Machine Learning Based Optimal Energy Distribution of Smart Grid

1 | Introduction

In the early days of electricity, the energy source was alternating current. Because of modernity, the number of consumer products is increasing, as is the demand for electricity. People are turning to alternative energy sources as demand for fossil resources rises. Recent improvements in semiconductor technology have allowed the use of wind and solar power for power possible. Because most electronic loads require a DC source, the ac energy can be converted to DC within the unit immediately. Prior to charging, the solar panel's DC voltage is converted to ac power but instead back to DC. PV is a system that generates DC power. A significant quantity of power is lost as a result of the additional converters lowering the device's performance. There is an easier way to get power directly from the source. After that, a DC micro grid is used. Using this strategy, more performance and dependability can be achieved.

When solar or wind power is insufficient, the power supply can tap into the batteries for backup. Microgrid controls can provide the area and the grid with power, frequency, and energy efficiency. It is critical to always operate in MPPT mode in order to effectively use available renewable energy sources. Different power flow management algorithms for grid-connected systems have been stated. In standalone systems, maintaining the voltage profile is so crucial that the MPPT mode is compromised. The DC link power is controlled in this project by the battery charge/discharge device circuit, and the greatest renewable energy are used. The created Power Flow Management algorithms may determine the mode of operation based on whether solar or wind electricity is available, as well as battery voltage and demand, to ensure that power to the load is reliable and uninterrupted. Solar PV arrays, wind energy conversion systems, battery banks, and power converters for interacting with the DC bus are all part of the proposed DC Microgrid.

1.1 | Motivation

With the massive increase in power usage and the advent of electric vehicles, power supply has received significantly more attention, and its disruption will bring people's lives to a standstill. Microgrids are really the only way to avoid power outages, and the constant rise in demand for dc loads has prompted academics to work on a dc distribution system. Working on a dc microgrid for improved efficiency and lower losses was our motivation.

Microgrids are utilised to achieve a number of objectives in such situations, Protection against supply disruptions (such as those caused by natural catastrophes), reduction of essential load outage time, reduction of CO2 emissions, improved grid stability, and seamlessly integrated of renewable with the system Each of those goals may be tied back to financial incentive in a variety of ways: increased value, lower losses, and higher returns on renewable energies, to name a few.

1.2 | What is a DC Microgrid

A Microgrid is a specialized power system that generates and uses its own DC electricity to operate independently of the main power grid. Solar panels, fuel cells, or wind turbines are the most typical means to generate power for DC microgrids, with any excess energy being stored in batteries. All of these components of a DC microgrid conveniently store or create DC power, making it instantly usable by computers, phones, LEDs, or most other end devices.

DC microgrids have a lower environmental impact than AC power systems. The autonomous of the power system is one component of a DC microgrid that provides for improved sustainability. Property owners can pursue your environmental targets with more freedom if they can control the production, distribution, including the use of power.

Building owners who have control over energy production can choose to use solar cells or wind turbines to generate clean, renewable Power supply rather than relying on power generation located km from that are really likely burning fossil fuels.

Power generation is localised via a DC microgrid, which reduces overall emissions by roughly 6% by minimising energy losses from transmission lines. Furthermore, since these resources are primarily DC producing and endpoint devices are often DC responsive, the Microgrid can avoid some AC/DC or DC/AC conversions, each of which results in a 10% efficiency loss.

1.2.1 | Reliability

A Microgrid is an important layer for making sure that facilities and buildings have reliable power. One distinguishing feature of the DC microgrid is its ability to island, this means it may separate from of the power grid or run local demands independently. This feature is frequently employed in emergencies when the main power grid is knocked down by disasters or bad weather. Take, for example, Tohoku Fukushi University. Because the institution's DC microgrid is able to endure during in the 2011 earth quake, which knocked down the city's energy grid for months, the university was able to stay powered.

DC microgrids are more resilient than present AC infrastructure, in addition to their capacity to island. There are thousands of kilometres of present AC infrastructure that are not appropriately weatherized. One of the main causes of the expensive power grid breakdown and disaster through Texas history was this. A DC micro grid, on the other hand, because it is a smaller construction, can be adequately weatherized to be more resistant to harsh weather or calamities.

1.2.2 | Integration

A DC microgrid is ideal for powering a smart building. Smart buildings are becoming the emerging solution as firms increasingly focus on creating work spaces that promote employee productivity, health, and wellness. Many sensors, light, screens, and perhaps other IoT enabled smart work to improve the workspace in these smart buildings. A PoE infrastructure can be set up to transport power and data and connect these devices. Because of PoE's low voltage DC nature, a DC microgrid is the ideal solution to generate power because it is a purely DC operation that avoids costly AC/DC conversions within such a building.
A DC microgrid's ability becoming a smart building component is another integration. Facilities management is able to effectively transmit the power to devices by connecting power sources to a smart infrastructure platform, resulting in lower energy use. A facility manager also will be responsible to monitor the DC microgrid's power generation, enabling for more informed energy decisions in line with the building's and company's energy goals.

1.3 | Advantages of DC Microgrids

1.3.1 | Efficient utilization and Clean energy

DC microgrids generate electricity using renewable energy sources, making them environmentally friendly. These numerous renewable energy sources from various locations are merged to build DC microgrids, which assure efficient energy consumption. If one site's power production yield is poor, it can borrow energy from some other station that is producing more.

1.3.2 | Low losses

Most of the modern world runs on AC systems due to the revolutionary device known as Transformer. The transformers alone can tip the balance of the DC vs. AC debate. With minimum circuitry and no movable components, transformers scale up and down voltage with a 100 percent efficiency. The extensive use of air conditioning systems is due to this. However, thanks to recent advancements, DC microgrids can now receive effective boost or buck converters to step up and down voltages, respectively. The main advantage of DC microgrids is that they have low losses due to the presence of loads close generation and storage unit, avoiding transmission losses. Low losses are due to the close proximity of DC microgrids. When the distance between the load and the microgrid is increased, however, the losses in a DC system are substantially higher than in an AC system.

1.3.3 | No reactive power in DC system

There is really no reactive component in DC microgrids because they are simply DC microgrids. Because it has a reactance, the AC system appears to have power. Due to capacitance and inductance effects, the reactive component reduces the power output. The DC system, on the other hand, has no reactive component, hence the perceived power is directly proportional to the system's true power.

1.3.4 | Other Advantages:

- Due of their higher conversion efficiency, they are an excellent choice for powering high-performance electrical machines.
- Low-cost converter systems that provide extra cost savings in addition to the cost savings from renewable energy.
- As there is no reactive current, the transmission efficiency is higher.
- Even in remote regions, the power supply is more reliable.
- Due to the high voltages at low ampere rages, the cabling is relatively less.
- Effortless controllability system that avoids complexity like synchronizing, harmonic, reactive power compensation, and frequency controls.

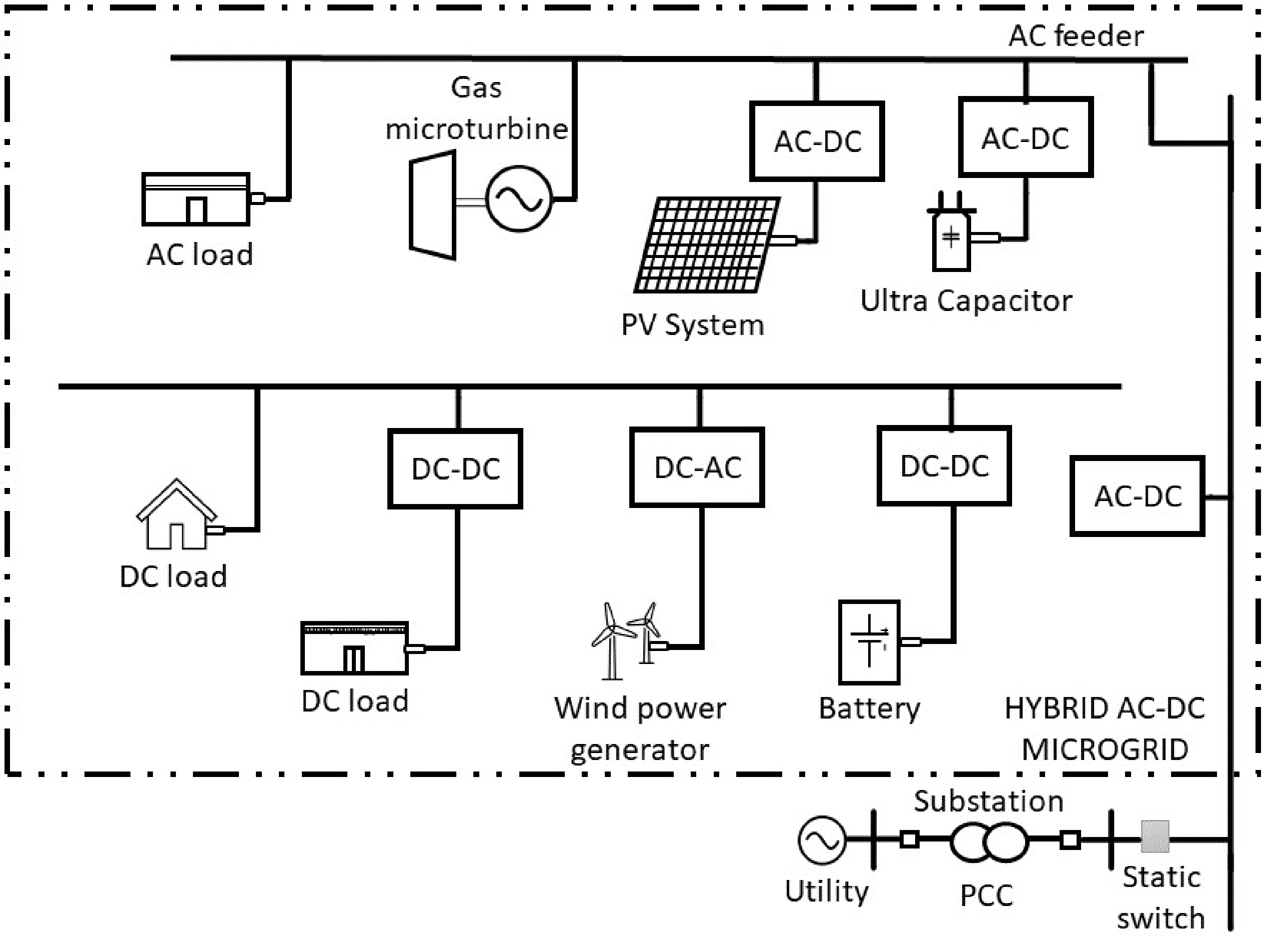

Figure 1.1: Microgrid realization

1.4 | Applications of DC Microgrid

We talked about the history of electricity, primarily alternating current (AC) and current source (DC), and how we got to the current norm of AC distribution. DC electricity was initially designed by 1800, but the introduction of the transformer in the 1880s ushered in the move to AC. Because distribution decisions were established over a century ago, it may be necessary to reconsider power distribution standards.

- When combined with distributed generation, DC microgrids are much more energy efficient than typical AC distribution. When power is transmitted by DC, microgrids, include on generation from solar panels, windmills, energy storage, or microturbines, is much more efficient. By leveraging DC architecture and removing inefficient conversions, DC generation, when combined with the expanding DC load profile, boosts energy savings. Lower grid strain and more efficient utility grid utilisation would result in energy savings. Due to short transmission lengths, excellent service dependability when combined with on-site generation, or effective storage, DC distribution provides a more reliable supply of electricity.

- Occupant safety is seen as an issue with Micro grid due to a lack of understanding and experience with these systems. Building occupants, on the other hand, never come into contact with voltage greater then 24VDC, which is substantially safer than the current 240VAC in India.
- DC Microgrids have a number of drawbacks, including a higher initial cost due to the system's unfamiliarity, as well as a general lack of code identification and efficiency metric recognition, making certification and code compliance difficult.
- Several case examples are mentioned that show energy reduction possibilities due to the absence of modelling ability in current electricity analysis systems, with energy savings of around 20%.
- It was concluded that the push to improve energy economy will drive further improvement in code development. In the next ten years, this pressure, together with the standardisation of the a 240v plug and sockets, will result in significant increase in DC microgrid usage.

1.5 | Components of a DC microgrid

1.5.1 | Generators

A DC microgrid's generation unit generates electricity using renewable energy sources such as solar panels and wind turbines. These sources were chosen since they can be put in remote places and do not require on-grid solutions in particular. Although wind turbines require a certain amount of space, they may be put anywhere there is enough wind. Other renewable sources necessitate specific site conditions, but these two can be deployed anywhere that has promise.

1.5.2 | Energy Storage System

Extra energy generated by our generation system is stored in the battery bank. This can store power from the grid to give electricity to the loads when renewable energy resources are scarce.

1.5.3 | DC and AC Loads

The DC microgrids can be used to supply energy to the loads. No need for Micro grids because there are no loads. Laptop, fans, motors, air conditioners, and other DC and AC loads.

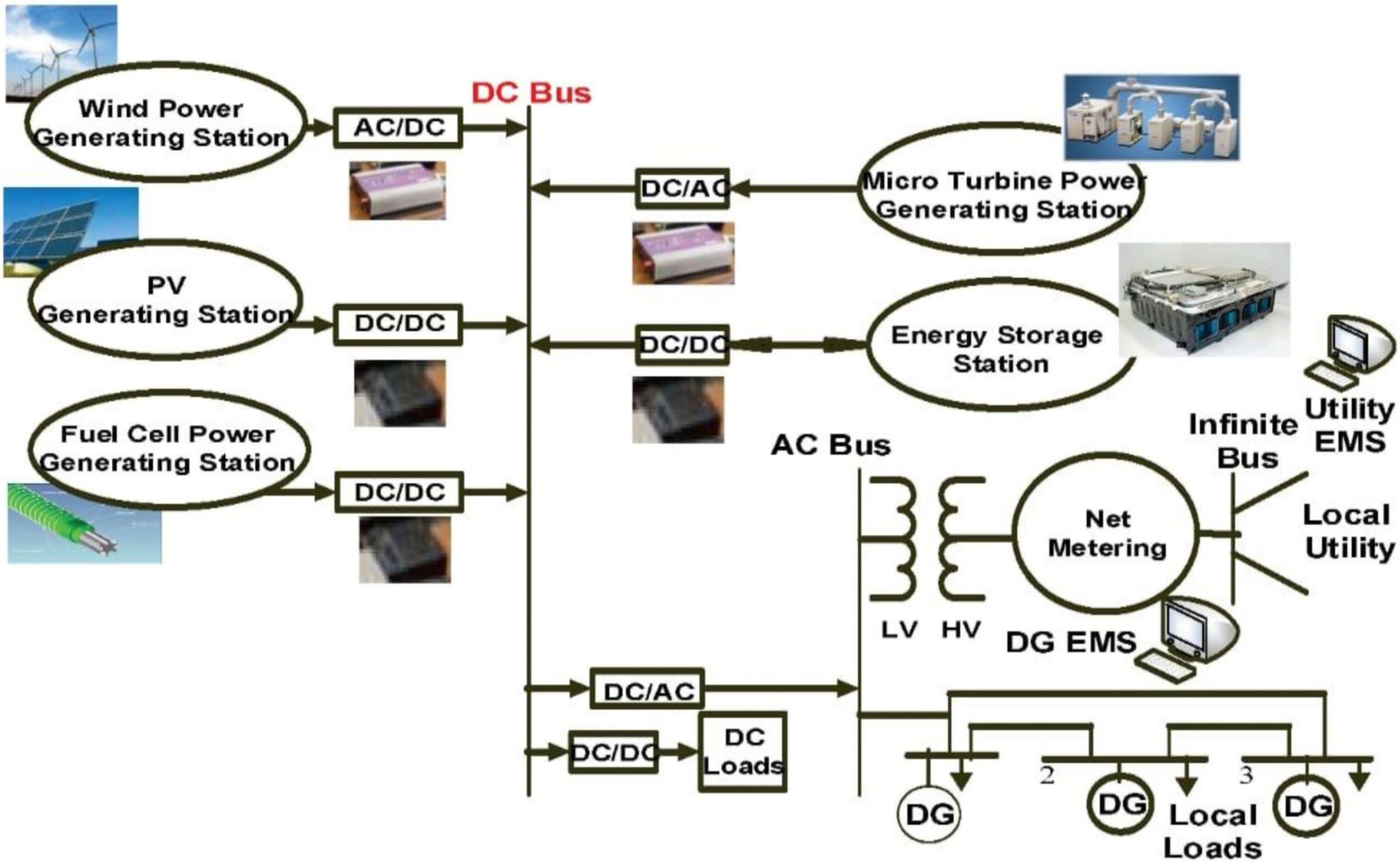

Figure 1.2: DC micro-grid typical Components diagram

1.5.4 | Grid voltage converter

The bi-directional grid current converters (GVC), which sends additional energy from the Power bus to the AC grid and also from the Ac system to the Dc supply, is also a key component of DC microgrids. This GVC is primarily in charge of maintaining the DC bus voltage.

1.6 | Architectures Of Microgrid

Introduction Microgrids (MGs) are single electrical power subsystems that are linked to a limited number of distributed generation (DERs), both renewable and conventional, such as photovoltaic, wind power, renewables, internal combustion engines, gas turbines, and microturbines, as well as a cluster of loads. Individual distributed energy resources used as micro-generation might result in issues such as local voltage rise, the ability to surpass the thermal limits of particular lines and transformers, as well as high construction costs. Microgrid can be a better solution for these problems. In a MG system, the DERs must be equipped with proper power electronic interfaces (PEIs) and control to ensure the flexibility to operate as a single aggregated system maintaining the power quality and energy output. From the grid point of view, For these issues, a microgrid may be a preferable option. The DERs in an MG system must have suitable power electronic interface (PEIs) and responsibilities to ensure that they can operate as a single aggregate system while maintaining power quality and energy production. The key advantage of an MG from the grid's perspective is that it's viewed as a regulated unit within in the power source that can operate as more than just a single load.

MGs benefit consumers because they can meet their electrical as well as heating needs locally, provide uninterruptible power, increase power quality (PQ), decrease feeding loss, and to provide voltage support. Furthermore, by adopting low-carbon technology, MGs help reduce pollution and global warming. One of MG's primary goals is to combine the advantages of nonconventional/renewable low- carbon generation technologies with high-efficiency combined heat and power (CHP) systems. The weather and topology of the area play a big role in deciding which distributed generator to use. The long-term viability of an MG system is determined by the country's energy situation, strategy, and policy, which differs by region. The purpose of this report does not include these issues. The architecture of existing or simulated MG systems presented in European locations is classified in this article based on grid integration, distribution, communication system, promotion of renewable, and storage.

The benefits and drawbacks of widely available and viable distributed generators (DGs) are briefly described. The advantages of storage as well as the currently available storage systems have been identified. The benefits and drawbacks of various distribution networks are also discussed.

1.7 | Basic MG Architecture

Figure 2 depicts the fundamental architecture of an MG system, which demonstrates that an MG system is made up of distributed generating (DG) resources, storage devices, distribution systems, and processing and communication systems.

1.7.1 | Distributed Generation (DG) Sources

Technological innovations such as wind turbines, solar PV, micro hydropower, and diesel, as well as well-established technologies such as single-phase or three-phase induction generators, and generator driven by Internal combustion engines, may be suitable for MG. When heating and electricity are used together, combined heat and power (CHP) operates as a whole system. Microturbines (usually powered by energy resources, hydrogen, including biofuels), Stirling engines and IC engines are among the sources used in CHP systems. CHP systems provide for the most efficient use of energy by absorbing extra heat, resulting in efficiency levels of further than 80

1.7.1.1 | Photovoltaic (PV) System

Solar PV generating is the process of producing electricity using solar energy. PV generation is currently preferred globally as Distributed Generation Units due to significant advancements in inverter technologies (DERs).

- Solar energy being the biggest sustainable source of energy,
- beneficial environmental impact,
- extended life time, and silent operation are all important benefits of a PV system.

Despite the fact that photoelectric (PV) cell can be employed as DERs in Milligrams networks, they have several drawbacks.

- High installation costs,
- low energy efficiency,
- geographical restrictions, and weather sensitivity

As the nature of PV generation is DC power, a suitable type of power converter must be employed to convert the DC voltage to AC voltage. Some applications of PV system are

- space programs,
- isolated regions where power grid is difficult to come by,
- illuminating road signs or road lights,
- roof projects for residential lighting and warmth are all examples of PV system applications.

1.7.1.2 | Wind Turbines (WT)

Wind turbines use wind energy conversion systems to transform power into electricity (WECSs). For decades, renewables has been popular.

Induction generators are commonly employed in WECSs. The tower, rotor, and nacelle are the three primary components of a wind turbine. The mechanical transmissions and generator are housed in the nacelle. Through rotor blades, a wind turbine collects the kinetic energy of airflow and transfers it to an induction generator via a gearbox. To generate electricity, the wind turbine drives the generator shaft. Wind turbines can have either a horizontal or vertical axis. Until the mid-1990s, the average commercial turbines size was 300 kW, but larger machines with capacities of up to 5 MW and more have lately been designed and deployed. Wind turbine captures the kinetic energy of wind flow through rotor blades and transfers the energy to the induction generator through the gearbox. The generator shaft is driven by the wind turbine to generate electric power. Wind turbines may have horizontal axis or vertical axis configuration. The average commercial turbine size was 300 kW until the mid 1990s, but recently machines of larger capacity, up to 5 MW and more, have been developed and installed[12].

1.7.2 | Energy Storage Systems

The incorporation of energy storage technologies, which balances short-term power requirements with generation, is one of the essential conditions for MG's successful operation. In most MG power systems, storage is provided by the generator inertia.

Depending on the extent of the new load, there may be a modest variation in system frequency when it comes online. To maintain energy balance, a system with numerous micro sources designed to run in an islanding mode must have some form of storage. With substantial time constants inside the ranges of 10 to 200s for various micro source materials (like as fuel cells or turbines), storage devices are critical to balancing the power following grid disturbances and/or major load shifts.

In the case of sudden system changes, these devices can act as an AC voltage source. Because of their physical limitations, they have limited energy storage capacity. The backup energy storage devices should be included in MG systems to ensure uninterrupted power supply. Suitable storage devices for MG system include batteries, flywheels and supercapacitors. Battery-energy storage technology will be in highest demand over the next 5 years. The three storage devices show the same efficiency around 90 to 95%. Whereas in terms of current price, battery is less expensive than the other two.

These devices can be used as an AC voltage source in the event of a rapid system change. They contain limited energy storage capability due to their physical restrictions. To maintain an uninterrupted power supply, MG systems should integrate backup energy storage devices. Batteries, flywheels, and supercapacitors are all good storage options for the MG system. Over the next five years, battery-energy storage technologies will be in significant demand. The effectiveness of the three storage devices is similar, ranging from 90 to 95 percent. Battery, on the other hand, becomes less costly than other two in terms of current price.

Aside from that, the battery has a large negative environmental impact, whilst the other two have a lower environmental impact. The flywheel and supercapacitor have a lifespan of more than ten years, however the battery has a maximum lifespan of five years and requires annual maintenance. Another storage option is a fuel cell, which turns a fuel's chemical energy into electrical energy immediately. As longer as hydrogen are continuously supplied, it can be described as batteries that never discharge. The generator's output ranges from 1 kW to 10 MW.

Electrical efficiency ranges from 30 to 60%, with overall efficiency ranging from 80 to 85%. Furthermore, they can run on energy resources, gasoline, landfills, gas separation fuel, petroleum, naphtha, methanol, and other fuels. There are two MG configurations available: one with and one without a storage system[6].

1.7.3 | Distribution Systems

The distribution network can be classified as three types:

- DC line
- 60/50 Hz AC line (line frequency)
- high-frequency AC (HFAC).

1.7.3.1 | DC Line

As most of the DERs generate DC power and the DC distribution system has no power quality problems, research on DC MG system is getting importance. But most of the loads are operated in AC system; hence, DC distribution system may not be popular yet.

1.7.3.2 | AC Line (Line Frequency)

Line frequency MGs are the most common type of MG. In the MG, the DERs is connected by a shared bus. A appropriate inverter converts the DC power from DERs to 50 Hz AC, which is subsequently sent to the load bus.

1.7.4 | Communication Systems

Communication networks are critical for energy control and protection. Power-line carriers, broadband over power cable, lease telephone line, global system for cellular (GSM) communication, Local area networks (TCP/IP), and wireless radio communication are the major communication techniques in use in the existing MG testbeds.

1.8 | Modes Of Operation

The DCMG is connected to a bidirectional converter, which balances both the grid and load sides of the power flow. In the event of a failure, the converter should be able to detach from the supply. At such point, the battery management system will assist in maintaining power to the load. Offgrid mode is the term for this. The converters switching should just be proper and smooth in order to maintain voltage levels as well as smooth power transfers. When the supply problem is resolved, the load should be reconnected to the main supply, and the battery should be charged for the next discharge period. In conclusion, all microgrids have essentially two modes of functioning. That is, there are two modes: grid connected and isolated. Grid connected mode is split into two categories: grid controlled and grid uncontrolled. This is largely determined by voltage regulation and power management.

1.8.1 | Grid connected mode

A power system is accountable for maintaining control between the load and the dc source bus voltage level in DCMG mode. If the entire amount of energy stored in the storage device is in excess, the surplus charge will be sent to the power grid. In this mode, power management will circulate the balances between the storage devices. As a result, DCMG can run smoothly and efficiently with minimal loss.

1.8.2 | Islanded mode

DCMG is not connected to the power grid and can function independently. These converter will be connected to the DC bus in parallel during islanding mode. During this procedure, the grid-connected converter will not run, while the microgrid converters will operate and maintain grid control. Only the Dc side voltage is controlled by the converter's storage elements because the converter are not coupled to give control on the DC bus. As a result, the battery will serve as the primary source of DC voltage, while the supercapacitor, and is one of the devices, will serve as a power source under transient situations.

1.9 | Operational Structure Of DCMG

1.9.1 | Single Bus DCMG Structure

This is the most straightforward way to set up a DC microgrid. In this topology, there is essentially one primary bus to which all other devices, like as a wind turbine, PV array, and battery bank, are linked as sources. Bidirectional power transmission is possible thanks to a stack of batteries connected to the main bus. As a result, the system's stability will improve. The utility grid and DC loads are coupled as a load. A radial arrangement is another name for this type of design. Power electronics converters and other connecting devices must be properly located to provide system stability and robustness. If the status of charge conditions of the battery is not properly attained, the single object failure problem can occur. The voltage regulation will improve as the number of batteries increases. This structure is better suited to low-voltage applications. For improved stability, two distinct DC/AC conversion approaches might be used.

1.9.2 | Multi bus DCMG Structure

This type of topology is made up of a number of single-bus systems. The present structure works as a more resilient and trustworthy structure due to the repeating of the same strategy. This design can be employed in naval ships because of its redundancy. The voltage range can be varied up to three levels due to the flexible nature of the device, allowing data to be transmitted to a neighbouring bus with less change of repetition. Although it has significant drawbacks, it is an excellent choice for secure communication. Because there are numerous voltage sources, choosing the right range of voltage will improve the system's efficiency, quality, and viability. Low and medium voltage systems can be used with these types of systems.

1.10 | Power Transmission

DC power is carried through conductors, insulators, and support structures in underground cables and overhead lines. Because of its resistance, low cost, good weight-to-strength ratio, and widespread availability, aluminium is extensively employed as a conductor. Equation can be used to calculate the results of a DC cable. To make aluminium stronger, it is usually reinforced with steel. To make material easier to manufacture, aluminium conductor, iron reinforced (ACSR) is made in strands. To aid in heat dissipation, overhead transmission wires are not coated with an insulator. Insulator discs are commonly used to separate cable bundles in AC transmission. The more insulating material required, the higher the voltage level employed. Support structures are built of wood or metal that's used to suspend these cables at a safe distance from the public[1].

$$R_{dc} = \rho l / A$$

Where ρ is the conductor's resistivity at a temperature t, l is the conductor length, and A is the conductor's cross sectional area.

1.11 | Power Quality

Power quality is a measurement of a power source's reliability and stability in terms of voltage, frequency, and waveform. DC systems provide improved power supply than AC systems because of frequency is zero in DC systems, making it considerably easier to create a signal that is within requirements. A microgrid should really be able to supply electricity to loads without causing damage, which is becoming more of a problem as the number of digital devices grows. Although the phrase "power quality" is used, the measure is actually "voltage quality." As DC systems no one has any phase angle between voltage and current, they have no reactive power, which improves power quality. There is also no harmonic distortion in a DC waveform since the frequency is zero. Harmonic components develop in multiple sets of the frequency of the power supply. In DC systems, voltage stability is the primary concern, so power converters and batteries can maintain DC voltage control.

1.12 | Our View

The majority of the testbeds are AC MGs, according to an analysis of MG architectures. The AC MG is simple to integrate with the grid because the gird and also most loads are both AC. One of the most important duties in AC systems is to maintain power quality. The fundamental advantage of a DC system, on the other hand, is there are very few power quality issues, requiring less additional control of components.

However, due to a lack of sufficient DC loads, the usage of DC MG are severely limited. The HFAC MG is a brand-new concept that might be used to integrate renewable energy sources into the MG. One of the key advantages is that this approach has fewer PQ issues.

The complexity of the control devices, considerable voltage drop, or higher long-distance power loss are the key issues with the HFAC MG system, which now limit its practical implementation and may be explored. Solar PV, wind, micro-hydro, and diesel are the most prevalent DG sources in MG systems.

Along energy traditional sources, RES are becoming extremely popular as Distributed generators in European locations. In the MG system, power quality could be a concern. Because renewables DG sources are so reliant on the environment, resource fluctuation causes certain PQ issues. As a result, every MG system must take PQ performance into account. A survey of the test-beds reveals that just a few MG test-beds have power quality devices installed.

As a result, more study is needed to improve the PQ and reliability, as well as the overall performance of MG system. One of the most significant options for an MG's successful and consistent operation is a storage system. The majority of extant test-beds contain battery storage; some also have capacitor banks and flywheels. Some MGs have such a combination of two or three storage units, while others have none at all. In most cases (save two), if there is no device that stores, at least one controlled DG sources is available at the system, according to the review. If there are no storage devices in the system and only RES is used as a DG source, grid integration is just a critical choice for such MG system. More research can be done in this area.

2 | Stability and Virtual Inertia

The capability of a power network to reestablish its equilibrium condition after being disrupted is known as power system stability. The most important thing to remember about transmitting power is whether the maximum of real power always focused towards the load. Due to constant load change (either increase or decrease), achieving this is almost impossible, but using various methods and analyses, the system can be operated in the most stable region, where this area of study comes into play.

The network is given back to its balance operating condition to ensure maximum power transmission after understanding the sort of instability induced into the system. Let's start with a basic understanding of the primary parameters that must be considered in order to create a stable network.

2.1 | What is Stability

The transmission system cannot store electricity, so the quantity of electricity fed in must always match the amount of electricity fed out. This implies that energy production and consumption must constantly be in balance. This equilibrium ensures that the grid operates safely and reliably at a constant frequency of 50 Hertz. The Swiss transmission grid is not the only one that uses a 50 Hertz frequency; the entire European linked system does as well. Swissgrid collaborates with other transmission system operators to ensure that the interconnected grid's frequency is maintained at all times.

2.2 | Types Of Stability

2.2.1 | Steady state stability

The stability of a system under a slow or gradual shift in load is known as steady state stability. When compared to the rate of changes of field flux of the device in response to the changes in load, it is believed that the change of load is relatively low.
Swing is caused by any change in the system's condition. Swing is the motion of the connected machines in relation to one another. Whenever a change occurs, all of the connected machines attempt to adapt.Swing is the result of this relative motion. Swing can be measured in terms of power or another electrical parameter.

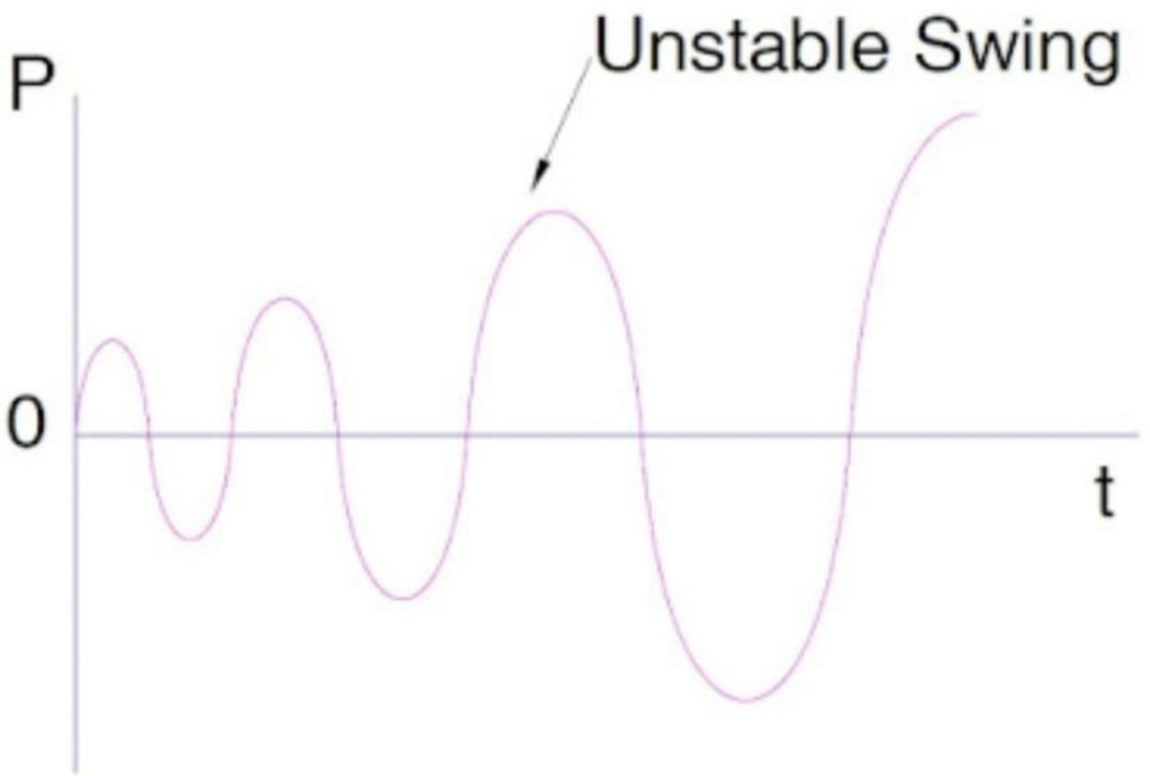

Figure 2.1: Unstable Swing

Now, in order for this process to be stable, all such swings must be dampened as soon as possible. The inertia of Rotor H, Damper winding, Field Winding, and other components of the generator provide the majority of the damping. A steady swing is seen in the diagram below. The swing/disturbance fades away, as shown in the graph. However, there are specific circumstances/operational points of the Generator where such swings/disturbances do not go away. The term ”unstable swing” refers to this type of swing/disturbance. If no precautions are taken, the Generator will lose synchronisation and become unstable[7].

2.2.2 | Dynamic stability

Dynamic stability refers to a power system's ability to return to a stable state of operation since varied forms (short circuit, breakdowns of any element of the power grid, etc.) in which improvements in the configuration parameters are compared to a values of parameters without trying to switch to asynchronous mode.
The transmission system operator (TSO) follows the following guidelines while deciding on the methods of dynamic stability analysis:

- If the TSO, taking into consideration emergency events from the past,

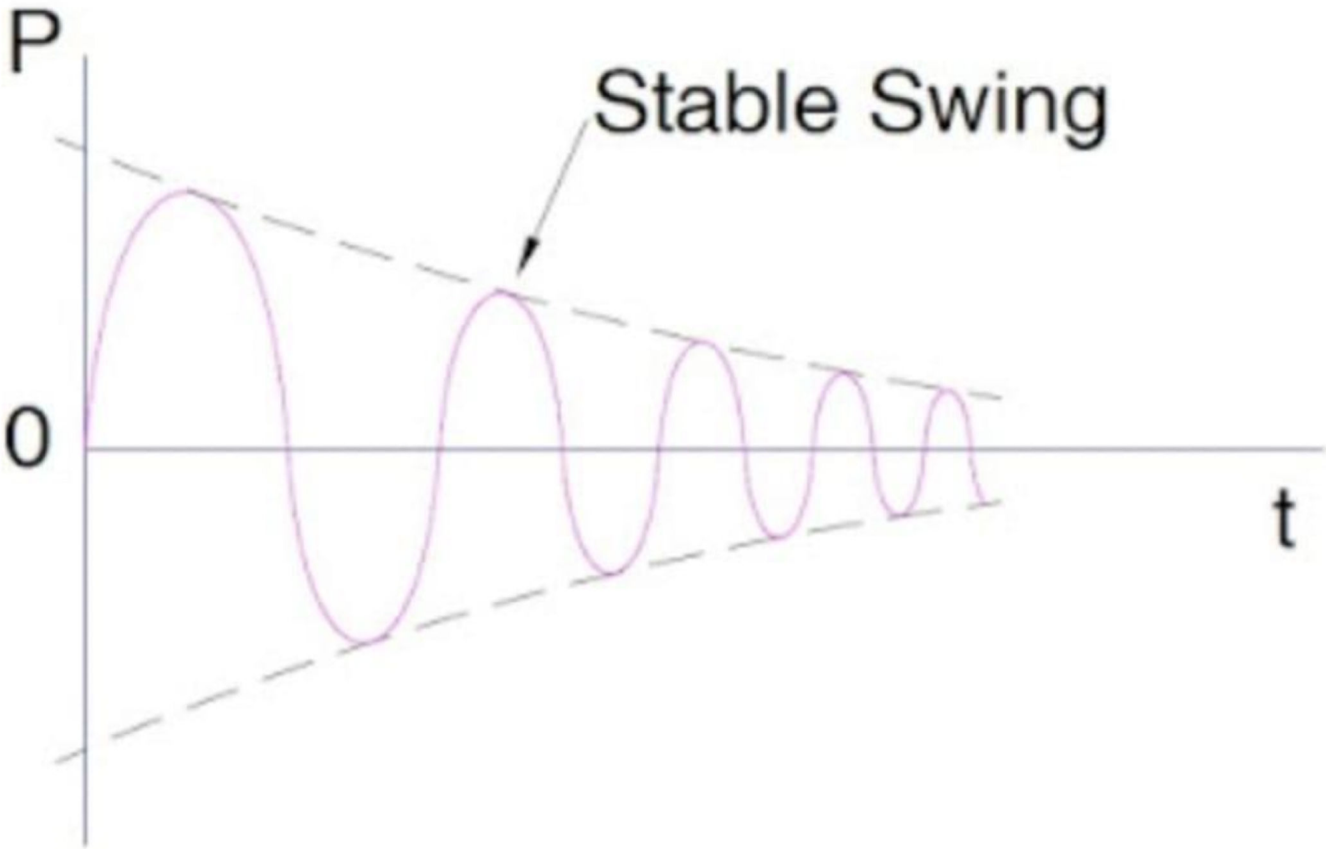

Figure 2.2: Stable Swingm

reaches the limitations of static stability even before limits of dynamic stability Only based on the success of dynamic response calculations completed for long-term planning, should a dynamic stability study be performed.

- If the limits of dynamic characteristics are reached earlier than that of the limits of deflection when planning outages, TSOs should conduct a dynamic stability analysis at the stage of planning processes one day ahead while these modes exist, taking emergencies from of the list of cases of emergency into account. The TSO may prepare corrective measures that can be used in real-time if necessary.

- When the system is in situation "N" in real time and the dynamic stability limits are reached before even the static stability limits, the TSO should analyse dynamic characteristics at all stages of planning processes and be able to reevaluate faster dynamic stability limits after a significant change in mode, taking into account cases of emergency from the list of crisis situations.

- If the dynamic sustainable analysis reveals a breach of the sustainable development boundaries, the TSO must create, plan, and implement corrective activities to ensure the transmission system's long-term viability. Users of the transmission and distribution systems may be included in these corrective efforts.

- When eliminating infringements that really can lead to large-scale bending of the system, TSO now must set up hardware, relay protection, and emergency control automation in just such a way that the crucial damage repair period estimated by him during the analysis of the existing stability is less than the crucial serious harm repair time.
- The computation of the system's response to a certain set of accidents, generally single or three-phase short-circuits, that can be removed by turning off power lines, is the goal of dynamic stability research. The reaction of generators is checked to determine that all equipment is operating synchronously, that the power system's oscillation damping is at an appropriate level, and that the voltage recoveries after an accident is completed effectively.

2.2.3 | Transient stability

The ability of such a synchronized power system to recover to stable state and retain synchronism after a reasonably big disturbance coming from extremely broad scenarios such as switch ON and OFF of circuit parts, or clearing of faults, etc. is known as transient stability in energy systems. Because power production systems are frequently susceptible to problems of this nature, it is critical for engineers being well in the system's stability circumstances.

In general, tests of transient stability with in power system are conducted for a minimum period of time equal to the time necessary for one swing, which is roughly 1 second or less. If the system is stable during the initial swing, it is assumed that the disturbances will decrease in succeeding swing, and the systems will be stable thereafter, as is the case.

To establish if a system is reliable theoretically, we must first compute the power system's swing equation.

Swing Equation for Determining Transient Stability

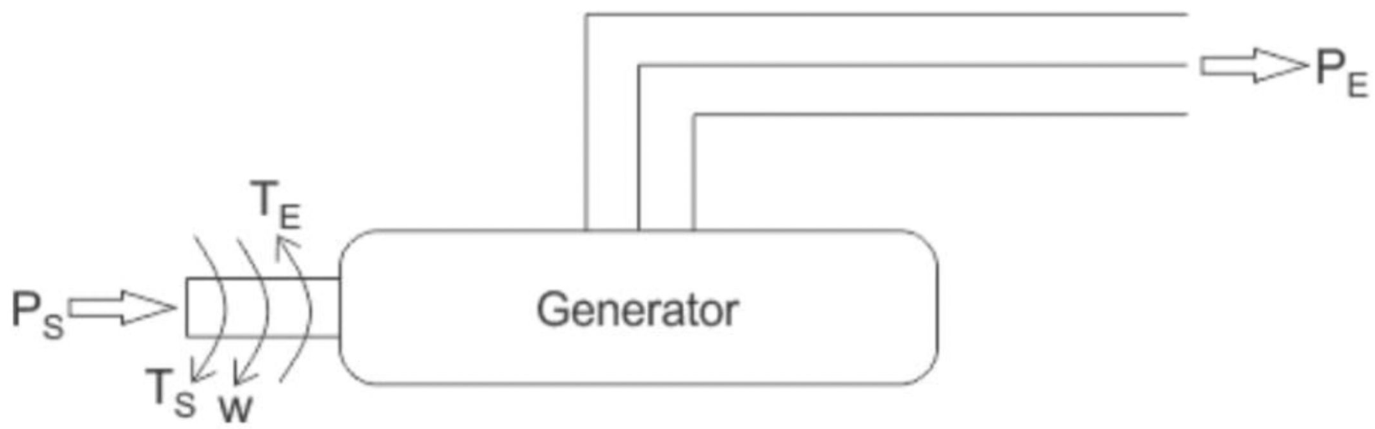

Figure 2.3: Energy Conversion

Assume a synchronous generator with input shaft power PS that produces mechanical power equal to TS, as illustrated in the diagram below, to evaluate the transient performance of a power grid using the swing equation. The machine rotates at a rate of rad/sec, and the output electromagnetic torque or power created on the receiver end are denoted by the letters TE and PE, respectively.
When a synchronous generator is supplied from one end and a constant load is applied from the other, there is a relative angular displacement between the rotation axis or the stator magnetic field δ , which is proportional to the machine's loading. At this time, the machine is deemed to be in a steady state of operation.
When we rapidly increase or eliminate load from the machine, the rotor decelerates or accelerates in response to the magnetic field of the stator. The machine's operating condition has now become unstable, and the rotor is said to be swinging with respect to the stator field. The equation we obtain, which gives the relative movement of the load angle ω with respect to the stator magnetic field, is called the swing formula for stability analysis of a power network.

For the sake of clarity, consider the instance where a synchronous generator is suddenly provided with an increased quantity of electromagnetic load, causing instability by causing PE to go below PS as the rotor decelerates.

2.3 | System Faults That Can Cause System Instability

The following are the most typical disturbances that cause industrial power networks to become unstable (in no particular order of probability):

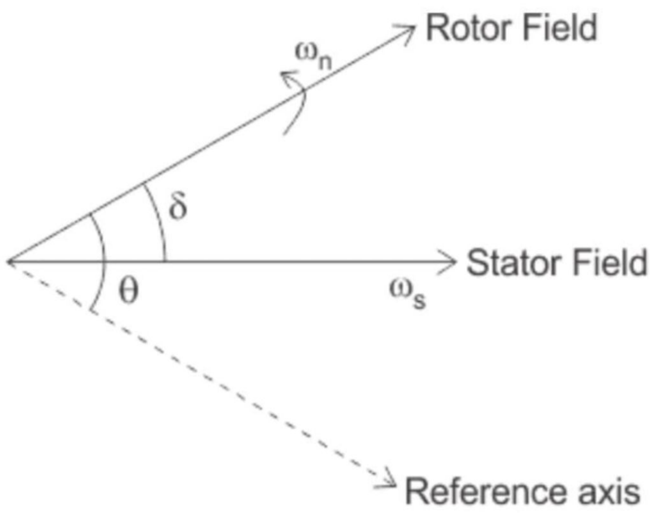

Figure 2.4: Angular position with respect to reference axis

- Short-circuit
- Loss of a tie circuit to a public utility
- Starting a motor that is large relative to a system generating capacity
- Loss of a portion of on-site generation
- Switching operations
- Impact loading on motors
- Abrupt decrease in electrical load on generators
- The effect of each of these disturbances should be seen from the previous discussion of the fundamentals of stability

2.4 | Virtual Inertia

Power generation and transmission have been centralised, with each power plant containing huge spinning turbines and synchronous generators and having a capacity of hundreds of megawatts. Large inertia and, as a result, high kinetic energy, along with the high short-circuit current ratio (SCR) linked with synchronous generators, results in a grid with stiff voltage and frequency.
However, generation is shifting away from large, centrally located power plants and toward distributed generators (DGs) that use smaller capacity sources like photovoltaic (PV), micro-turbines, and fuel cells.
When linked to the grid, almost all of these source requires inverter on the front end. Droop control or other form of centralised communication can be used to share power across different DGs in an isolated micro grid.In DGs

with a powerelectronic interface, active power frequency (P-w) and reactive power-voltage (Q-V) droop is used to manage frequency and voltage. Inverters have a low inertia since they do not even have a spinning mass. Inverter-based static sources may have a higher penetration in microgrids, resulting in poor frequency and voltage response during significant disturbances. This transient responsiveness problem could turn into a transitory stability problem if the concerns aren't addressed. The impact of high penetration of different DG technologies on the system's transient stability is investigated.
DGs based on synchronous machines reduce maximum frequency deviation at the cost of increasing oscillation duration (due to inertia), whereas inverter-based DGs reduce rotor-angle deviations and improve voltage profile at the user end of the system at the expenditure of increasing frequency deviations due to faster control and increased system damping.

In addition to DGs, energy storage devices like ultra capacitors and batteries can increase the system's transient response. However, in a big power system with a high number of DGs, the storage-based approach may be useless and costly due to disturbance location considerations. In such a case, disturbances might cause massive frequency variations that exceed the frequencies and threshold, ending in generation tripping or wasteful load shedding[2].

2.4.1 | Concept Of Virtual Inertia

Virtual synchronous generators, virtual synchronous machines, and synchronverters are all terms used in the literature to describe the concept of introducing inertia virtually to decrease frequency variations in microgrids by changing inverter regulation. When the inverter's inertia is increased, the maximum rotor speed deviations of the neighbouring source is reduced.

The idea of virtually introducing inertia by altering the control scheme of existing inverter rather than using a specialised inertia source has still not been described yet. The interactions issue of inverter and diesel generator-based sources is examined in the reference. The electromechanical modes and, as a result, overall stability of a diesel- based generator with a large droop gain are demonstrated to be affected.

Microgrid stability degrades if the diesel generator contributes more by raising the gain due to time lag related with synchronous generator regulation.

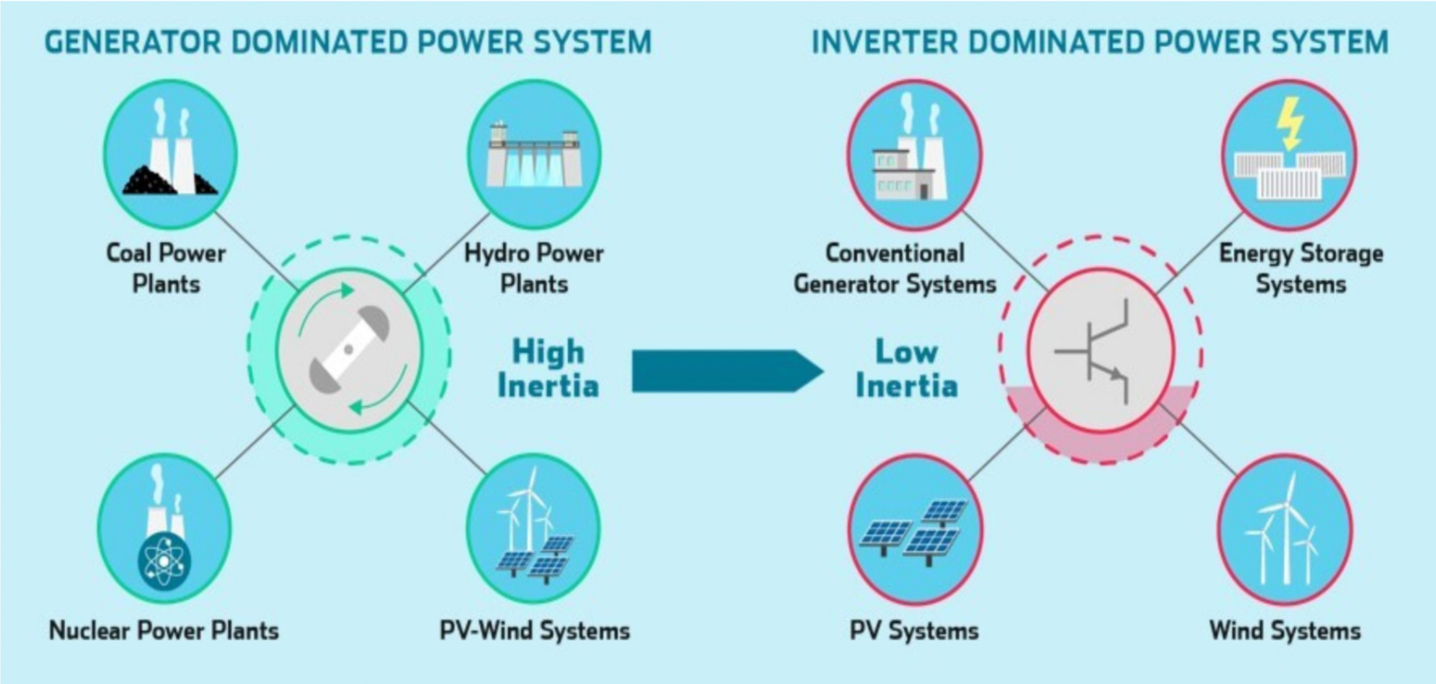

Figure 2.5: System Inertia

To provide a smooth transition during scheduled islanding, the set points of the microgrid's DG are modified (before to islanding).

When the microgrid switches from grid-connected to islanding mode, there are less transients. The divergence in power and frequency swings produced by unplanned islanding is determined by the supply-demand mismatch in the islanded network. Using fast-acting converters interfaced DG units, the transient can be reduced. When a microgrid is islanded, a big variation in load/source can cause a transient stability problem, and when it is grid connected, the same disturbance can cause a small-signal stability problem.

2.4.2 | Effect of Inertia on the System

Inertia is inversely proportional to the rate of changes of speed, and thus to the system frequency deviation. Due to considerable inertia and fast field management of synchronous generators, stiff power grids retain frequency and voltage during disruptions. Synchronous generators store a huge quantity of kinetic energy due to the increased inertia of the rotors.

The mismatch in mechanical or electrical power for one synchronous generator causes speed slowing if the load is increased. For the time being, the rotor's kinetic energy will be used to compensate for the imbalance. The resistance of an object to variations in rotational speed is measured by rotational inertia.E equation that expresses the relationship between power, angular speed, and inertia in a power system.

$$RoCoF = \frac{d(\Delta f)}{dt}$$

Meanwhile, the governor raises the input mechanical power until 'Pm' equals 'Pe' and the system settles at a new frequency in steady state. Similarly, under reactive power demand, such as induction motor starting or faults, generator field control operates swiftly to maintain system voltage. As a result, the frequency and voltage of the power system are tightly regulated. Although inverters were static or do not have spinning masses, they can have infinite inertia if the output phase angle of the inverter is kept constant during power changes.

Droop control and current limits on inverter switches, on the other hand, reduce inverter inertia. During disturbances, such sources may be unable to adjust voltage and frequency. As a result, frequency and voltage instability may occur in micro grids using inverter-based sources.

2.4.3 | Virtual Inertia as an Ancillary Service

Many studies have suggested that virtual inertia could be used as an extra service to enhance frequency stability in big power grids. It has been provided a control method to integrate DC micro - grids as virtual inertia imitating units in the traditional AC grid. The resources within the DC microgrid can be deployed like an additional source for inertial response using the control scheme. Modern data centres are another important source of underutilised energy. Data centres require a high level of reliability, which necessitates the usage of huge volumes of backup storing energy during regular operations.

Demand response approaches have been demonstrated to be effective in utilising these resources in research. This notion can be expanded to include the usage of data centre resources to simulate virtual inertia. As previously mentioned, virtual inertia-based interfaces can be connected with data centre resources for frequency adjustment.

A unit commitment model has been provided to allow an economic study of the virtual inertia system by combining system inertia from conventional plants and virtual inertia from wind power plants into system scheduling. Modern windmills are already required to supply inertial auxiliary services under various rules and regulations. The "hidden inertia" of wind turbines can be captured using the approaches outlined in the preceding sections.

Manufacturers of commercial wind turbines, such as WindINERTIA and ENERCON, currently offer virtual inertia response. In addition, prominent inverter manufacturers such as FREQCON, Schneider Electric, and ABB already offer inertial response capabilities out of the box. The use of electric vehicles (EVs) to deliver supplementary services has become a hot issue in academia. In most EVs, the control algorithm of the bidirectional converters can be changed to simulate virtual inertia.

2.4.4 | Inertia Estimation

The overall inertia constant of a power system has been calculated through research. The goal of the study was to figure out how much spinning reserve the power system needed. However, unlike traditional synchronous generation, virtual inertia simulated with ESS and RES will not be constant.

Whether or not RES units are online, as well as available resources (wind velocity, irradiance, and state of charge in the case of ESS), will determine the amount of inertia available in the system. In the forthcoming power system with substantial RES penetrations, system inertia estimation will be crucial for system operators' planning purposes. Moreover, such estimations can provide useful information about a power system's stable real-time operation. It was proposed to estimate inertia using frequency transients collected with synchronised phasor measuring units (PMUs).

A method is described for estimating the inertia response of a power system under significant wind penetration using the swing equation. For correct inertia estimation, accurate detection of frequency occurrences and exact ROCOF measurements are required. In modern power systems with RES units engaging in the inertial responses, the system's inertia will be heavily influenced by the availability of RES resources at any given time.

As a result, data from PV and wind forecasts can be used to supplement and improve the inertia estimation methodologies outlined above. Accurate inertia estimate methods will assist system operators in establishing a framework for procuring inertial services.

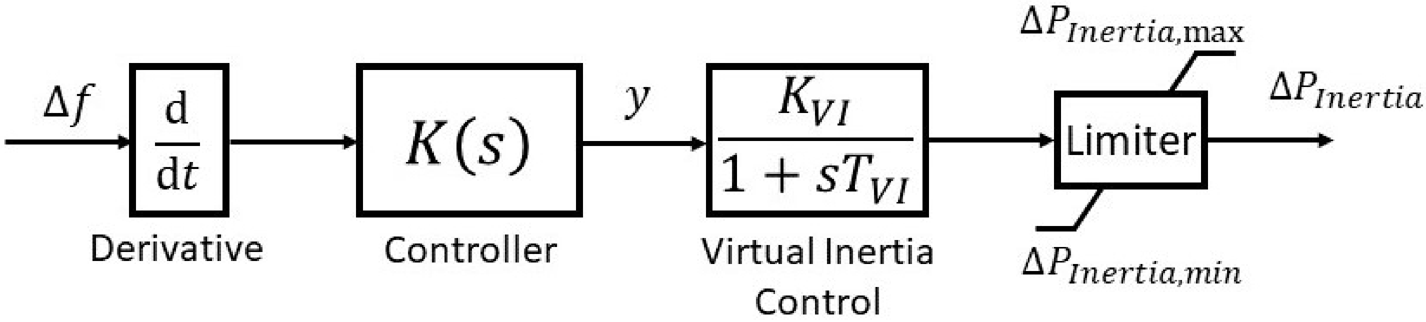

Figure 2.6: Virtual inertia control block

2.4.5 | Modeling, Control and Aggregation of Virtual Inertia Systems

The majority of study has focused on individual implementation of virtual inertia and inertial response's larger effects. There are currently no accurate, mathematical models that capture the dynamics, which are required for parameters tweaking and understanding behaviour when virtual inertia systems are connected to the power system.

A virtual inertia system has now been constructed using a small-signal model. Through Eigenvalue analysis, the model was used to identify essential operating modes, and a technique for assessing the system's sensitivity to parameter gains was presented. A small-signal prototype of a synchronverter has also been constructed. This type of model aids in the fine-tuning of controller gains and gives granular control on how the whole system should be run.

The influence of microgrids with high renewable energy source penetration on frequency stability has already been studied using an analytical approach. To make effect analysis easier, performance indexes that are not dependent on the experimental setup have also been proposed.

The behaviour and synchronisation of virtual inertia systems with existing SGs will be significant challenges that will require additional investigation. With so many virtual inertia units, the combined and aggregated operation, as well as optimal location, will be major research problems in the future.

The use of inertia as a "service" for power quality is one option that merits further investigation. As a microgrid operator, for example, you can provide inertial services based on particular parameters like maximum permissible ROCOFs and/or frequency deviation. The Quality - Of - service

(QoS) metrics developed for cloud computing services can be used to assess power quality in terms of inertial response availability in power systems.

The response time following a frequency disturbance and/or the availability of inertia can be used to evaluate the quality. This will let microgrid operators build a framework for incorporating inertial response services into their systems according on the needs of their end-users.

2.4.6 | Energy storage resources for virtual inertia systems

The use of inertia as a "service" for power quality is one option that merits further investigation. As a microgrid operator, for example, you can provide inertial services based on particular parameters like maximum permissible ROCOFs and/or frequency deviation. The Quality - Of - service (QoS) metrics developed for cloud computing services can be used to assess power quality in terms of inertial response availability in power systems.

The response time following a frequency disturbance and/or the availability of inertia can be used to evaluate the quality. This will let microgrid operators build a framework for incorporating inertial response services into their systems according on the needs of their end-users. Novel solar panel technology with built-in storage capacity could be another option for PV systems to provide inertia. Researchers have recently begun to focus on alternative energy sources for virtual inertia. The so-called "thermal inertia" of commercial buildings' heating, ventilation, and air conditioning (HVAC) systems is one of the primary topics that is attracting attention[9].

As previously stated, the power consumption of power electronics-based HVAC equipment can be adjusted to offer inertial response without compromising consumer comfort. Similarly, with wide-scale integration of RES units, big HVAC installations in data centres could be another possible source of inertial response in the forthcoming grid. As discussed, the power consumption of the power electronics based HVAC units can be controlled to provide inertial response while ensuring that the customer comfort is not effected.

3 | Voltage Control Strategies

The modern power system is progressing from a synchronous machine-based system towards an inverter-dominated system, with large-scale penetration of renewable energy sources (RESs) like wind and photovoltaics. RES units today represent a major share of the generation, and the traditional approach of integrating them as grid following units can lead to frequency instability. Many researchers have pointed towards using inverters with virtual inertia control algorithms so that they appear as synchronous generators to the grid, maintaining and enhancing system stability. This paper presents a literature review of the current state-of-the-art of virtual inertia implementation techniques, and explores potential research directions and challenges. The major virtual inertia topologies are compared and classified. Through literature review and simulations of some selected topologies it has been shown that similar inertial response can be achieved by relating the parameters of these topologies through time constants and inertia constants, although the exact frequency dynamics may vary slightly. The suitability of a topology depends on system control architecture and desired level of detail in replication of the dynamics of synchronous generators. A discussion on the challenges and research directions points out several research needs, especially for systems level integration of virtual inertia systems.

3.1 | PID Controller

A PID controller is an instrument used in industrial control applications to regulate temperature, flow, pressure, speed and other process variables. PID (proportional integral derivative) controllers use a control loop feedback mechanism to control process variables and are the most accurate and stable controller. PID control is a well-established way of driving a system towards a target position or level. It's a practically ubiquitous as a means of controlling temperature and finds application in myriad chemical and scientific processes as well as automation. PID control uses closed-loop control feedback to keep the actual output from a process as close to the target or setpoint output as possible.

The first evolution of the PID controller was developed in 1911 by Elmer Sperry. However, it wasn't until 1933 that the Taylor Instrumental Company (TIC) introduced the first pneumatic controller with a fully tunable proportional controller[10]. A few years later, control engineers went eliminate the steady state error found in proportional controllers by resetting the point to some artificial value as long as the error wasn't zero. This resetting "integrated" the error and became known as the proportional-Integral controller. Then, in 1940, TIC developed the first PID pneumatic controller with a derivative action, which reduced overshooting issues. However, it wasn't until 1942, when Ziegler and Nichols tuning rules were introduced that engineers were able to find and set the appropriate parameters of PID controllers. By the mid-1950's, automatic PID controllers were widely adopted for industrial use.

3.1.1 | Working of a PID Controller

A proportional integral derivative (PID) controller can be used as a means of controlling temperature, pressure, flow and other process variables. As its name implies, a PID controller combines proportional control with additional integral and derivative adjustments which help the unit automatically compensate for changes in the system.

3.1.1.1 | Working Principle

The working principle behind a PID controller is that the proportional, integral and derivative terms must be individually adjusted or "tuned." Based on the difference between these values a correction factor is calculated and applied to the input. For example, if an oven is cooler than required, the heat will be increased. Here are the three steps:

- **Proportional tuning** involves correcting a target proportional to the difference. Thus, the target value is never achieved because as the difference approaches zero, so too does the applied correction.
- **Integral tuning** attempts to remedy this by effectively cumulating the error result from the "P" action to increase the correction factor. For example, if the oven remained below temperature, "I" would act to increase the head delivered. However, rather than stop heating when the target is reached, "I" attempts to drive the cumulative error to zero, resulting in an overshoot.
- **Derivative tuning** attempts to minimize this overshoot by slowing the correction factor applied as the target is approached

3.1.2 | Types of PID Controller

There are three basic types of controllers: on-off, proportional and PID. Depending upon the system to be controlled, the operator will be able to use one type or another to control the process.

3.1.2.1 | On/Off Control

An on-off pid controller is the simplest form of temperature control device. The output from the device is either on or off, with no middle state. An on-off controller will switch the output only when the temperature crosses the setpoint. One special type of on-off control is a limit controller. This controller uses a latching relay, which must be manually reset, and is used to shut down a process when a certain temperature is reached.

3.1.2.2 | Proportional Control

Proportional controls are designed to eliminate the cycling associated with on-off control. A proportional controller decreases the average power supplied to the heater as the temperature approaches setpoint. This has the effect of slowing down the heater so that it will not overshoot the setpoint but will approach the setpoint and maintain a stable temperature. This proportioning action can be accomplished by turning the output on and off for short time intervals. This ”time proportioning” varies the ratio of ”on” time to ”off” time to control the temperature.

3.1.2.3 | Standard PID Controller

This standard PID controller combines proportional control with integral and derivative control (PID), which helps the unit automatically compensate for changes in the system. These adjustments, integral and derivative, are expressed in time-based units; they are also referred to by their reciprocals, RESET and RATE, respectively. The proportional, integral and derivative terms must be individually adjusted or ”tuned” to a particular system using trial and error. PID controllers provide the most accurate and stable control of the three controller types.

3.1.3 | Tuning a PID Controller

Many rules have evolved over the years to address the question of how to tune a PID controller. Probably the first, and certainly the best known, are the Zeigler-Nichols (ZN) rules.
Zeigler-Nichols (ZN) Rules First published in 1942, Zeigler and Nichols described two methods of tuning a PID loop. The first method entails measuring the lag or delay in response and then the time taken to reach the new output value. The second depends on establishing the period of a steady-state oscillation. In both methods these values are then entered into a table to derive values for gain, reset time and rate. In some applications

it produces a response considered too aggressive in terms of overshoot and oscillation. Another drawback is that it can be time-consuming in processes that reacts slowly. For these reasons some control practitioners prefer other rules such as Tyreus-Luyben or Rivera, Morari and Skogestad.

3.1.3.1 | Manual Tuning

Manual tuning of PID controller is done by setting the reset time to its maximum value and the rate to zero and increasing the gain until the loop oscillates at a constant amplitude. (When the response to an error correction occurs quickly a larger gain can be used. If response is slow a relatively small gain is desirable). Then set the gain to half of that value and adjust the reset time so it corrects for any offset within an acceptable period. Finally, increase the rate until overshoot is minimized.

3.1.3.2 | Automate Tuning

Most PID controllers sold today incorporate auto-tuning functions. Operating details vary between manufacturers, but all follow rules where the controller "learns" how the process responds to a disturbance or change in set point and calculates appropriate PID settings. Newer and more sophisticated PID controllers, such as OMEGA's Platinum series of temperature and process controllers, incorporate fuzzy logic with their auto-tune capabilities.
This provides a way of dealing with imprecision and nonlinearity in complex control situations, such as are often encountered in manufacturing and process industries and helps with tuning optimization.

3.1.3.3 | Temperature Controller Tuning

In the case of a temperature controller like OMEGA's CNi8 series, when "Auto Tune" is selected the controller activates an output. By observing both the delay and rate with which the change is made it calculates optimal P, I and D settings. Manual tuning PID temperature controller allows for fine-tuning if needed. (Note that this controller requires the set point to be at least 10°C above the current process value for auto tuning to be performed).

3.1.3.4 | Controller Gain Tuning

PID controller gain tuning can be difficult. The proportional method is the easiest to understand. In this instance, the output of the proportional factor is the product of gain and measured error ϵ. Thus, larger proportional gain or error makes for greater output from the proportional factor. Setting the proportional gain too high causes a controller to repeatedly overshoot the setpoint, leading to oscillation. While setting the proportional gain too low make the loop output negligible. One way to offset this steady-state error is using the Zeigler-Nichols method of setting the I and D gains to zero and then increasing P gain until the loop output starts to oscillate[8].

3.1.4 | Advantages of PID Controller

- Improving the stability of the system.
- Reduces the steady-state error.
- Feasible and easy to implement.
- Makes the system faster by reducing the time constant.

3.1.5 | Disadvantages of PID Controller

- Low robustness.
- PID controllers are linear and symmetric so in nonlinear systems, the performance of controller varies.
- Noise in derivative part.

3.2 | Fuzzy Logic Controller

Fuzzy logic is applied with great success in various control application. Almost all the consumer products have fuzzy control. Some of the examples include controlling your room temperature with the help of air-conditioner, anti-braking system used in vehicles, control on traffic lights, washing machines, large economic systems, etc.

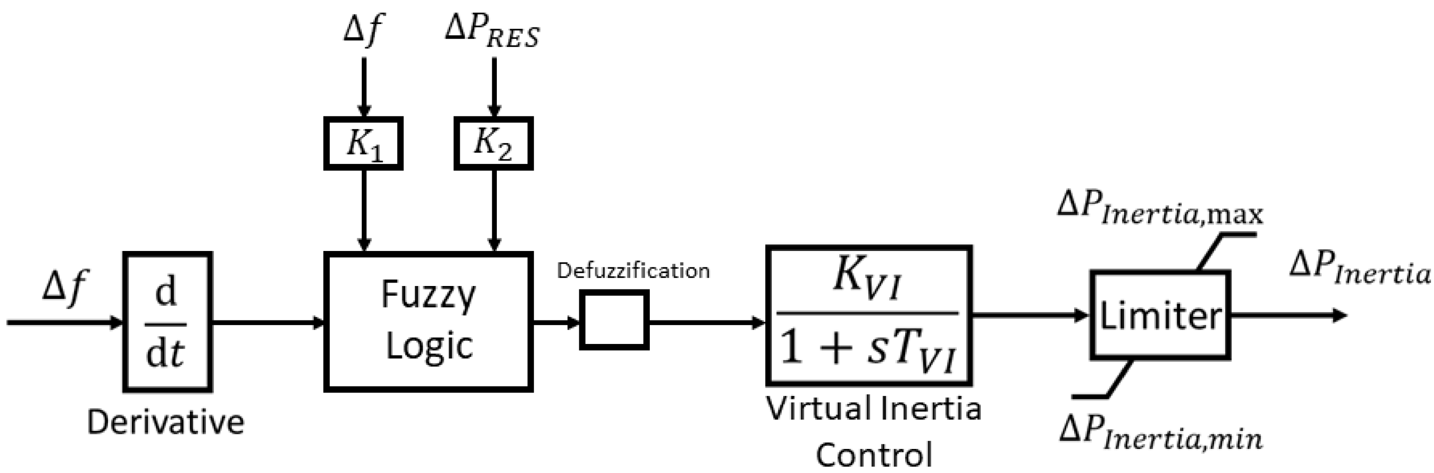

Figure 3.1: Fuzzy Logic Controller scheme

3.2.1 | Fuzzy Logic in Control Systems

A control system is an arrangement of physical components designed to alter another physical system so that this system exhibits certain desired characteristics. Following are some reasons of using Fuzzy Logic in Control Systems.
While applying traditional control, one needs to know about the model and the objective function formulated in precise terms. This makes it very difficult to apply in many cases. By applying fuzzy logic for control we can utilize the human expertise and experience for designing a controller. The fuzzy control rules, basically the IF-THEN rules, can be best utilized in designing a controller.

3.2.2 | Assumptions in Fuzzy Logic Control (FLC) Design

While designing fuzzy control system, the following six basic assumptions should be made

- **The plant is observable and controllable** It must be assumed that the input, output as well as state variables are available for observation and controlling purpose.
- **Existence of a knowledge body** It must be assumed that there exist a knowledge body having linguistic rules and a set of input-output data set from which rules can be extracted.
- **'Good enough' solution is enough** The control engineering must look for 'good enough' solution rather than an optimum one.
- **Range of precision** Fuzzy logic controller must be designed within an acceptable range of precision.
- **Issues regarding stability and optimality** The issues of stability and optimality must be open in designing Fuzzy logic controller rather than addressed explicitly.

3.2.3 | Architecture of Fuzzy Logic Control

following diagram shows the architecture of Fuzzy Logic Control (FLC)

3.2.4 | Major Components of FLC

Followings are the major components of the FLC as shown in the above figure

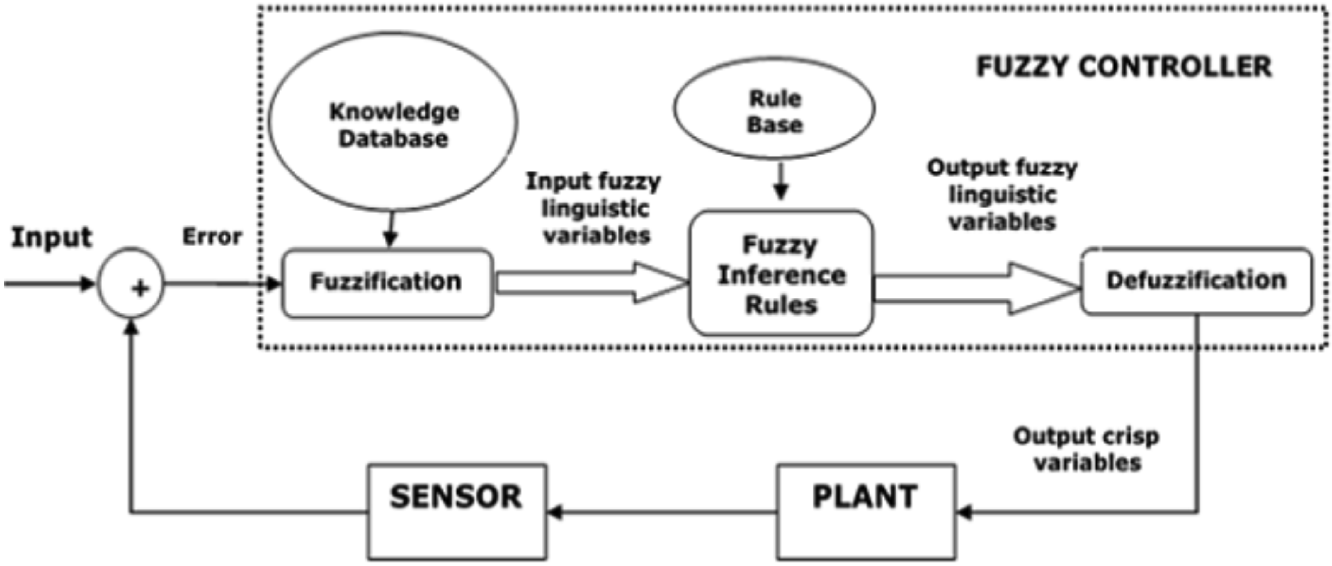

Figure 3.2: Fuzzy Logic Controller

- **Fuzzifier** The role of fuzzifier is to convert the crisp input values into fuzzy values.
- **Fuzzy Knowledge Base** It stores the knowledge about all the input-output fuzzy relationships. It also has the membership function which defines the input variables to the fuzzy rule base and the output variables to the plant under control.
- **Fuzzy Rule Base** It stores the knowledge about the operation of the process of domain.
- **Inference Engine** It acts as a kernel of any FLC. Basically it simulates human decisions by performing approximate reasoning.
- **Defuzzifier** The role of defuzzifier is to convert the fuzzy values into crisp values getting from fuzzy inference engine.

3.2.5 | Steps in Designing FLC

Followings are the major components of the FLC as shown in the above figure

- **Identification of variables** Here, the input, output and state variables must be identified of the plant which is under consideration.
- **Fuzzy subset configuration** The universe of information is divided into number of fuzzy subsets and each subset is assigned a linguistic label. Always make sure that these fuzzy subsets include all the elements of universe

- **Obtaining membership function** Now obtain the membership function for each fuzzy subset that we get in the above step.
- **Fuzzification** The fuzzification process is initiated in this step.
- **Combining fuzzy outputs** By applying fuzzy approximate reasoning, locate the fuzzy output and merge them.
- **Defuzzification** Finally, initiate defuzzification process to form a crisp output.

3.2.6 | Advantages of Fuzzy Logic Control

Let us now discuss the advantages of Fuzzy Logic Control.

- **Cheaper** Developing a FLC is comparatively cheaper than developing model based or other controller in terms of performance.
- **Robust** FLCs are more robust than PID controllers because of their capability to cover a huge range of operating conditions.
- **Customizable** FLCs are customizable
- **Emulate human deductive thinking** Basically FLC is designed to emulate human deductive thinking, the process people use to infer conclusion from what they know.
- **Reliability** FLC is more reliable than conventional control system.
- **Efficiency** Fuzzy logic provides more efficiency when applied in control system.

3.2.7 | Disadvantages of Fuzzy Logic Control

We will now discuss what are the disadvantages of Fuzzy Logic Control

- **Requires lots of data** FLC needs lots of data to be applied
- **Useful in case of moderate historical data** FLC is not useful for programs much smaller or larger than historical data..
- **CNeeds high human expertise** This is one drawback as the accuracy of the system depends on the knowledge and expertise of human beings.
- **Needs regular updating of rules** The rules must be updated with time

3.3 | Adaptive Learning Controller

Over the years, advancements in the fields of artificial intelligence and machine learning have piqued the interest of power system stability controller designers. VI controllers based on Reinforcement learning approach is designed by converting the stability and optimal control problem into a reinforcement learning task. For every action performed by the agent, as a result, the agent receives feedback in the form of a reward or penalty.
The advantage of reinforcement learning algorithm over previously discussed strategies is that the algorithm functions based on the analysis of interactions with the environment. Adaptive neural network (ANN), deep learning, adaptive dynamic programming (ADP), reinforcement learning (RL) and other aspects of machine learning are favourable ways to address the designing of VI controllers due to the total data-driven optimization. Although, higher computational programming is required to design a controller because the algorithm uses deep neural networks.
Fuzzy logic controllers have limited control areas as the logic's parameters are decided by the fuzzy rules and are to be manually operated. The main focus of this study is the adaptive learning techniques which are limited only by the availability of data, with development in sample data available the reinforcement learning algorithms can be trained to provide effective outcomes for every real world application. Machine Learning Technologies and controller designing is discussed in detail in chapter 4.

4 | Machine Learning based Control

Machine learning is a branch of artificial intelligence (AI) and computer science that focuses on using data and algorithms to replicate how humans learn in order to improve accuracy over time. Machine learning is an important component of the rapidly growing field of data science. In data mining projects, algorithms are taught to provide classifications or predictions using statistical methodologies, exposing key insights. Then, with the purpose of influencing crucial growth KPIs, these insights drive decision-making within applications and companies. The demand for data scientists will increase as big data expands and grows, demanding their assistance in identifying the most important business issues and, as a result, the data required to address them.

4.1 | How Machine Learning Works

- **A Decision Process** In general, Machine learning algorithms are used to produce predictions or classifications in general. Your algorithm will generate an estimate about a pattern in the data based on certain input data, which can be labelled or unlabeled.

- **An Error Function** An Error Function is a programme that generates errors. The model's prediction is evaluated using an error function. If there are known instances, an error function can compare them to evaluate the model's correctness.

- **An Model Optimization Process** Models Weights are modified to lessen the difference between the known case and the model estimate if the model will fit better to the data sets in the training data set. This evaluate and optimise procedure will be repeated by the algorithm, that will update weights on its own until a certain level of accuracy is reached.

4.2 | Machine Learning Methods

Machine learning classifiers fall into three primary categories

4.2.1 | Supervised machine learning

Learning that is supervised the ML task of developing broad hypotheses for outputs and inputs trained by linking labelled external input and output pairs is known as supervised learning. After training, the mapping function can also be used to forecast future data.

In the last two decades, a broad range of supervised learning algorithms have been created and are frequently employed to improve smart grid systems. In the recent decade, artificial neural networks (ANNs), that are designed to mimic the biological nervous system, had a huge impact on a wide range of fields. ANN approaches, like many other Machine learning techniques, do not require explicit programming and instead rely on algorithms to create data-driven predictions.

ANNs are particularly efficient at solving image processing and Smart Cities 2021, 4551 pattern recognition challenges that are difficult to address using standard approaches. Extreme learning machines (ELMs) are ANN algorithms that use a single hidden layer feed forward neural network to handle smart grid challenges including power system stability monitoring and fault identification.

The back-propagation neural neural network (BPNN) is used to learn neural networks by altering network weights periodically until the output and ground truth errors reach a specified level. BPNN is a neural network method that has been frequently used.

A feed-forward neural network technique is a multilayer perceptron. The probabilistic neural network (PNN), which uses the parent probability distribution function of every class to estimate the class given input data, is another well-developed feedforward neural network.

A substantial development of new AI algorithms with the backing of powerful computer hardware has occurred, allowing AI to enter the so-called AI 2.0 stage, driven by rising volumes of data and the need to handle more complicated issues. Starting with multilayer deep neural networks, deep learning (DL), a subset of machine learning (ML), was originally utilised for image processing (DNNs).

Deep belief networks, convolution neural networks (CNNs), recurrent neural networks (RNNs), generative adversarial networks, and autoencoder are just a few of the successful structures that have been presented to handle smart grid problems in recent years.

Aside from the techniques outlined above, a variety of AI methods are used to solve regression and classification problems. In smart grid systems, the k-nearest neighbours (KNN) technique, which is particularly quick for training, also is utilised for classification and regression.

In smart grid systems, the decision tree learning model and logistic regression have been widely adopted because they are simple to analyse and execute. Linear regression (LR), Gaussian process regression (GPR), support vector regression (SVR), and multivariate adaptive regression spline (MAR) are examples of regression methods that can be used to solve problems like smart grid forecasting, defect detection, and demand response.

4.2.2 | Unsupervised machine learning

Learning Without Supervision After decades of development, supervised learning algorithms exhibit excellent results, but they are only useful when users have some ground truth or knows which pattern to seek for, but it isn't always the case in the real world.

Unsupervised learning is important because it may be used to infer possible information or uncover hidden patterns in data that hasn't been labelled. Anomaly detection, stability evaluation, load forecasting, and other applications use techniques such the limited Boltzmann machine, autoencoder, and variational autoencoder.

Clustering is the unsupervised task of categorising a population or set of data points into a set of groups in which the data in the same categories are comparable. For fault detection and load forecasting, K-means, fuzzy c-means, hierarchical clustering, and DBSCAN (density-based spatial clustering of applications with noise) are often employed. When processing smart grid data, dimensional reduction (DR) techniques are frequently used to remove redundant characteristics by transforming data from a high-dimensional space to a low-dimensional space.

Principal component analysis (PCA), linear discriminant analysis, extended discriminant analysis, and non-negative matrix factorization are some of the DR approaches often utilised in the smart grid.

4.2.3 | Semi-supervised learning

Between unsupervised and supervised, semi-supervised learning is a good compromise. It guides categorization and extraction of features from such a larger, unlabeled set of data using a smaller labelled data set during training.Semi-supervised learning can overcome the problem of not having enough labelled data to train a supervised learning algorithm (but not being able to finance to label enough data).

Algorithms for reinforcement learning in machine learning When it comes to solving smart grid problems, RL is becoming increasingly popular. Agents, environment, rewards, and action are all components of RL. The goal of RL is to maximise the total reward through a continual process of getting rewards and punishments for each activity. RL can respond to unforeseen circumstances while having limited information of the surroundings and feedback on the value of his decisions.

The most common RL algorithms. In attack detection and energy management, Q- learning and SARSA (state–action–reward–state–action) are utilised. DRL (deep reinforcement learning) is an algorithm that blends DL perception with RL decision- making.

AlphaGo demonstrates DRL's success by combining a rich perception of high- dimensional input with policy control. In smart grid systems, DRL algorithms such as deep Q networks and deep deterministic policy gradient are common.

It's a kind of mechanism in which the system is rewarded or punished based on the task it does. As they train system to accomplish a specific task and it fails, the system may be penalised; if it succeeds flawlessly, the system will be rewarded. It usually works on a scale of 0 to 1, with 0 denoting punishment and 1 denoting reward.

4.3 | ML in Control Systems

Multiple components of the control circuit are frequently based on differential equations explaining the system behavior, which are extremely difficult to solve explicitly.

ML, on the other hand, may offer extra tools for studying such equations.

To estimate solutions of ordinary and partial differential equations, neural networks are utilised in various forms (PDEs).

A deep neural network-based approach for estimating the solutions of a PDE is provided. The network is trained with no prior knowledge of the solution, and a theorem is provided saying that as the size of the network grows, the neural network will converged to the PDE solution.

The nonlinear dynamic equations with neural network $\phi\hat{}$ to model unknown parameters in parallel with known parameters and model structure ϕM/ is used to estimate the vehicle accelerations ν given the position/orientation η, velocities ν and control inputs τ.

In the same way that ML can be used to develop a dynamic model without solving the equation, it can also be used to train a dynamic model on same form. All parameters, with the exception of the hydrodynamic damping parameters, can be estimated with sufficient accuracy using standard methods in most circumstances. As a result, a neural network is used to estimate the terms, while the existing parameters are presented by the known model ϕM.

To compensate for the damping, the neural network is used for a feedback linearizing control after training. To achieve formation control, a neural network is employed to estimate the dynamics of a leader and the followers, and so this approximation is being used in a loop control law.

This control law also necessitates knowledge of the agents' internal states, which is obtained by using another neural network as an observer to estimate the angular and linear velocity of the robot, which are believed to have limited communication.

As a result, machine learning technique are used in the control loop's dynamic controller and internal observers.

4.3.1 | Kinematic Control/Decision Making

In circumstances where the environment must be analysed in real time, machine learning is frequently used in the kinematics control component. In such circumstances, camera images and other sensor data from the exterior observation component are frequently used as input to the algorithms.

A quadrotor has been trained to follow a forest track autonomously to aid in search and rescue activities. The robot includes the front view camera to accomplish this. The images are fed into the kinematic controller, which generates a computed likelihood of the trail being left, straight, or right in relation to the camera reference frame using only a deep convolutional neural network (CNN). The intended direction and forward velocity are then recalculated using these probabilities.

To ensure appropriate docking, a deep convolutional neural network is being used in the kinematic control for an underwater snake robot. A single camera is mounted on the snake head, which feeds images to the kinematic controller. During training, a camera position system measures the robot's location (x, y) and orientation, which is then combined with a typical kinematic controller to determine the desired heading ds required to follow a route to the docking station..

The path is constructed in such a way that the docking station is seen from the path's camera. The dynamic controller receives the error $\psi = \psi$ des - ψ as the input.

However, in uncontrolled situations such as subsea, determining the robot's position and orientation is difficult. As a result, given solely camera input, a neural network is trained to estimate. As a result, the network is trained to behave similarly to a classical kinematic controller without relying on state measurements that may not be available outside of the controlled environment.

4.3.2 | Dynamic Control

Machine learning can also be used as a form of dynamic control. Machine Learning Control (MLC) is the principle of using machine learning algorithms to learn an adequate control law b = K(s) that maps the system input (sensor devices s) to an output data (actuators b) motivated by problems involving complex control tasks where modelling the system and developing a useful control law may be difficult or impossible.

Data is instead used to create effective controllers. For the dynamic controller, a similar approach is used as in. For a quadcoptor that must avoid columns on its route, a deep neural network is taught to replicate the behaviour of an MPC.

The MPC requires position estimation or measurements. The neural network, on the other hand, is not position-dependent and relies solely on data obtained directly from the vehicle's onboard sensors.

Because the MPC is used during training, training can be done in a controlled setting where the whole state is known during training (e.g., using motion graphics), but unavailable during testing. The neural network works admirably throughout testing, even when faced with modelling flaws and never-before-seen conditions such as many barriers. It is contemplated in a bipedal robot..

The dynamics are modelled similarly to that of a robot manipulator, but they additionally incorporate static and dynamic friction, as well as various disturbance torques and faults.

These are unknown, thus they can't be included in a feedback linearizing controller directly. As a result, the bipedal robot's dynamic controller is

$$\tau_{total} = \tau + \tau c$$

where τ is provided by and τc is a term that compensate for the errors and disturbance factors, hence ensuring better response speed and lowering steady state error.

This term is obtained from the results of a recurrent neural network (RNN) yrnn, and simulations show that employing the RNN reduces the tracking error e substantially as compared to using only the feedback linearizing controller[11].

4.3.3 | Characteristics of ML-based controllers

Deep reinforcement learning-based controllers (also known as DRL-based controllers) are ML-based controllers that have a number of distinctive and enticing features.

- **Learning** Machine teaching is the mechanism by which DRL-based controllers learn by systematically and continually practising. As a result, these controllers can detect variations and exceptions that seem to be difficult to capture in expert systems and control with fixed-gain controllers. The simulator can expose the DRL engine to a wide range of process states. Many of these stages would not be met in the real world, even as AI engine (mind) could try to run the plant far too near to or beyond the physical facility's functioning limits. In this situation, the excursions (which would almost certainly result in a process trip) are learning opportunities for the brain to learn which behaviours to avoid. When you do this enough times, your brain processes information what to do and not. Furthermore, the Deep reinforcement learning engine can learn from a huge number of simulations at the same time. Instead of giving the brain data from a single plants, this can understand from hundreds of simulation, which each moves faster than typical real-time to create an optimal learning experience.

- **Delayed gratification** Delayed gratification is a term that refers to the act of waiting for something to happen. DRL-based controllers can begin to recognize inefficient behaviour in the short term, allowing for long-term gain optimization. Humans call this propensity "delayed gratification," as per Sigmund Freud and even Aristotle around 300 B.C. When AI behaves in this manner, it is able to push through difficult local minima and toward more optimal solutions.

- **Non-traditional input data** DRL-based controllers control the intake and can assess sensor data in a way that automated systems can't. An AI-based controller, for example, can take into account visual information about product quality or the status of equipment. When conducting control measures, it also considers categorising machine indications and warnings. Sounds signals including vibration sensor inputs, comparable to those heard by human operators, can be used by AI-based controllers to identify how to make process decisions. The capacity to process visual information, like flare size, distinguishes and shows the capabilities of DRL-based controllers.

4.3.4 | Enabling DRL-based control systems

Delivering DRL-based controls to a process facility involves four steps-

- Preparation of a companion simulation model for the controller.
- Design and training of the controller.
- Assessment of the trained controller.
- Deployment.

4.4 | Bayesian Regularization

In contrast to classification, which is used to predict categorical (distinct) values, regression is a Machine Learning task that predicts continuous values (real numbers). To gain a better understanding of regression's fundamentals.

When there is insufficient data in the dataset or the data is unevenly dispersed, Bayesian Regularization can be highly effective. In contrast to normal regression procedures, where the output is derived from a single value of each attribute, the output of a Bayesian regularisation model is derived from a probability distribution. A normal distribution is used to generate the output, 'y.' (where mean and variance are normalized).The goal of Bayesian Linear Regression is to identify the 'posterior' distribution for the model parameters rather than the model parameters themselves. The model parameters, as well as the output y, are estimated to come out of a distribution.

- **Posterior** It is a term that refers to something that comes after something else. It is the likelihood of an event, such as H, occurring given that another event, such as E, has previously occurred as P(H — E)
- **Prior** It is the likelihood that an event H occurred before another event., for example P(H)
- **Likelihood** It's a likelihood function with a marginalisation parameter variable.

This is actually equivalent to the Bayes' Theorem.
We have such a posterior distribution for the model parameters that is proportional to a likelihood of the data scaled by prior probability of a parameters, as opposed to Ordinary Least Square (OLS).

The degree of likelihood would increase as the quantity of data points increases, becoming significantly bigger than the original value. The value for the factors converging to the obtained values by OLS when there are an unlimited number of data points. As a result, we start our regression procedure with a guess (the prior value). As we add additional data points to our model, it becomes less inaccurate.

To make Bayesian Ridge Regression accurate, a huge portion of training data is needed. This is just a taste of the mathematics that goes into creating a Bayesian Ridge Regressor.

The objective of this essay is to provide a greater overview of Bayesian regularisation, including when to use it, benefits, and drawbacks, as well as how to implement it. So, that was a quick overview of the mathematics underpinning Bayesian regularisation and Bayesian Ridge regression.

4.4.1 | Advantages of Bayesian Regularization

- Very effective when the size of the dataset is small.
- Particularly well-suited for on-line based learning (data is received in real-time), as compared to batch based learning, where we have the entire dataset on our hands before we start training the model. This is because Bayesian Regularization doesn't need to store data.
- The Bayesian approach is a tried and tested approach and is very robust, mathematically. So, one can use this without having any extra prior knowledge about the dataset.

4.4.2 | Disadvantages of Bayesian Regularization

- The inference of the model can be time-consuming.
- If there is a large amount of data available for our dataset, the Bayesian approach is not worth it and the regular frequentist approach does a more efficient job.

4.5 | Designing AI Controller

Control systems have evolved over years, and artificial intelligence (AI) technology are assisting in the development of the next generation of control systems in some cases.

The proportional-integral-derivative (PID) controller is a layered set of capabilities: the proportional term directs toward the signal, the integral term zeroes in on the setpoint, and the derivative term can reduce overshoot.

Although the control ecosystem appears to be a complicated network of interconnected technologies, it may be simplified by thinking of it as a family tree with ever-evolving branches. Any control system technology has unique features not found in previous technologies. Feed forward, for example, enhances PID control by forecasting controller output and then

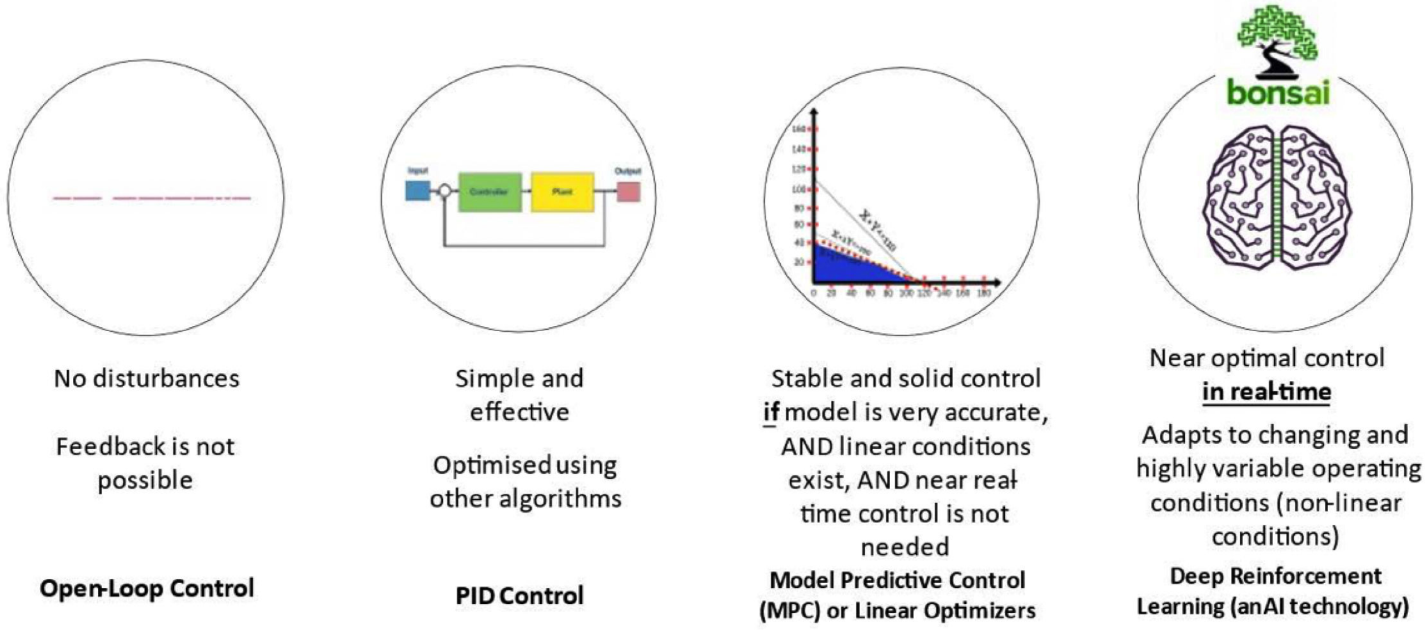

Figure 4.1: Evolution of control strategies

using the predictions to distinguish noise occurrences from disturbance mistakes.

Model predictive control (MPC) extends this by overlaying future control action outcomes predictions and regulating multiple associated inputs and outputs. The adoption of AI technologies to cultivate industrial controls is the most recent evolution of control strategies. The use of reinforced learning-based controls is one of the most recent developments in this field.

Using a simulation or "digital twin" environment to practise and understand how decisions are taken is required to enable DRL-based controllers. The benefit of this strategy is that the mind can acquire both what is "good" and "bad" for the system in order to reach specified goals. Given the amount of simulation required for training the brain over the state space of process and the fact that the real environment has far more variables than are usually represented within a process simulation model, reduced order models that preserve fundamental physics principles offer great method of training the brain [4].

These models enable for the development of complicated process simulations while also being speedier during run-time, allowing for a more efficient brain development. Tag-based process simulations are noted for their simple design, convenience of use, and ability to adapt to the a broad range of simulation demands, all of which are ideal for training DRL-based brains.

Tag-based simulator have become far more important in making the task of the an automation engineer fewer laborious in this modern day, when panel of lights and switch have been consigned to the rear corner of the staging floor.

For decades, using simulations to verify a systems on a factory acceptance test (FAT) before to deployment has been the ”bread and butter” of process simulation software - well before the appearance of modern jargon like digital twin.

The same simulators could be used to teach AI engines to control industrial processes more effectively. Simulators must be able to operate in a distributed form over numerous CPUs and maybe in the ”cloud” to do this. To either exercise, train, or review prospective new algorithms in parallel execution, many instances of the simulation are required. Once this has been accomplished, tag- based simulator-based operator trainer systems can be utilised to train DRL-based AI engines.

5 | Smart Grid

Government laws, consumer efficiency demands, and the advent of new sophisticated software or infrastructure innovations are all influencing the world's future electric systems. Furthermore, environmental concerns have prompted governments all over the world, especially at the federal and state levels, to implement regulations that have been moving its entire power system toward efficiency, conservation, and renewable energy sources.

These are the primary forces driving the adoption of a wide range of new alternative energy and storage technologies, as well as new power efficiency and conservation strategies. Individuals are becoming much more proactive and empowered to participate in energy usage decisions that affect their daily life. At almost the same time, their energy requirements are growing. Consumer participation, for example, will eventually include widespread the use electric cars (all these trucks and cars), navigation system of the in equipment to encourage green technology, property of distributed energy resources from increasingly renewable energy, as well as strategic planning of energy storage systems to match supply and demand locally.

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Although many distinct definitions for the Smart Grid have been presented, most users have chosen definitions that are specifically focused on their own implementations and local needs. In the next section, they explain the Smart Grid in its fullest sense. We begin by describing the conventional construction electrical power system, and then we identify areas that must alter in order to offer the knowledge and control required to convert to the future Smart Grid, which will be safe, secure, and efficient.

5.1 | Definition Of The Smart Grid

The Smart Grid detailed within that Special Issue is really not "pie-in-the-sky," but rather a genuine worldwide change for which huge amounts of money will be invested throughout the next century on real advanced technology that provide intelligent grid management in the coming years.

However, some components of the Smart Power grid described above may turn out to be ineffective, in which case they would have to await before lower technologies are being developed or societal advantages outweigh the costs. That is, this ultimate Grid Computing is a concept, with cost justification required at every step prior to implementation, followed by verification and validation before to widespread adoption.

Considering the above, the Smart Grid is defined as an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient and sustainable.

This definition covers the entire spectrum of the energy system from the generation to the end points of consumption of the electricity. The reader will note that many definitions proposed by other users are subsets of this system-ofsystems definition; as for example, if defined as smart metering, it addresses the consumption and to some extent the distribution part of this definition but not the full spectrum of integration required to implement the Smart Grid.

The development of a power grid will be a long and gradual process that will take decades to complete. This is not essential or practicable to implement all features at once in order to be qualified as a Smart Grid; instead, each new product can be implemented independently. Each will necessitate cost justification as well as an acceptable return on capital. However, after the innovations have been tested, the compatibility of open platforms should allow every addition to "Plugand-Play" into the Smart Grid. The Smart Grid, assuming it is achieved successfully, will include the following qualities that are not present in a traditional electric energy system:

- Secure communications (two-way) covering the system from end-to-end,
- Cables, joints, and other major components are all sensed and deviations are detected: Breaks, transformer, customer use, power quality, and other factors will all be considered. Real-time monitoring.

Large amounts of incoming information will be generated as a result of the foregoing qualities, which must be transformed into spacial awareness of the grid's state. The controller technologies of the future may have to computerise data and energy planning so that knowledge is simplified, problems are given a diagnosis instantly, appropriate actions are recognised and executed rapidly in the sector, and feedback mechanisms provide metrics that confirm that the work done is having the desired effects. The following properties will be present in such Smart Grid controllers:

- **Self healing** Automated replacement or removal of possibly damaged equipment from service it before breaks, as well as system reconfiguration to redirect energy sources to ensure that all customers have electricity.
- **Flexible** Connections of dispersed generation and power store at any spot on the system and at any time.
- **Predictive**Machines and supervised learning, weather impact forecasts, and stochastic analysis are used to predict the next most likely events so that necessary actions can be done to reconfigure the system before the next worst events occur.
- **Interactive** Transparently active necessary information is presented regarding the Not just to the operators, but also with the clients, the system's status is communicated. to allow all essential players in the power system to participate actively in Contingency management at its best.
- **Optimized** Knowing the state of every central ingredient in actual or near real time, as well as having control systems to enable alternative routing methods, allows for independent optimization of electrical flow across the system.
- **Secure** Safe and sound Given the Smart Grid's end-to-end system's two-way communication capacity, all important assets must be both physically and cyber-secured.

5.2 | Charactersitic

The smart grid provides a comprehensive answer to the challenges that plague the electrical system.Smart grid has been discovered to have a number of properties, some of which are listed below.

- **Dependability** Trustworthiness The two most significant elements of smart grid are fault detection and self-healing. As a result, the supply

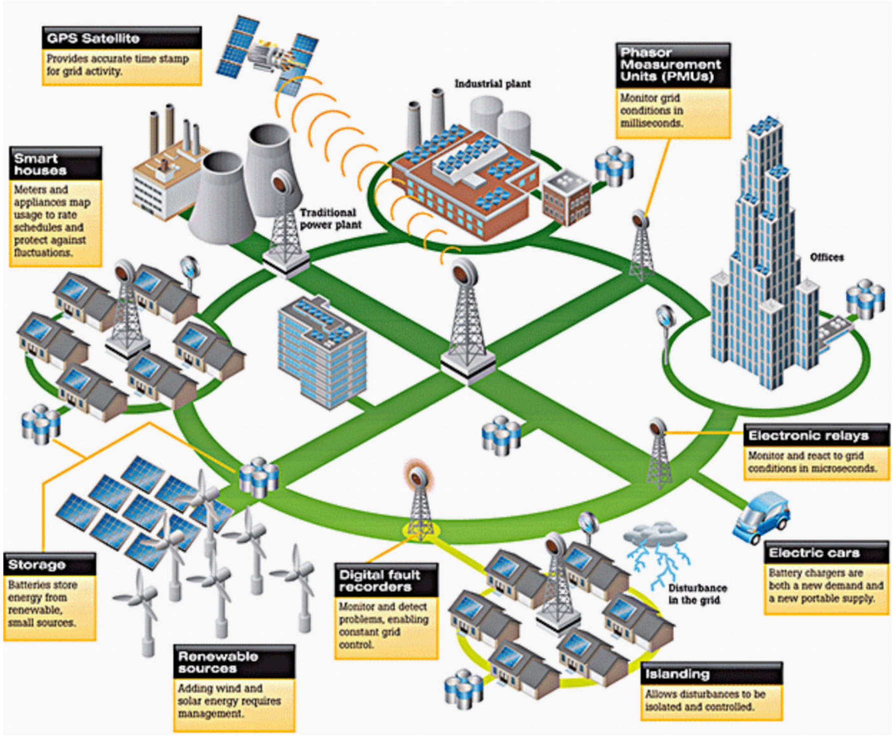


Figure 5.1: Smart-Grid

is unbroken and smooth, ensuring a regular supply.
A smart grid is comparable to a networks of links since it has numerous paths. This helpfulness, however, has significant drawbacks. One of these is that if a line takes higher voltage than it can handle, it will have a power outage. This can be regulated by lowering the voltage.

- **Bi-direction energy flow** Energy flow in both directions Previously, grids only allowed for one-way energy transfer, however smart grids allow for bi-directional energy flow. This was made possible by sophisticated transmission techniques and an automated distribution system.

- **Efficient**Smart grid technology has aided in the improvement of power transmission and distribution system. The technology's demand-side management feature is well-known. As a result, the generation distribution channels experience less load. Whenever the load on the distribution lines grows, the power city transmits an alert to those channels that are using the most energy. This is a signal that they should use backup generators. The strain on the wires is reduced as a result. Peak levelling is a technique that is used to reduce energy consumption during peak hours.
During peak times of energy usage, the price of energy is higher, while during off-peak hours, the price is lower. The pricing are communicated to the clients. Customers therefore use less energy during peak hours, resulting in a load reduction on the line.

- **Customer friendly** Smart grid technology aids in the satisfaction of

both suppliers and customers. The suppliers benefit from increasing energy prices because the load is lower during peak hours.
The same is true for customers, who must pay a lower price for less utilization during those hours. During those hours, clients are usually using generators.

- **Sustainable** Due of their increased flexibility, power systems are much more sustainable than traditional grids. Because of this, other renewable energy sources such as solar and wind power can be utilised. Disorder in the calm weather sometimes causes disruption in the distribution channels, making it difficult for the engineers to maintain a consistent supply.

- **Secure** Given the Smart Grid's end-to-end system's two-way communication capacity, all important assets must be both physically and cyber-secured.

5.3 | Major Components Of The Smart Grid

The Smart Grid, as demonstrated by the qualities listed above, entails the installation of a significant amount of modern, intelligent technology at important generating, transmission, distribution, and consumption locations.

Based control techniques for communications, information management, diagnostics analysis, and job management are required for this technology becoming an effective element of the operation of an integrated Smart Grid.

The Smart Grid must function as a system-of-systems: an integrated machine. Because old "blind" demand will transform into managed "visible" demand, the Smart Grid will revolutionise the conventional paradigm of energy management and operations . Customer Demand, Demand Response, and Curtailable Loads are all examples of demand that can be converted into supply in some instances (such as with electric vehicles and distributed battery storage).

AMI and Home Location Networks (HAN) give additional Demand Response features, such as the utility's intelligent automation of refrigerators and/or air conditioners, and curtailable load based solely on electronic communications. Many consumer utility intermediary firms offer subscription-based automated curtailment systems.

Certain "Self-Healing" characteristics more commonly available on the Web can be included into automatic reconfiguration processes.

5.3.1 | Photovoltaics

A photoelectric (PV) system is made up of one or more photovoltaic arrays, an inverter, and other electrical or mechanical components that use the Sun's energy to generate power. PV systems come in a wide range of sizes, from smaller rooftops or propulsion devices to large utility-scale power plants. Although Photovoltaic systems can run off-grid, this article concentrates on PV systems that are connected to the power, also known as grid-tied PV systems.Due to a growing need for the creation of sustainable electricity and the replacement of old sources of energy with sustainable ones, the power sector is currently experiencing a massive shift around the world.

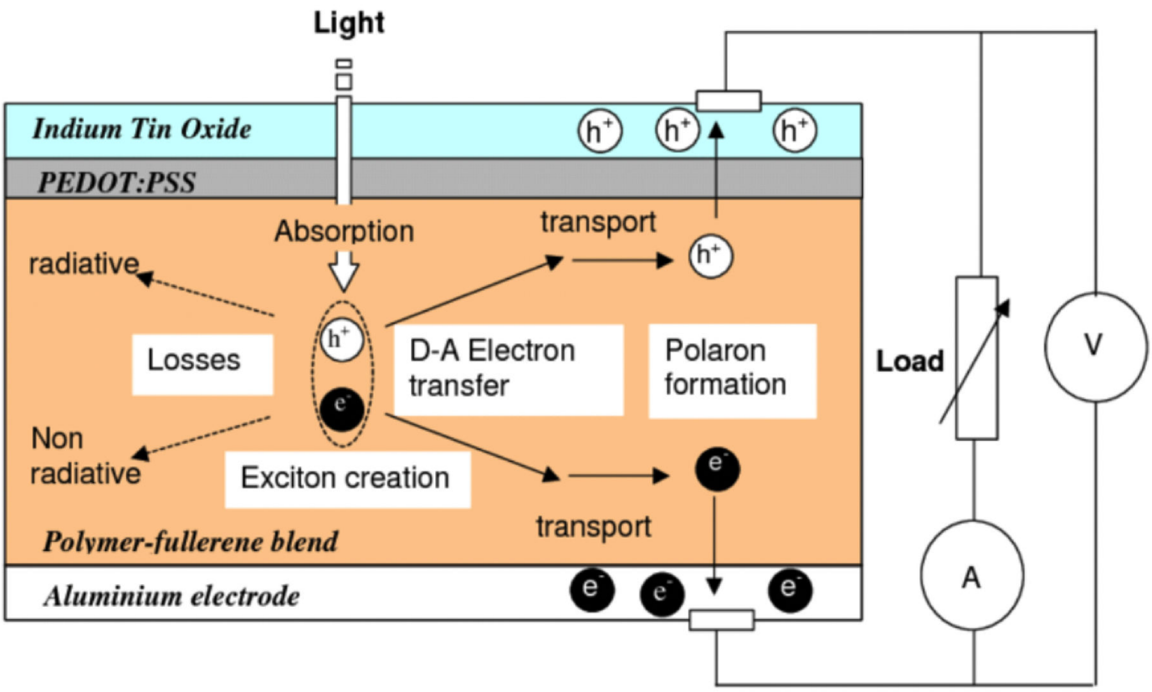


Figure 5.2: PV cell

This has aided in the widespread utilization of solar technologies. As a result, solar energy, particularly photovoltaic (PV) solar panels, is among the most promising renewable energy solutions that does not contribute to climate change and global warming. The global use of Photovoltaic technology has increased, partially as a result of lower costs for Pv panels and power converters, and partly as a result of the desire for more reliable, efficient or clean energy.

As a result, there is a strong interest in harnessing solar radiation for electricity generation, including the development of new materials, energy storage systems, power converters, and control approaches for these applications, among other things.

However, integrating PV energy into in the large-scale grids of today's power distribution systems frequently necessitates planning as well as impact analysis at the generation distribution system levels. This is mostly essential to assess and analyse the variation that this energy production source introduces.

5.3.2 | Solar-grid integration

Solar-grid connection is a network that allows a significant amount of photovoltaic (PV) power to be integrated into to the national power system. This is a critical technology because integrating standardised Photovoltaic system into grids optimises building energy balance, improves PV system economics, lowers operational costs, and adds value to the customer and utility. As there is an increasing desire for alternative clean energy to replace fossil fuels, solar-grid connection is now a regular practise in many nations throughout the world. Solar-powered electricity installed capacity has grown at an exponential rate, reaching over 290GW by the end of 2016.

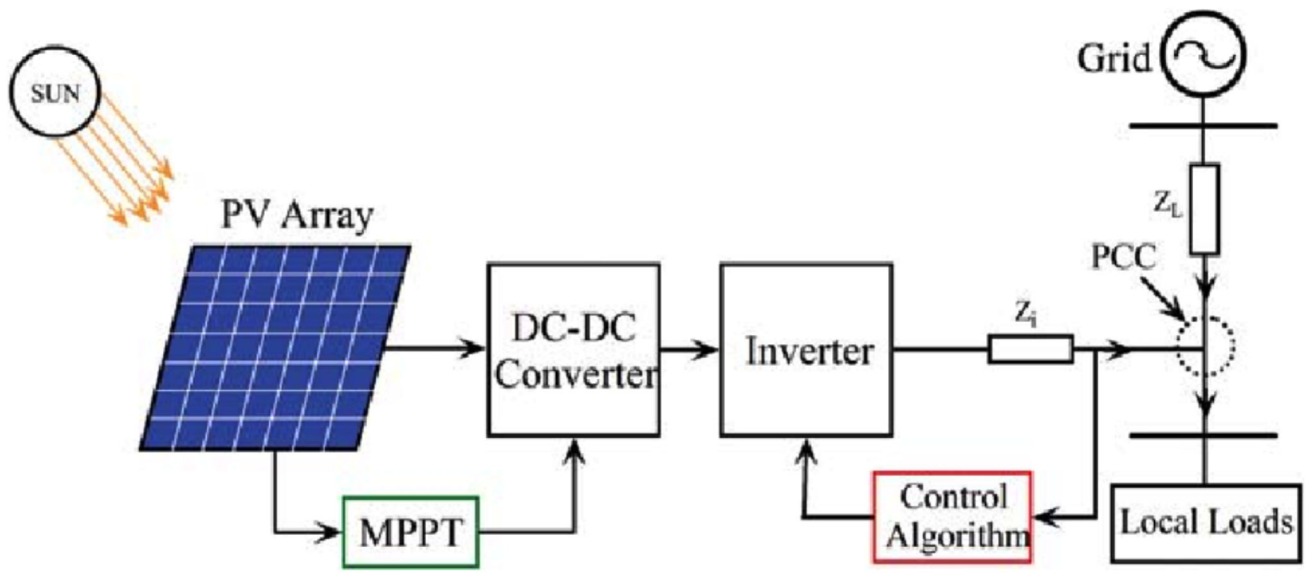


Figure 5.3: Grid-Interfaced solar photovoltaic system

Advanced inverters, anti-islanding technologies, transmission line process . research, solar-grid forecasting technology, and smart grids technology are all examples of solar-grid integration technology.

A important aspect in grid-connected Photovoltaic system is the development and operation of power converters, as well as how to reach high efficiency for various power combinations. Peak power, energy accuracy, control energy injected into the grid, and low overall switching frequency of the currents delivered to the grid are all requirements for converter connection. As a result, the performance of grid-connected inverters is primarily determined by the control approach used.

In this sense, the focus of this special issue is on recent developments and emerging trends in PV solar system grid integration:

- New trends with respect to grid integration for PV systems.
- PV solar energy in large-scale systems requires energy storage.
- Modeling and designs for new power conversion topology for Photovoltaic system systems for grid connection.
- Photovoltaic system power applications in large-scale grid networks require advanced control techniques.
- Stability analysis of grid-connected PV systems.

5.3.2.1 | Modelling Of Solar PV

PV systems are powered by solar energy, with PV cells serving as one of the most basic generating component. A diode as well as a current source were coupled pro with such a series resistance to make the PV cell. The following is the relationship between current and voltage in a single-diode cell:

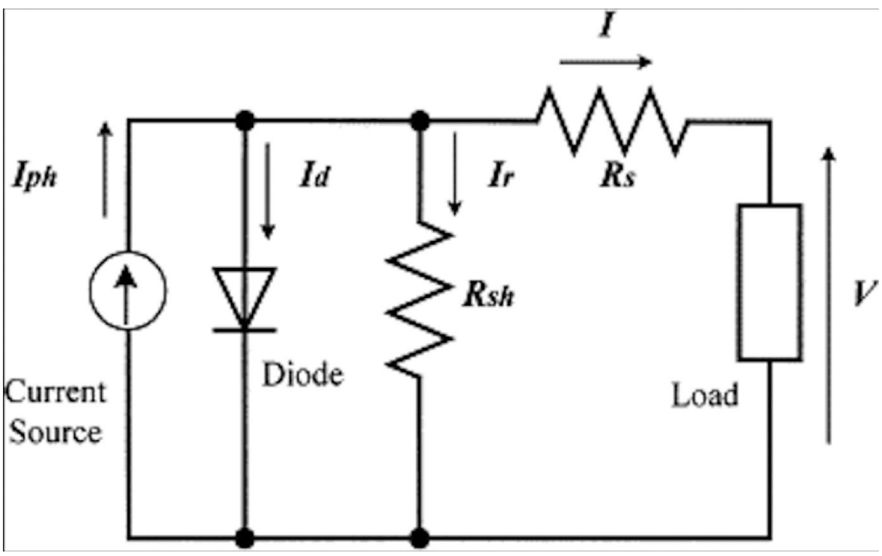


Figure 5.4: Equivalent circuit of PV cell

5.3.2.2 | DC/DC Boost Converter and MPPT

A buck converter is a DC/DC step-up converter that converts solar voltage to a specified voltage level as required by the load. Figure 3 shows the arrangement, which includes an Input dc voltage Vin, an inductor L, a switch S, a diode D1, and a filter capacitor C. When the switch S is turned on, the boost inductor stores the energy supplied by the input voltage source, and the charged capacitor maintains the load current throughout this period, ensuring that the load current remains constant. When switch S is turned off, the input voltage and stored inductor voltage emerge across the load, increasing the load voltage.

5.4 | Energy Storage System

The inclusion of large energy storage capability will be a vital element to the Smart Grid. PV, Solar Thermal, and Wind are intermittent power sources that require storage to meet demand during cloudy and/or windless periods.

The Electrical Energy storage Organization keeps track of the costs of large and small-scale energy storage systems, ranging from Lithium-Ion, Nickel-Cadmium, and Lead-Acid batteries, to flywheels and super - capacitors, to various big battery storage systems, and finally to large-scale compressor and hydroelectric cavern storage that involves water pumped back upstream during the night.

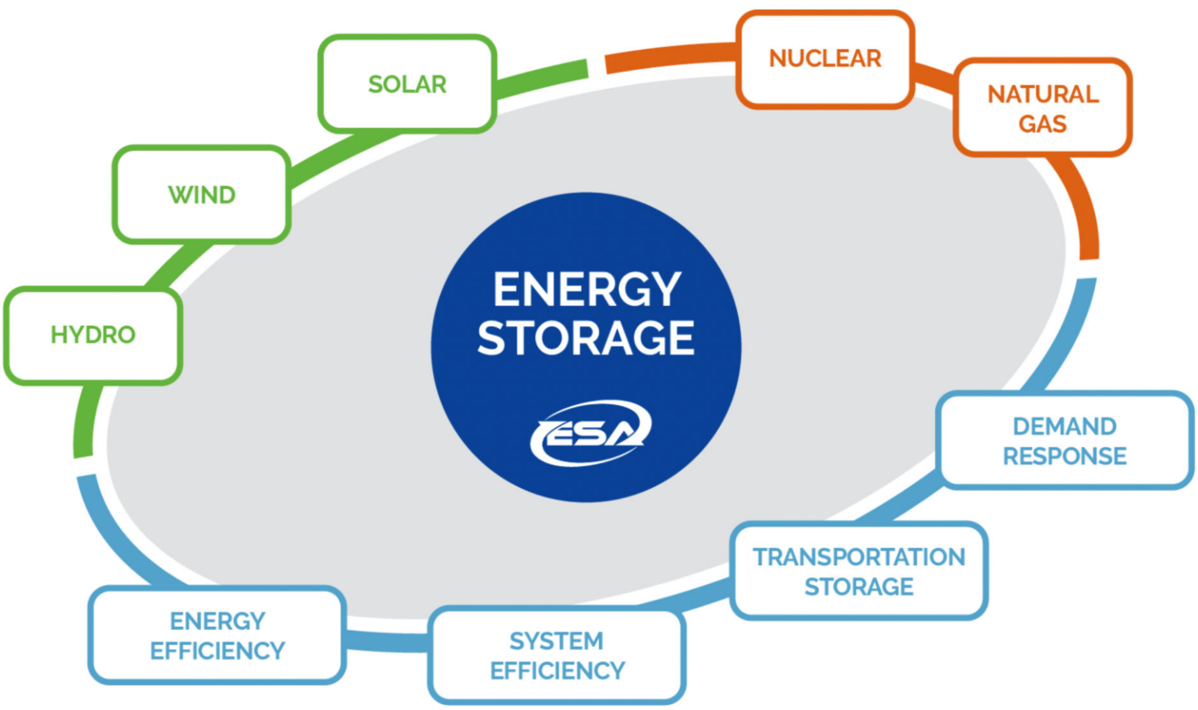


Figure 5.5: Benefits of BSS

All of these technologies are technologically conceivable if they are inexpensive, which is a barrier that has yet to be overcome. Alternative energy deployment on a wide scale will be constrained unless it is. Melting salt, warming vegetable oils, melting ice for HVAC compressor operation, and using fuel cells as electricity storage devices have all gained wider, even though limited, adoption.

The battery is critical in ensuring that the load receives uninterrupted power. The battery control system's goal is to control the battery current so that the required power can be obtained. The model also includes charging / discharging current limits, as well as maximum SOC limits.

A dynamic and multi Buck-Boost DC/DC converter connects the BESS (Battery storage system) to the DC grid. Based on the energy requirements, the BESS will operate in charging, discharging, or floating modes, with these modes being controlled by the Dc link voltage at the BESS point of coupling.

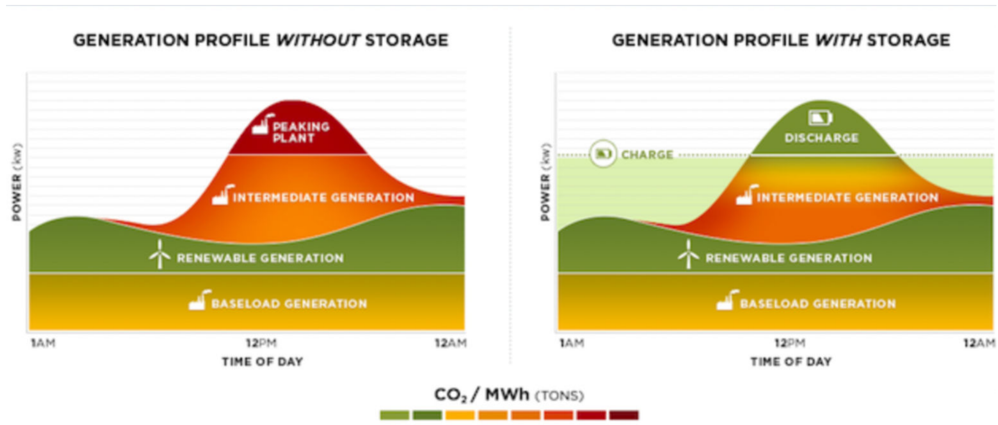


Figure 5.6: Load Distribution with ESS

As a result, the BESS must provide the requisite DC voltage level in the microgrid's various operational modes. Switch S2 is triggered when charging, and the converter operates as a boosting circuit; otherwise, switch S1 is engaged when discharging, and the converter operates as a buck circuit. Switch S1 is actuated so when potential at the DC link is less than the voltage reference. Switch S2 is engaged when such voltage just at DC link is greater than the voltage reference.

The Energy Storage (ESS) is a mechanism or set of equipment that converts electricity from power grids and stores it in order to provide electrical energy when it is needed later. An ESS aids in the efficient use and management of electrical energy, as well as the assurance of a consistent power generation and cost savings An ESS and a personal power station, such as a solar or wind renewable energy system, can provide electricity for a private power network that is operational 24 hours a day, seven days a week.

A batteries is an electric device with two or more cells connected electrically for the storage or production of electric energy that powers electronic gadgets and machines.

5.4.1 | Grid Integration of ESS)

Energy storage is the storage of electrical energy when volume increases consumption and the use of the stores when demand exceeds production. Hydropower, compressed air energy, batteries, flywheels, and capacitors are all examples of power storage.

A backup power system is a backup device that can provide enough power to operate crucial technology until commercial power comes back to a home, business, or industry. (See EPS (Emergency Power System); UPS (Uninterruptible Power Supply); ESS for further information) (Energy Storage System).

System Energy Storage refers to a set of techniques for storing electrical energy on a large scale inside a power grid. When volume increases consumption, power is stored and released to the grid when output falls below consumption.

The Superconductors Magnetic Power Storage (SMES) System stores power from the grid inside the magnetic field of a superconducting coil that was freeze cooled to a temperatures less than its superconductivity temperature with near-zero energy loss.. It's been presented as a storage alternative to enable large-scale photovoltaic use as a way to smooth out power generation variations.

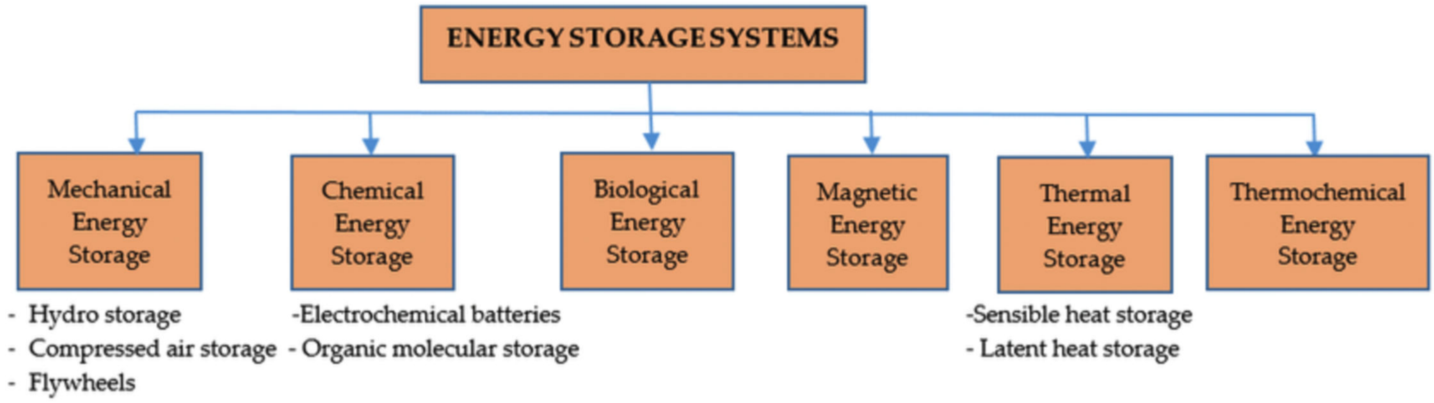


Figure 5.7: Energy storage Systems

5.4.1.1 | Battery

The weight of active material in a battery determines its capacity, which is the total potential electrical charge given in ampere- hours. The simplest working unit in a battery bank is the battery cell, which is a single unit.

The amount of charge cycles a battery may go through at a given depth of drain before failing to achieve the capacity or efficiency performance criteria.

The set of techniques and materials used by an energy accumulator to store electric power in electrochemical storage systems or electrolyte solutions is known as battery energy storage.

The period in which a cell or batteries is capable of running above a specific capacity or efficiency performance level is referred to as battery life.

A Batteries Rack is a supporting framework for a set of Batteries as well as Battery Cells. In the field of photovoltaics, a captive electrolytes batteries is a battery with an immobilised electrolyte.

The Carbon Zinc Cell Batteries is a cell dry primary battery that generates electricity through the electrolytic oxidation of carbon.

Discharge Factor is
1) A number equivalent to the time in hours during which a battery is discharged at constant current usually expressed as a percentage of the total battery capacity (e.g., C/5 indicates a discharge factor of 5 hours);
2) In a nozzle or other constriction, the discharge coefficient is the ratio of the actual discharge to the theoretical discharge (e.g., the ratio of the mass flow rate at the discharge end of the nozzle).

The rate at which electrical current is drawn from the batteries in amps or time, or at which a process creates waste or a product, is known as the discharge rate..

The Dish Stirling System is a form of Solar Photovoltaic Power (CSP) system that uses a convex dishes to reflect and concentrated solar energy onto a receiver that is filled using hydrogen or helium as just a transferring gas.

The term "dry cell" refers to a battery system with a captive electrolytes that is used as a battery system that cannot be recharged.

An electrolytic cells are devices with an electrolytes and two electrodes that is used to generate power through a chemical process or a chemical conversion in a liquid through electrolysis.

A Gel Type Battery is a valve-regulated, maintenance-free lead- acid batteries in which the electrolytes is made out of a silica gel matrix.

The cheapest rechargeable battery is the lead acid battery, which is widely used in automobiles and trucks. Plates of pure lead, lead-antimony, or lead-calcium are covered in a sulfuric acid solutions electrolyte in a lead acid battery.

A Liquid Electrolyte Batteries is a battery that contains a liquid acid and water solution. When a battery is charged, the electrolyte acts as a catalyst, facilitating the migration of ions from of the cathode to anode, and vice versa when the battery is discharged.

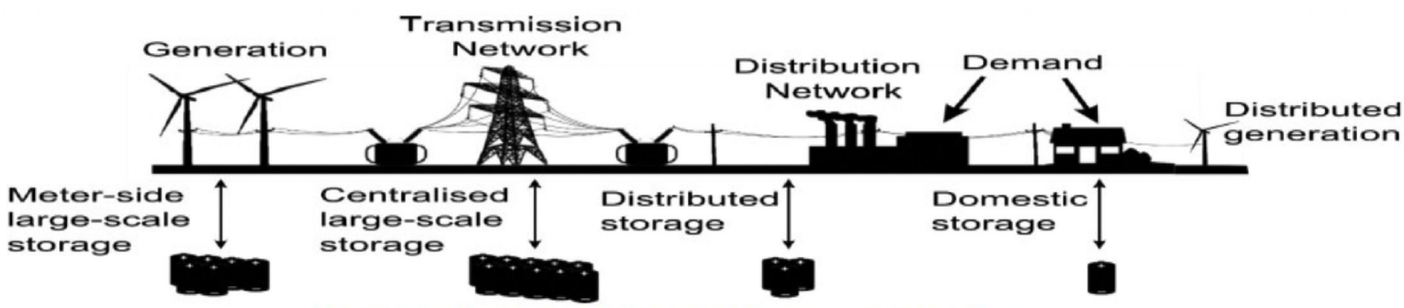


Figure 5.8: Grid integration of ESS

The Lithium Sulphur Batteries (Li-S Battery) is a rechargeable battery that has molten salt as the electrolyte and uses lithium as the negatively charged electrode as well as a metal sulphide as the positive electrode.

Because lithium has a low atomic weight and sulphur has a moderate weight, a Li-S battery is comparatively light. The Maintenance Free Batteries is a sealed battery that does not need to be maintained on a regular basis.

The Nickel Cadmium Batteries (NiCd Battery) is a rechargeable battery that contains nickel or cadmium plate as well as an alkaline electrolyte. The primary battery is a non-rechargeable batteries that cannot be charged back to its original capacity.

Battery manufacturers use the term "rated battery capacity" to describe the maximum energy that a fully charged batteries can deliver. The amount at which a batteries lowers its stored charge without any connections between the electrodes is known as self- discharge.

The maximum recommended duration for which items remain effective, free of deterioration, and acceptable under specific condition of usage is called shelf life; the amount of time that products remain unused before falling below a given level of performance is called shelf life.

The shelf life of a battery is the amount of time that it can be stored and still be effective, useful, or acceptable for consumption.

Solar Battery is
1) a device converting solar radiation into electricity;
2) a built - in rechargeable that combines solar energy storage with battery energy storage.

A storage battery is a type of battery that gathers and stores electricity and can convert it from electrical to chemical form and back.

5.5 | Wind Energy System

The wind energy consists of a wing that catches the kinetic energy of the wind, a turbine that generates mechanical power, and a permanent - magnet generator that generates ac power and supplies it to the DC bus through a diode rectifier. This is the structure that has been retained for this simulation and analysis work.

The technical method for converting wind energy into electrical energy is referred to as wind energy converters. The combine electrical and mechanical elements, which have been balanced together within control circuits, must be described in order to convert wind energy into useful electrical energy. The electrical functioning of the WECs and its interaction with power grid will be at the forefront of this book's scope.

5.5.1 | Grid Integration Of Wind Energy

Wind energy grid integration is essentially the sum of all efforts connected to linking WPPs to a grid. Based on when the activity take place, they are divided into three categories. The first phase, planning, entails activities that take place prior to the integration of a WPP.

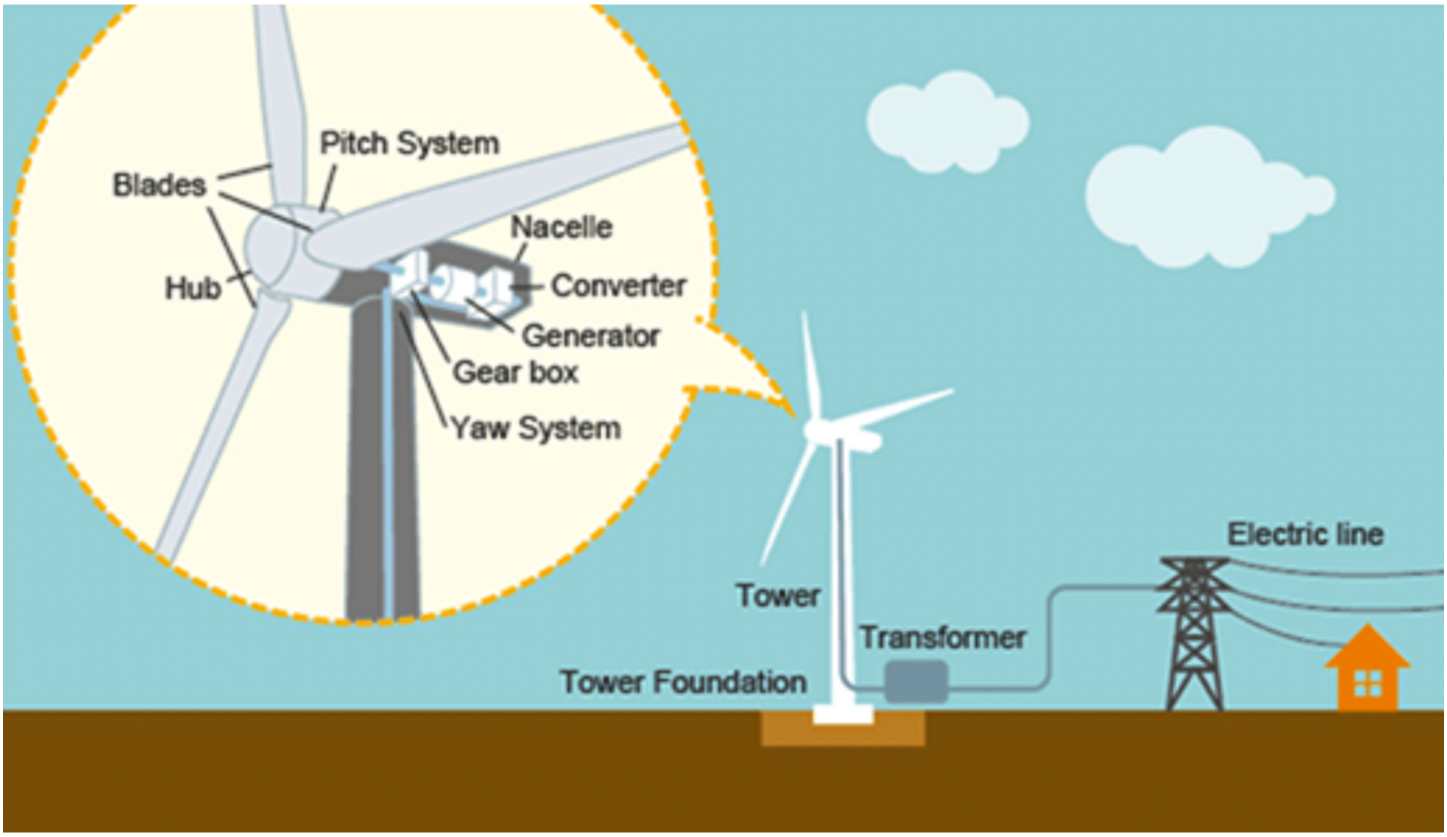


Figure 5.9: Grid integration of WT

The actions that take place during in the actual connection of a wind turbine to the grid are referred to as physical connection. System operations are the actions that take place after the WPP has been linked to the grid.

What makes incorporating wind energy so special?
The properties of wind resources, wind energy regulations, or wind turbine generators are discussed in this section.

- **Variable Power** Because the wind speed varies, the energy production of WPPs varies. Hour-to-hour, day-to-day, month- to-month, and year-to-year fluctuation are all examples of variability. Variability and uncertainty are two distinct ideas that are sometimes confused. The earth's rotation (day–night cycles), tilt axis of the earth (summer and winter), and other natural phenomena all influence wind speed. Higher wind speeds in the early morning and late evening, as well as higher wind speeds in the spring and autumn, are examples of variability. Variation in wind energy output is caused by wind speed and direction from hour to hour, day to day, and month to month. As long as enough fuel is delivered, a conventional base-load power plant can be considered to have low fluctuation; any variation is due to activities planned such as periodic maintenance. Because of sunrise and sunset, solar dominates intraday fluctuation among changeable renewable energy sources. Wind and solar have similar variability when daily variability is removed.

- **Uncertain Power** The uncertainty of wind speed is the source of uncertainty. Starting with the hypothetical situation, the uncertainty is the unpredictability around the changeable pattern of wind speed. Because winds is a weather event, it causes uncertainty on all time scales, including year to year, month to month, day to day, hour to hour, and smaller. Wind energy production is forecasted using a number of forecasting methodologies. (i) I The accuracy of a day-ahead forecast is lower than that of an hour-ahead prediction, which is lower than that of a 15-minute-ahead forecast;
  (ii) As the quantity of turbines in a WPP grows, so does the forecast accuracy.
  (iii) Forecast accuracy improves as the quantity of WPPs grows and the WPPs are distributed across the globe.
  (iv) Wind energy has a higher level of uncertainty than solar energy among renewable energy sources.

- **Geographic Diversity, Size, and Distance from Load** Wind energy plants are built where there is a lot of wind. Areas with abundant wind resources are often located distant from population centres for most parts of the globe. The reason for this is that living in places with consistently high wind speeds is challenging. Such places are either covered by a "weak" grid or are not served by the a central grid. A transmission lines line carrying a little amount of power characterises a weak grid. The necessity to develop new or improve existing transmission lines has implications for wind projects in such places. Long distance transmission lines from the WPP to the load centre may cause voltage fluctuations. Grid Wind Power Integration: Industry Standards for Developing Wind Market 5 that is greater than the grid code's permitted limit. Reactive current compensators on the lines should be used to manage this.

The density of WPPs is the second geographical feature. A wind farm's density is typically 5 to 8 megawatts per square kilometre. A 50 MW WPP, for example, would cover 6–10 square kilometres. A WPP's production is an average of many turbines, so if the grid has numerous WPPs, wind energy grid current is just an average of the WPPs. Aggregation aids in the reduction of wind energy uncertainty and, to a lesser extent, wind energy variability.

Wind Energy Myths Related to Grid Integration	**Reality**
Wind's variability and uncertainty can't be regulated by a grid since it's too disruptive.	Electricity networks are built to handle load unpredictability and uncertainty, as well as the breakdown of one or more producing units, transmission lines, or substations on occasion.
In a matter of seconds, wind power can be completely depleted. Wind farms can trip due to minor grid perturbations, resulting in a cascade of failures and the grid's eventual collapse.	Grid collapse and cascade failure are not caused by WPPs. Wind speed doesn't really immediately decrease, and wind turbines do not all experience a same wind speed. When the generation output of many turbines is combined, the wind generating output appears to diminish smoothly. This is in contrast to solar plants, where output can drop dramatically when clouds approach.
Excessive cycling of thermal plants is caused by ind energy, which increased the price of thermal generating greatly.	According to studies, the rise in the cost of heat generation is negligible.
Excessive cycling of thermal plants is caused by d energy, which increases GHG emission	According to studies, the increase in GHG emissions from thermal plant cycle is negligible
Wind energy does have a high cost in terms in reserve and storage.	Resources always are maintained at the system level, not at the generational or type of generational level.

Table 5.1: Common Myths about Grid Integration of Wind Energy.

5.6 | Smart Grid Control

A key to the implementation of the Smart Grid is to create the intelligent management of the margin between the ever-expanding demand for electricity and its efficient, safe, secure, and sustainable supply at all points along the distribution path.

Electricity is no longer entering the grid exclusively at massive power plants on the transmission beginnings of the grid, but it will also be generated from distributed resources at customer sites throughout the distribution grid, and even from energy storage at consumer sites and substations.

This Smart Grid data and energy management system must be, by definition, adaptive and stochastic, meaning that it is prepared to respond to varying weather conditions, crew status, and equipment performance changes while optimizing supply to meet demand within economic constraints that simultaneously minimize costs for consumers, regulators and industry stockholders.

Some utilities now use complex, computational command and control systems similar to those used in petrochemical and nuclear plant management, such as decision support and portfolio management tools, activity based accounting, and preventive maintenance programs.

However, the computational systems utilized in these controller calculations are generally policy-and-rules-based decision systems. Risk and variance are considered using linear programming algorithms.

These systems are very good at identifying the "next worst" condition that can happen to the electric grid at any given time, but not so good at determining actions to prevent the "next most likely" condition to occur on the electric grid.

Controlling the new complexities of the Smart Grid is a multi-stage, time-variable, stochastic optimization problem to the Operation Research engineer and operator. The Adaptive Stochastic Controller (ASC) for the Smart Grid requires the import of Approximate Dynamic Programming (ADP) and Mixed-Integer, Nonlinear Programming solvers that are more familiar to the petrochemical and transportation industries.

If the electricity industry successfully imports these intelligent controllers, economic benefits will be on the order of savings we have measured after transitions to such autonomous, adaptive controllers in these other industries.

ADP Adaptive Stochastic Control optimizes by solving the Hamilton-Jacobi-Bellman equation using ADP interacting with the electric system model used by engineering to plan improvements in the grid today.

Feedback loops and a critic function are critical to establish cause-and-effect, similar to the ways that models are used in Model Predictive Control (MPC) in other industries.

Optimization Problems	Currently used Techniques	Next Generation Techniques
Unit Commitment / Hydro dispatch	Dynamic Programming (DP)	ADP & its variants
Control Coordination	Decomposition Optimization	ADP, AHP, and EP methods
Machine Controls and Stabilization	Optimal Control	ADP and Evolutionary Programming
Optimal Reconfiguration	Mixed Integer Programming	Dynamic Stochastic Optimal Power Flow (DSOPF) and its variants
Loss Minimization	NLP and Interior Point methods	
Economic dispatch for Large Systems	NLP, DP methods	
Locational Marginal Pricing	LP methods	ADP
Data Mining	State estimation (SE)	ADP and EP methods
Optimal Sensor Placement	IS methods such as ANN	ADP and DA

Table 5.2: List of typical problems and optimization solutions

As a consequence, the control aim of maximising of actual option value is combined with efficient and safe operations. Utilities' current business strategies are likewise based on risk/reward optimization algorithms, however these are often Net Present Value (NPV) calculations used in portfolio management. Such linear techniques will be ineffective in the future Smart Grid, which will be too dynamic and complicated. From consumer to utility to generating, real-time choice optimization and autonomous control will be necessary.

The real-time control of distributed energy storage Until now, pumped hydro has been the primary source of load and source control. Recent demonstration projects, on the other hand, are opening up new ways to demonstrate the usefulness of energy storage in grid stabilisation, operations support, power quality management, and load shifting applications. The following are examples of high-value applications to consider:

- In the event of a loss of generation or transmission, "instantaneous" vs Ramp Rate Limited Generation Based Spinning Reserve as Bridge Power to Standby Generation is preferred.
- End-user Energy Management and Power Quality/Reliability Requirements
- Reserve Power for System Power Reliability, Security, and Quality
- Utility Load Shifting for Supply Infrastructure Asset Optimization and Emergency Response
- Utility Load Shifting for Supply Infrastructure Asset Optimization and Emergency Response

Optimization and Stability ADP Adaptive Stochastic Control for Load and Source Management must make real-time choices based on pricing and market information given to the controller. Among the real-time alternatives are:

- option value of arbitrage
- option value of peak shaving
- option value of greater network reliability
- option value of environmental benefits
- Dynamic Treatment

ADP Adaptive Stochastic Control also optimises maintenance operations using Dynamic Treatment. Machine Learning and statistical failure models established for the medical sector that employ causal inference, propensity and survival analysis have been demonstrated to be useful in determining therapy steps to prevent electric grid breakdowns[3].
Adaptive Stochastic Control's dynamic treatment output is a prioritisation of work that needs to be done and control actions that need to be taken, either discretely or continuously, to keep grid devices like distributed generation and storage, sectionalizing switches, and load pockets within optimal performance bounds.

Transmission Adaptive Stochastic Control Static and dynamic security assessment capabilities, as well as self-checking of relay settings on essential transmission facilities, are all included in the Smart Grid's Adaptive Stochastic Control functions. Advances in state estimators capable of real-time simulations for big networks will need to be included into the overall management of the Smart Grid when phasor measuring devices are deployed to monitor grid performance across heavily laden regional transmission interconnections.

5.7 | Challenges To Achieving A Comprehensive Smart Grid

One of the Smart Grid's main goals is to increase our ability to consume more, but less expensive, electricity to enable improvements in everyone's level of life on the planet. We must make the change as cost-effective as possible, or we will never get there from here. If the endeavour is to be sustainable over the 20 to 30 years necessary for a full conversion to a comprehensive Smart Grid in any country, essential performance indicators that continually and automatically score gains made by the Smart Grid will be required. To document these improvements, an initial baseline for all main components of the current grid must be established, and then the impact of new construction and installation must be measured against that baseline on a constant basis.

The validation of Adaptive Stochastic Controllers for the Smart Grid to shift load around congestion, manage peak demand, weather, and equipment faults will be a benefit of this paper, as it will minimise the need for costly new power plants and substations. Computers controlling these Adaptive Stochastic Controllers, which manage every level of the new Smart Grid on a global scale, might someday eliminate the need to develop terawatts of additional generation. The Smart Grid is projected to increase the capacity factor of the electric system over time by better managing supply and demand.

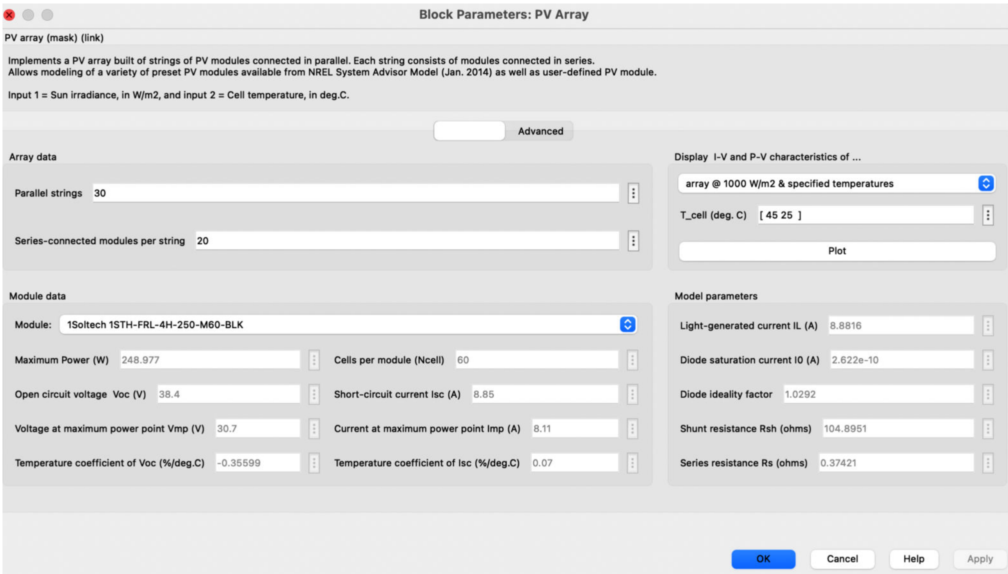
By adding current controller intelligence to the old system, it enables for more effective re-use of existing hardware infrastructure. Understanding the dangers and consumer effect of utilising existing resources to their full potential should enable Smart Grid utilities to minimise peak demand while lowering capital and operating costs by preventing all types of emergencies during peak load periods. It is our industry's common responsibility to maintain global tracking measures to demonstrate that the Smart Grid deployment we are all embarking on achieves the expected advantages. Best practises should be simply and quickly disseminated.

6 | Modeling & Simulations

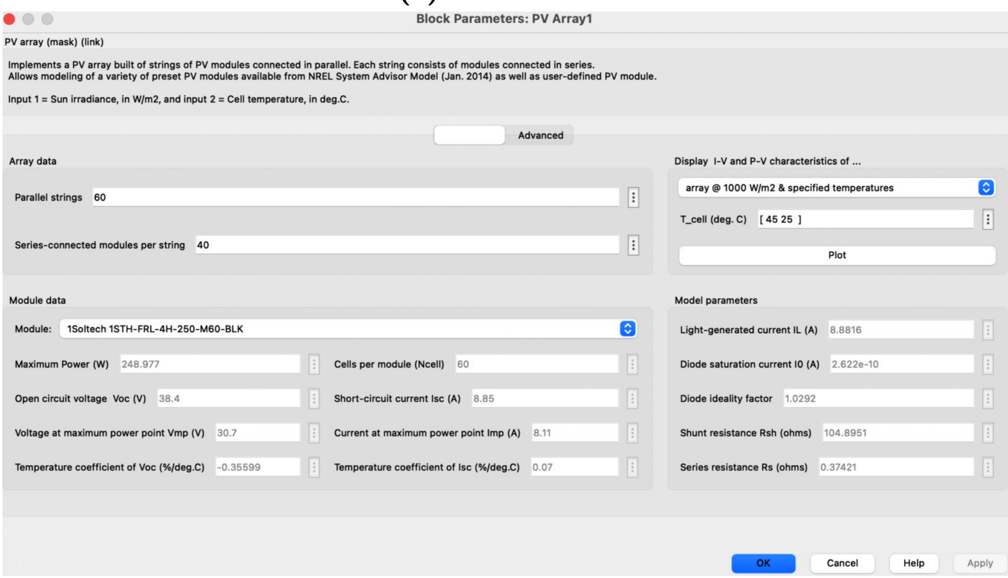
The following simulations were carried out and tested in MATLAB Simulink©, environment to check the feasibility of the created smart grid system. Main objective of the project is to replace conventional controllers with Machine Learning algorithm based controllers for smart grid voltage deviation control. The suggested strategy's promising transient voltage recovery speed and steady-state performance (voltage oscillation) were confirmed by simulation results from MATLAB/ Simulink©, even while under overloaded fault conditions and rapid load shifts.

6.1 | PV Module

PV systems are powered by solar energy, with PV cells serving as the most basic generating component. A diode and a current source were linked antiparallel with a series resistance to make the PV cell.



(a) PV for MG1



(b) PV for MG2

Figure 6.1: PV parameters

6.2 | DC/DC Boost Converter and MPPT

A boost converter is a DC/DC step-up converter that converts solar voltage to a specified output voltage as required by the load. Figure 3 shows the arrangement, which includes a DC input voltage Vin, an inductor L, a switch S, a diode D1, and a filter capacitor C. When the switch S is turned on, the boost inductor stores the energy supplied by the input voltage source, and the charged capacitor maintains the load current throughout this period, ensuring that the load current remains constant. When switch S is turned off, the input voltage and stored inductor voltage emerge across the load, increasing the load voltage. As a result, the load voltage is determined by whether switch S is on or off, and the duty ratio D. The MPPT technology improves the efficiency of solar panels. The MPPT is a device that harvests the greatest amount of power from the solar cell and adjusts the duty ratio of the DC/DC converter to match the load impedance to the source.

The conventional MPPT is replaced with the Machine learning algorithm controller for better transient voltage recovery speed and steady-state performance.

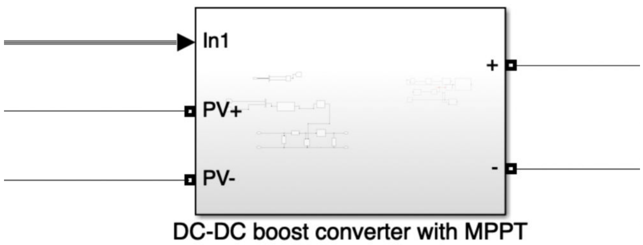


Figure 6.2: DC-DC converter with MPPT

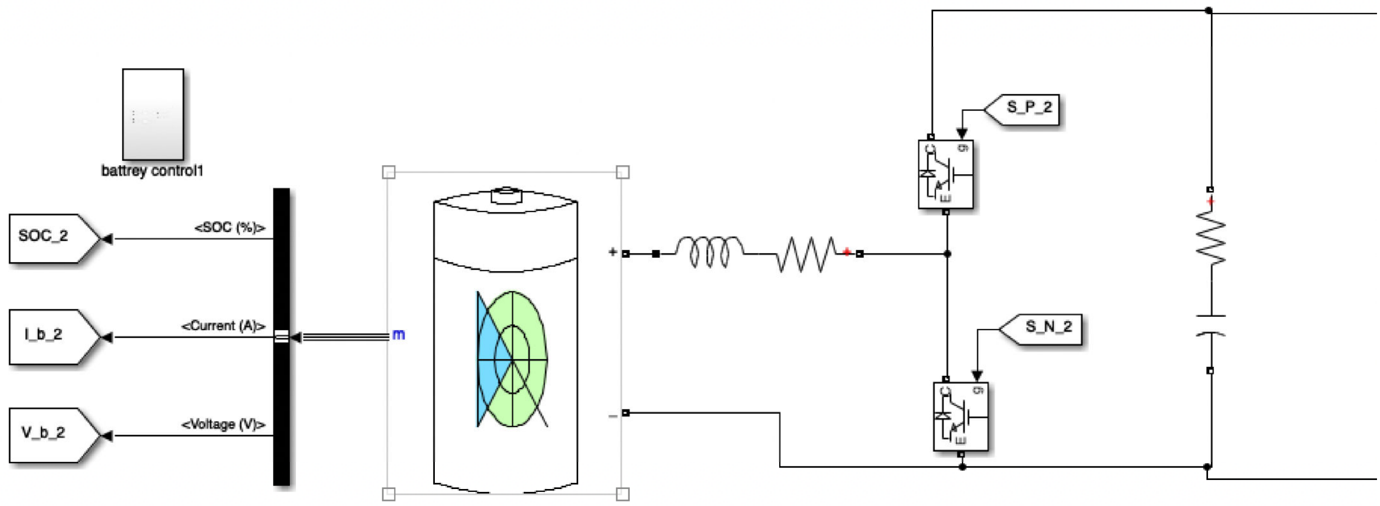


Figure 6.4: Battrey with bi-directional converter

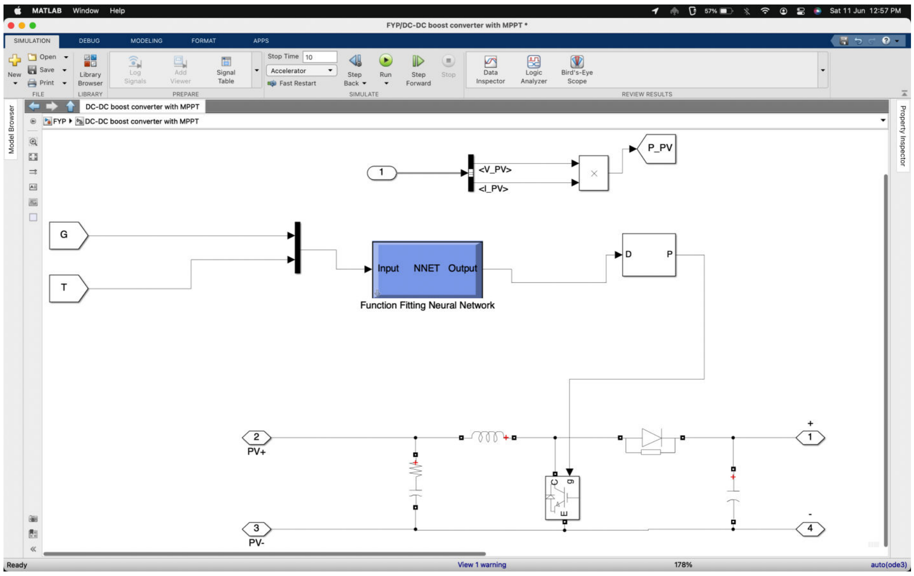


Figure 6.3: ML algorithm based MPPT

6.3 | Battrey System

A bi-directional Buck-Boost DC/DC converter connects the BESS (Battery energy storage system) to the DC grid. Depending on the energy requirements, the BESS will operate in charging, discharging, or floating modes, with these modes being controlled by the DC bus voltage at the BESS point of connection. The battery is critical in ensuring that the load receives uninterrupted power. The battery control system's goal is to manage the battery current so that the needed power may be obtained. The model also includes charging and discharging current restrictions, as well as maximum SOC limits[2].

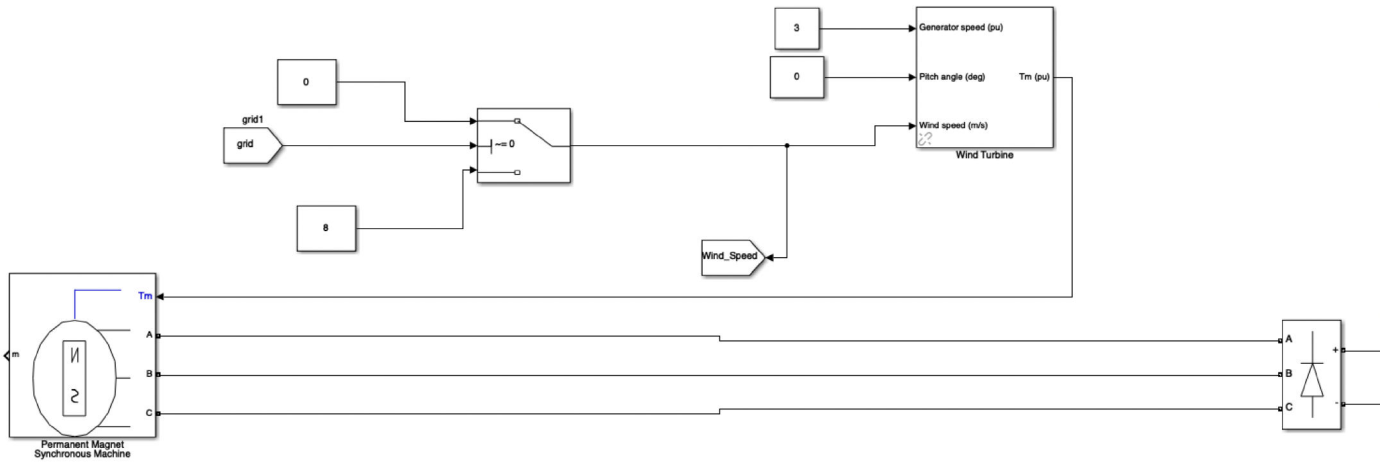


Figure 6.6: Wind turbine with AMF

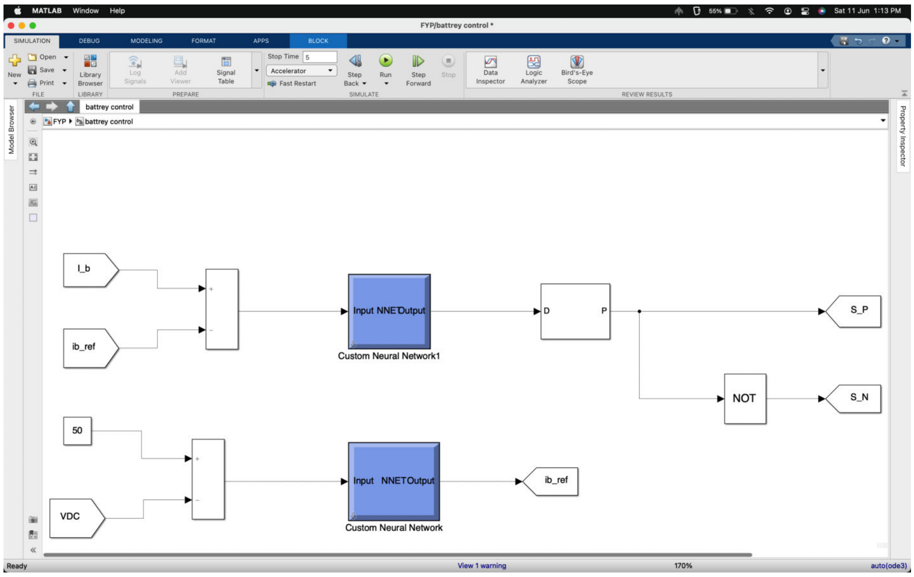


Figure 6.5: ML algorithm based battrey control

6.4 | Wind Turbine

The wind energy system consists of a wing that captures the kinetic energy of the wind, a turbine that generates mechanical power, and a permanent magnet synchronous generator that generates ac power and supplies it to the DC bus via a diode rectifier. This is the structure that will be used in this modelling and simulation.

The technological method for converting wind energy into electrical energy is referred to as wind energy converters. The combined mechanical and electrical components, which are balanced together in control circuits, must be described in order to convert wind energy into useful electrical energy. The electrical functioning of the WECs and their interaction with the power system will be at the forefront of this book's scope.

6.5 | Utility Grid

The Utility grid is connected to the load with an islanding command at T=0.5 which disconnects the load from the grid and the microgrid serves the load independently.

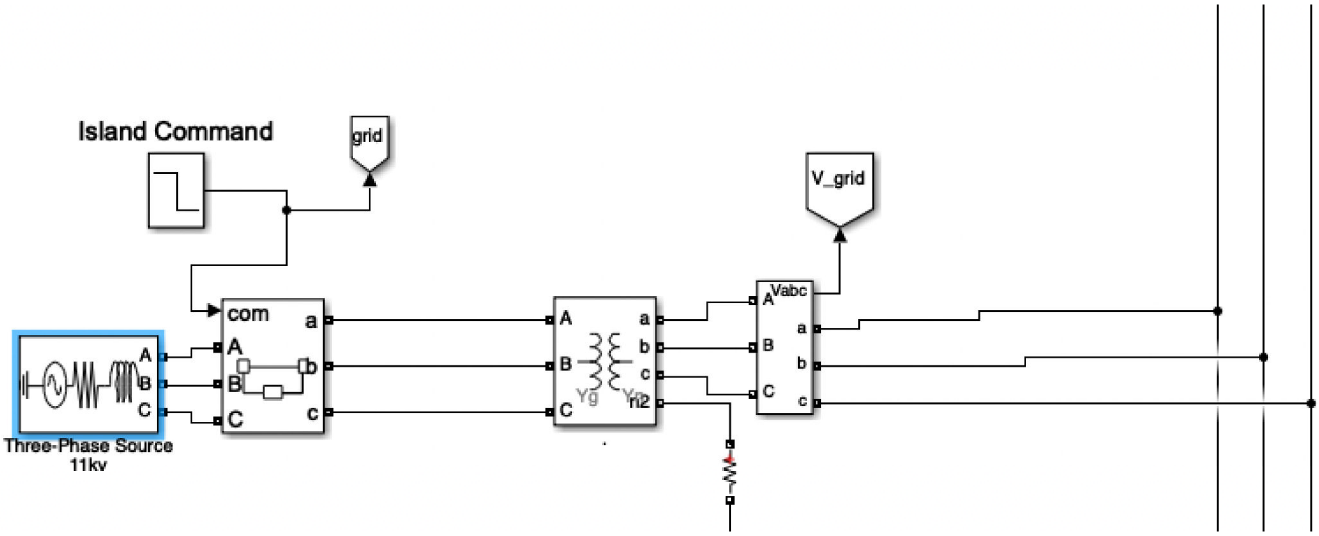
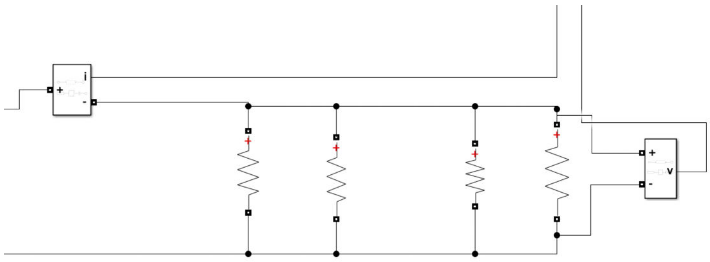


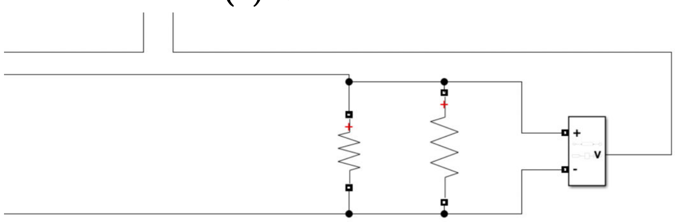
Figure 6.7: Utility Grid

6.6 | Loads

The designed Smart grid provides energy to two different types of load i.e. commercial load and domestic load which is 10kW and 5kW respectively. This load demand is fulfilled by firstly the Utility grid and after T=0.5 the microgrids run independently to serve the load demand by producing energy only from RES DGs.



(a) Commercial Load



(b) Domestic Load

Figure 6.8: Loads

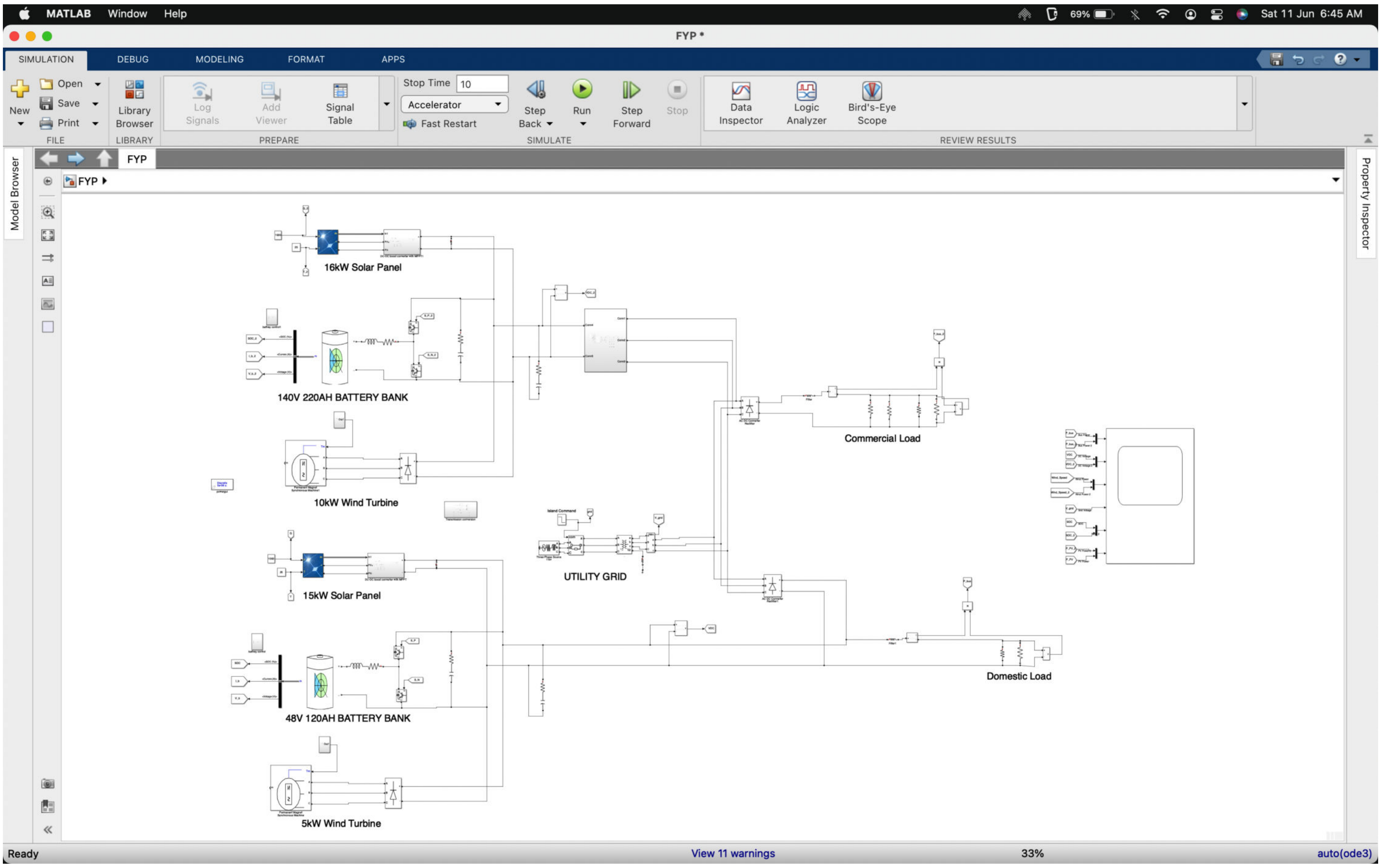


Figure 6.9: Smart Grid Model

7 | Results & Discussion

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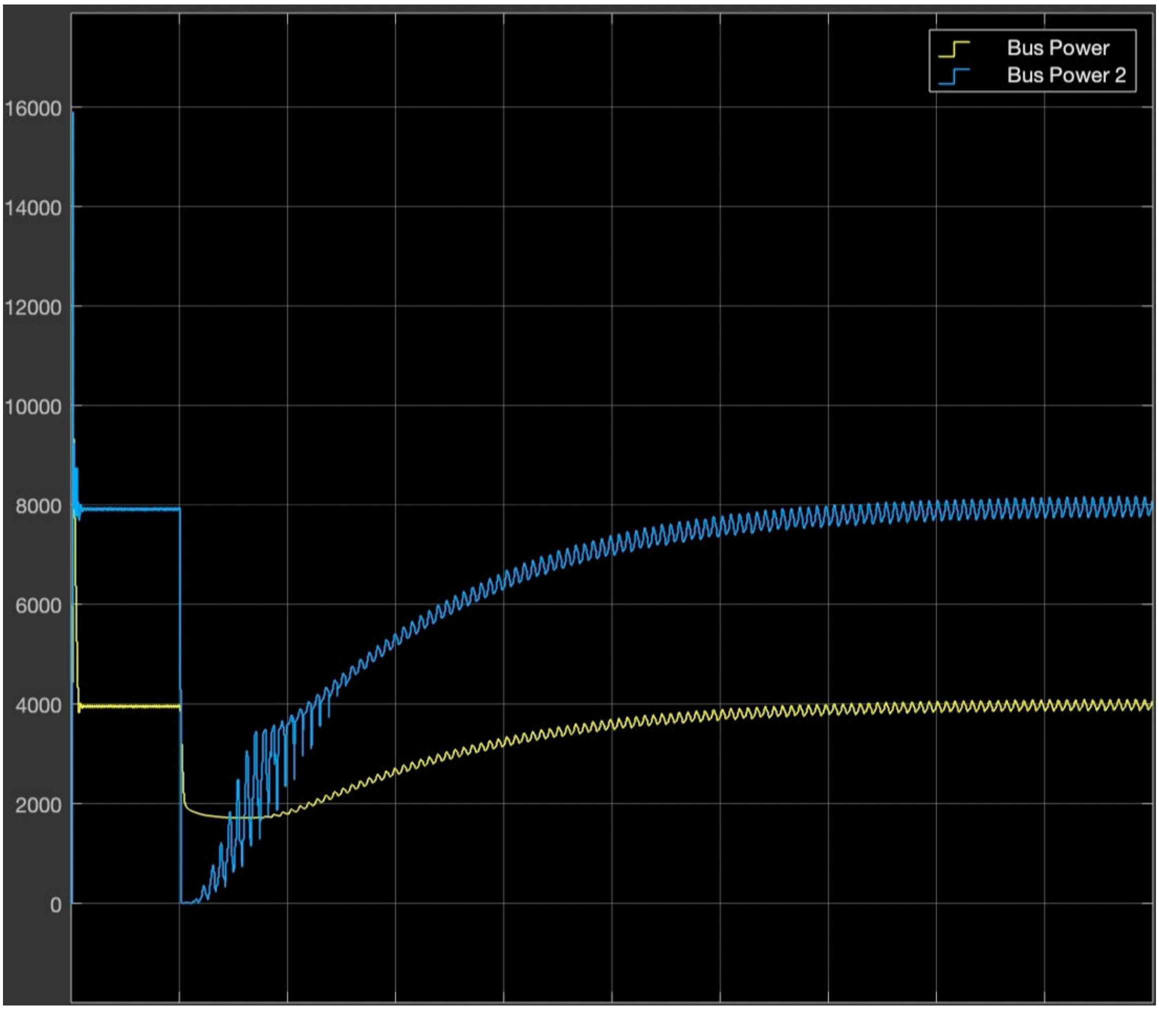
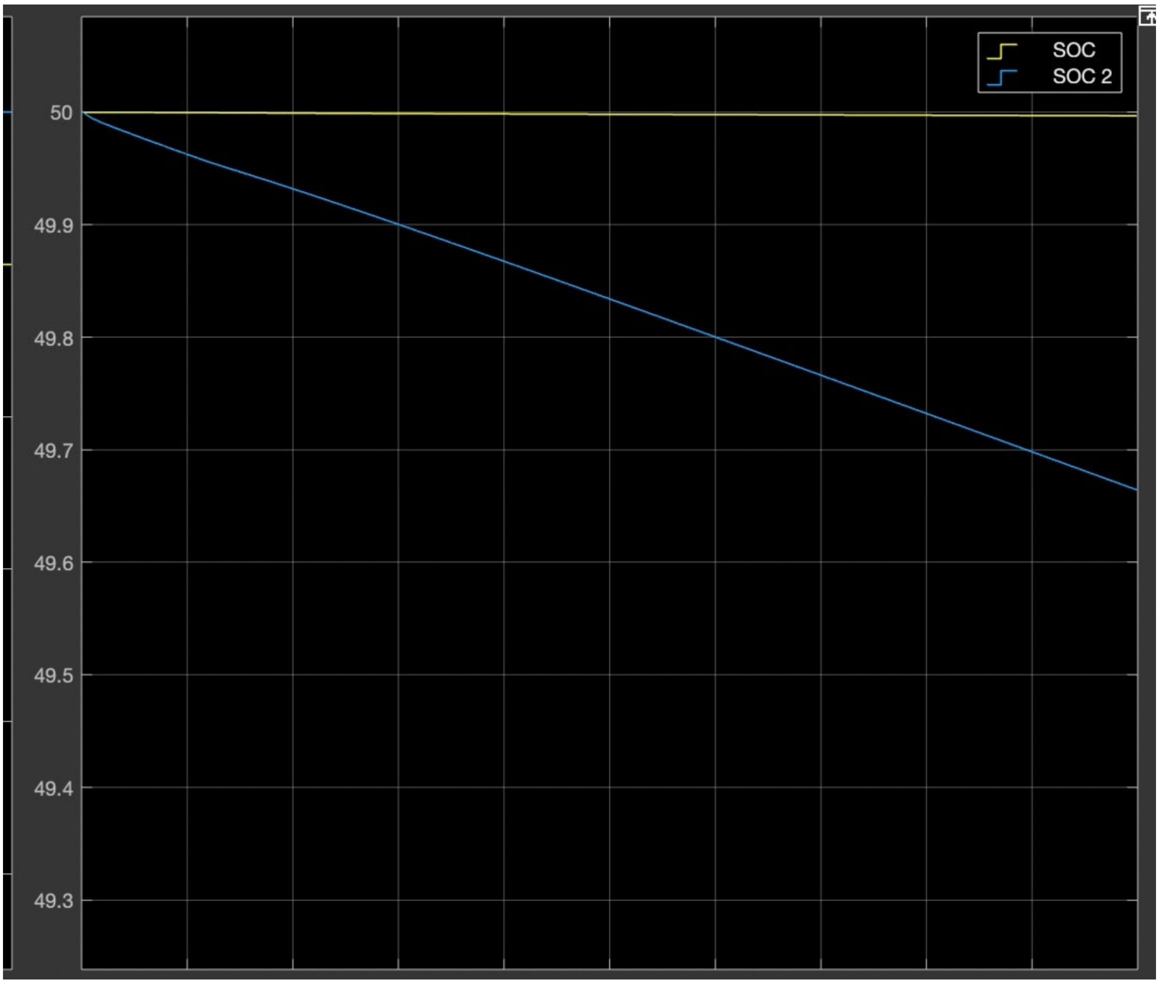
When compared to grid-connected microgrids, isolated DC microgrids must be able to deliver a steady, stable power source. As a result, this research provides a DC microgrid that is extremely responsive to changing irradiances while maximising storage capacity. In addition, an energy management control system (EMCS) is used to improve the microgrid's charging and discharging operations. The planned DC microgrid for electricity of a small town is simulated in the MATLAB/Simulink environment. Despite fluctuations in solar irradiation, the modelling results showed stable DC voltage waveforms under various operating situations. It has been discovered that the PV array, battery, and wind complement each other well enough to keep the DC bus voltage at 220V during transients [5].

Several research projects are now underway in the fields of DC grid control strategies, architecture, various energy management schemes, and energy storage approaches. Many characteristics, such as resilience, dependability, scalability, cost, and system resiliency, are attracted by the structure of every power system. Single-bus, Ring-bus, Multi-bus, Zonal-bus, Ladder-bus, and Multiterminal DC MG architectures are among the microgrid structures available. All of these structures have advantages and disadvantages. More study is needed in this area to alleviate the disadvantages, lower the degree of complexity, and introduce redundancy.

According to the results of the above surveys, a single controller cannot provide all of the following functionalities: voltage regulation and control, current and power control, proper current and power-sharing, PQ control, ancillary services provision, energy market participation, and grid operation. Secondary distributed control with DC bus signalling (DBS) power management might be a future trend in the DC system. With the use of a storage media for power management, the DC grid voltage is balanced between power consumption and generating units. Some challenges with robust control of all modes of operation, including islanded, grid-connected, and transient modes, still exist. Power losses in storage devices, reaction time, SoC levels, and charging methods should all be taken into account by the EMS.The following are the outputs:

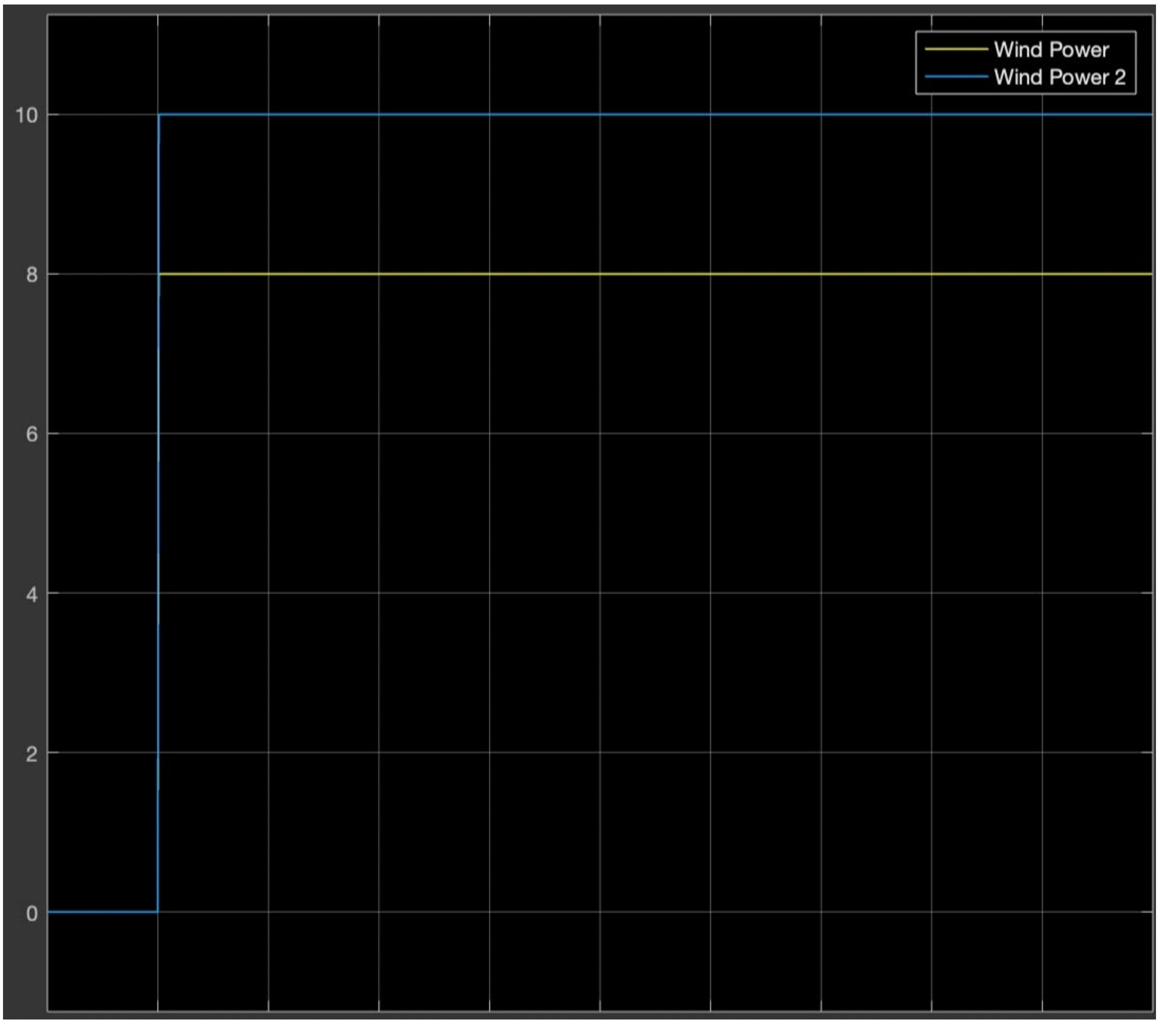


(a) Bus Power

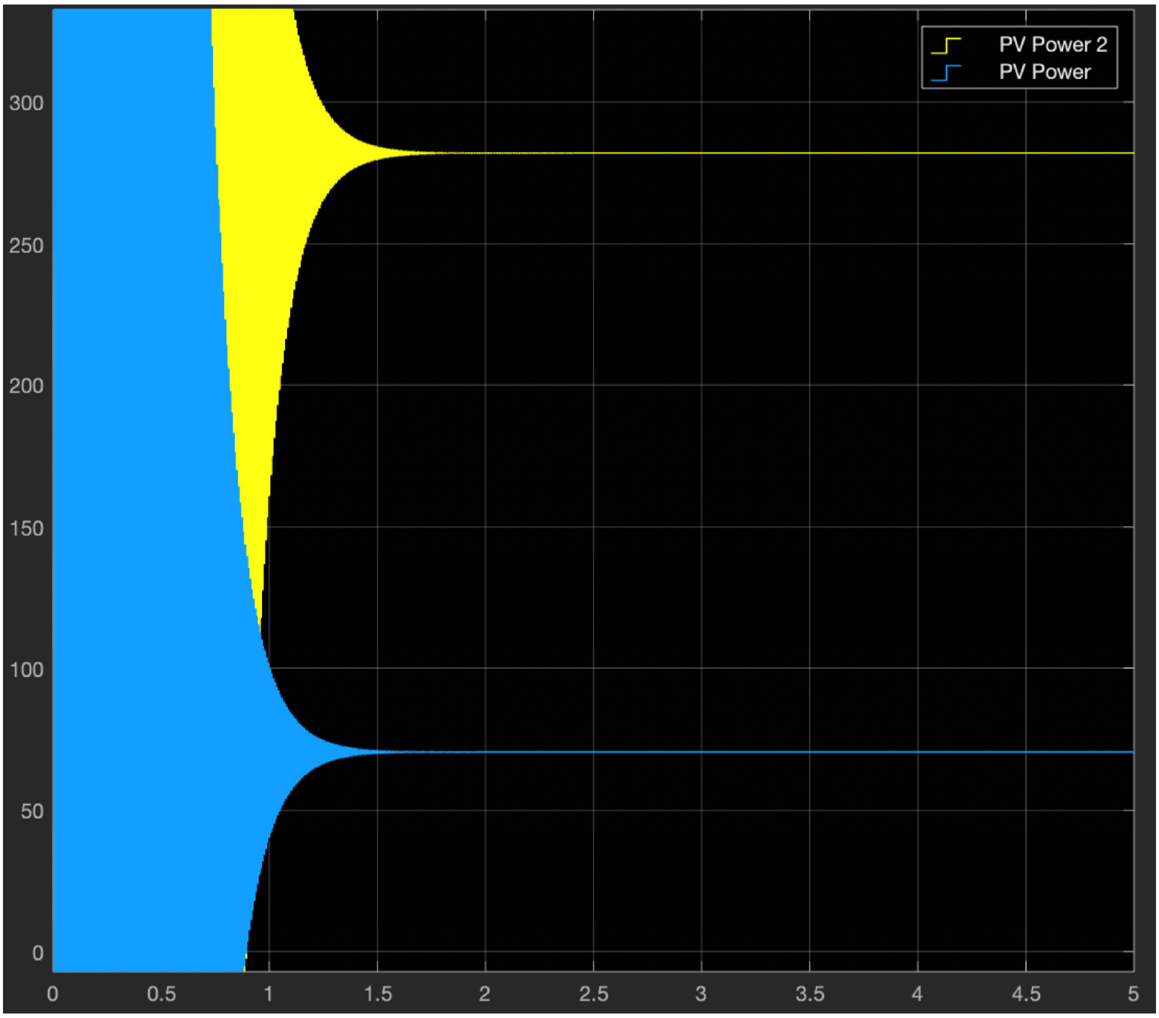


(b) Battrey SOC

Figure 7.1: Results

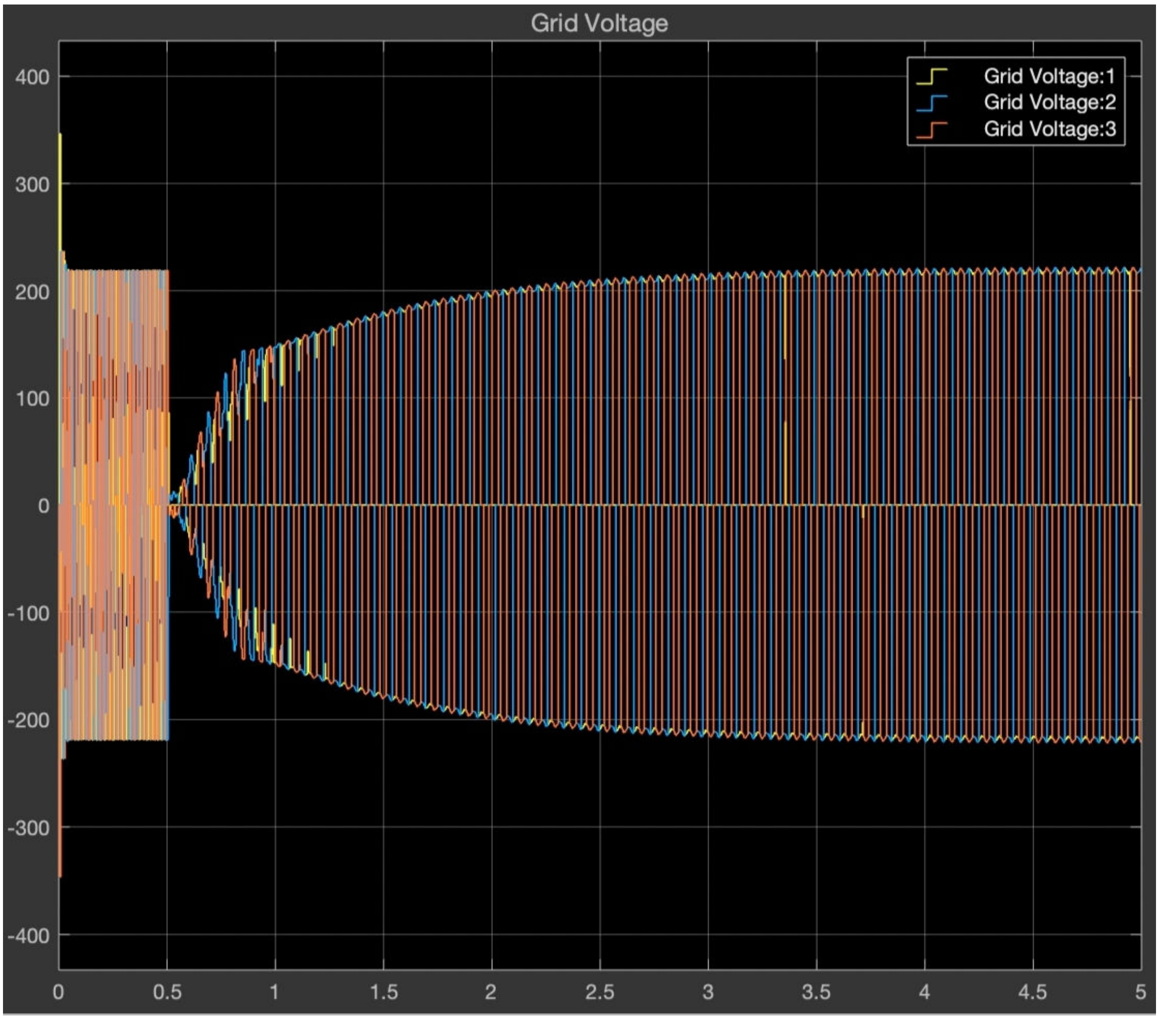


(a) Wind Power

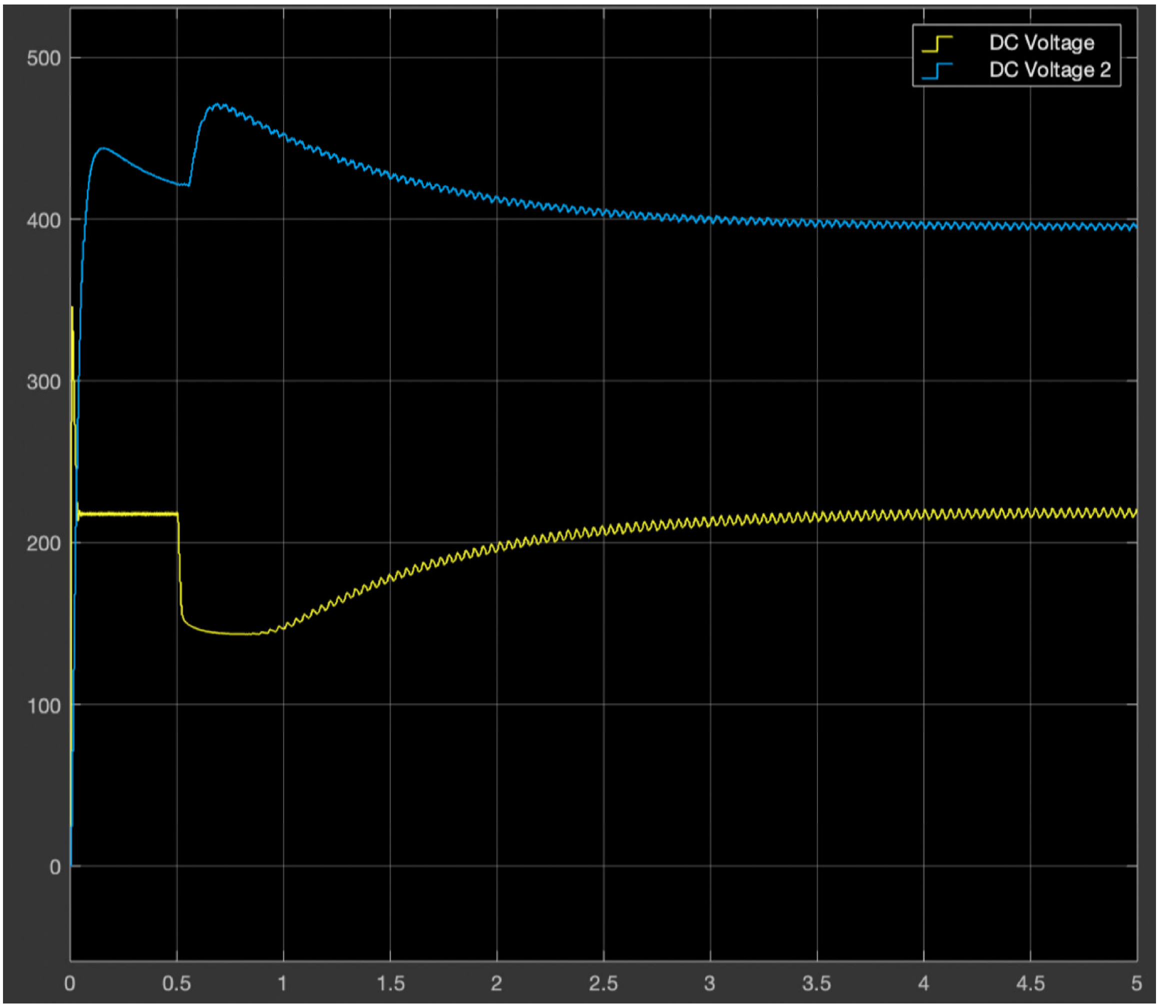


(b) PV Power

Figure 7.2: Results



(a) Grid Voltage



(b) DC voltage

Figure 7.3: Results

8 | Conclusion

PV generation with intrinsically low operating rates should be put dispersedly in the demand area to improve the overall economic efficiency of the electric power system, including power transmission and distribution. We presented the DC micro grid system as a solution for the substantial installation of PV generation and the stabilisation of power flows in commercial networks based on this concept. We used a DC micro grid system with an RF battery to show the system's primary technique of balancing power supply and demand. The technical feasibility of the DC micro grid system was shown in this experiment. We will put this system into practise and increase its economic efficiency in response to social requirements and trends.

Energy management is vital for decreasing overall system size and device power ratings, extending the lifespan of storage units, and feeding key loads. A plug-and-play capability at multiple hierarchy levels is a major primary goal of the future DC grid. A DC MG should allow DG units and power electronic converters to easily disengage and reconnect at the component level. Similarly, at the system level, the MG should easily go from grid-connected to islanded mode. A controller is effective if it maintains stability while coordinating the system and its components.

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