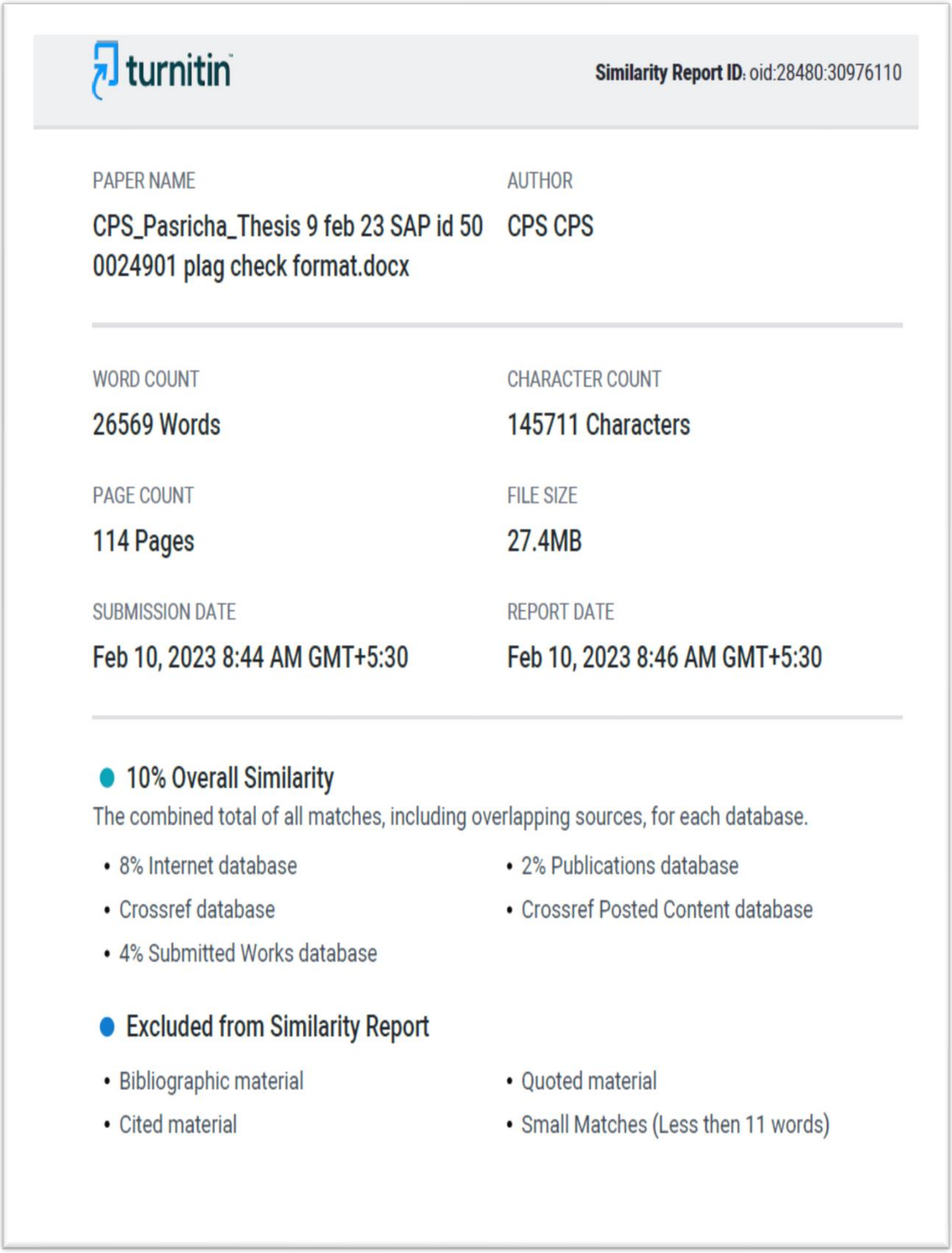

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