MULTIPLE OPERATING MODE-BASED ELECTRIC VEHICLE CHARGING STATION

MAJOR PROJECT REPORT

OF

MASTER OF TECHNOLOGY
IN

POWER ELECTRONICS AND SYSTEM

Submitted by:

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DECLARATION

I**, KHALED BAHRELDEN SALEH IBRAHIM,** Roll No. 2K20/PES/26 of M. Tech (Power Electronics and System), hereby declare that the Major Project II titled "**MULTIPLE OPERATING MODE-BASED ELECTRIC VEHICLE CHARGING STATION"** I hereby confirm that the document submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi, is an original work and does not contain any content copied from other sources without proper citation. Furthermore, this work has not been used previously to obtain any Degree, Diploma, Associateship, Fellowship, or other similar recognition.

Place: Delhi

Date: 25/04/2023

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CERTIFICATE

This is to certify that the Major Project II titled "**MULTIPLE OPERATING MODE - BASED ELECTRIC VEHICLE CHARGING STATION**" is a bona-fide record of work done by KHALED BAHRELDEN, Roll No. 2K20/PES/26 at Delhi Technological University, New Delhi for the Major Project II. this project was carried out under my supervision and has not been submitted anywhere else, either in part or full, for the award of any other degree or diploma to the best of my knowledge and belief.

Place: Delhi

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ABSTRACT

This work aspires to enhance the continuity of the feeding charging facility of electric vehicles (EVs) by incessant charging stations (CS) for several modes, grid mode, diesel generator (DG) set mode, or off-grid mode. This is accomplished by binding the three modes, grid-connected, Solar PV, battery energy storage system (BESS), and DG set to charging an EV. Originally the design of the CS used the SPV array to let BESS utilized to charge the EV battery. Secondly, employing the grid to charge the storage system of the EV, and if there is unavailable power, the DG set, will provide energy to the CS. The supply of CS from the DG set, or the grid option occurs when it's zero sunlight extracted by SPV and the BESS is exhausted. Even so, at 80-85% the load will be maintained in order to obtain ultimate the efficiency of the fuel in each of the load statuses while the Diesel generator produced energy. In a set of BESS, the performed frequency and voltage is controlled by CS. On the other hand, it emphasizes that the extracted energy either from the DG set or grid is at unity power factor (UPF) even though at non-linearity loads. The achieving of concurrence is done at the point of common coupling voltage, to the DG or grid to realize constant charging. The performance of transferred power of the active or reactive vehicle to home, vehicle to grid (V2G), and vehicle to vehicle is accomplished to raise CS practicability efficiency.

In the based system it used a PI controller, and due to that the steady state is low and the harmonic as well are high. In the proposed design the replacement of the PI controller with the ANFIS controller will be the solution for these problems.

ACKNOWLEDGEMENT

It gives me immense pleasure to turn my sincere thanks and appreciation to my respected guide **Mr. GAURAV KAUSHIK** (EED, Delhi Technological University), for his valuable guidance, help, encouragement, and useful suggestions for this work. Also, I deeply thank all my friends and others who helped me direct or indirect with the completion of this major project II.

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List of Acronyms

DG Set	Diesel Generator Set
BES	Battery Energy Storage
CS	Charging Station
EV	Electric Vehicle
UPF	Unity Power Factor
PCC	Point of Common Coupling
PV	Photo Voltaic
MPPT	Maximum Power Point Tracking
V2V	Vehicle to Vehicle
V2G	Vehicle to Grid
VSC	Voltage Source Converter
RES	Renewable Energy Source
IGPT	Insulated Gate Bipolar Transistor
PID	Proportional Integrated Derivatives
THD	Total Harmonic Distortion

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Recently, electrification of the vehicles (or EVs) is known as the exceedingly effective and functional kind of conveyance with naught output emissions. In the opinion of EVs and their merits, nearly 3.5 million vehicles are fast and widespread in the streets, also it is anticipated to overpass more than 100 million in 2030 [1]. Sizable charging equipment suggests plan challenges for the enormous electrical power. moreover, the practicality of EVs show when the CS is fed by renewable energy resources which are immaculate from greenhouse gases. Anyhow, utilizing classical energy such as fossil fuel resources to generate power, will not eliminate greenhouse gas emissions. Thus, there is a necessity of using renewable resources to generate electrical power which can highly reduce emission and gives ecological benefits. Currently, among various sustainable sources like PV array power, geothermal energy, hydro-energy, wind power, and many more, and by observation of the named generations, solar PV-based generation is highly appropriate to the aim of CS due to its profuse in the environment [2]. In locations like India, it's obtainable roughly all over the year. While hydro and wind power are deemed. These powers are probably more beneficial in coastal areas and hilly.

When EV charging is functional with sustainable energy, however, their combination with the nowadays existing CS increases the problem of a complicated power conversion system, and it leads to a loss of power. Further, any transformation step needs a detached control, that requires being integrated together with the remaining controllers. Therefore, there is imperative to make the incorporation control have various practical and multi manners of working assisting the objective of an integrated control method with cooperation between different sources of energy.

Massive endeavor has been made to emphasize the electricity of CSs relies on pure green energy technology. [3] discuss the role of solar energy to charge EVs by using high- power bi-directional EVs chargers, but the pattern charger is not adaptable for AC charging. [4] discussed the value of renewable energy as a substitutional energy source for CSs. When considered [5] offer amend novel Z-source converter to serve the goal. But the shaped CS is unable to operate in grid-off mode. Therefore, the charger is incapable to provide charging in the islanding condition. [6] proposed a system that amalgamates solar PV and the EV CS, yet the fabricated design of CS not considered power quality snags that appear in the grid system.

The [7] proposed the optimal scheme for the EV charging stations in the work area in multi modes of charging. [8] Suggest the use of solar PV energy installed in commercial areas due to reducing the effect on the grid when designing the CS for achieving high benefits of utilization. [9] examined the life of battery storage while running under solar energy in the residential area-set-up solar PV. CS can energies based on wind power which is more salutary in order to its obtainability has been discussed in [10] - [12].

Currently, EVs work as distributed power resources to allocate varied additional duties, because of the colossal amount of power that is obtainable in the EVs battery. [13] discuss the power from solar PV use in charging stations able to implement vehicle-to-grid power exchange. [14] proposed solar PV energies electric vehicles and residential CS. [15] The framework of the power plan along with the varied control operation for multiple household levels, BESS, and solar PV for all island modes and grid-connected modes. In the proposed papers [16] to [18] the smart role of residential CS is performed as storage for supporting power from EV to home, as well V2G which will be beneficial to the network system.

Furthermore, in many publications, the achievement of CS has illustrated either power grid or off-grid mode. Also, in order to have a certain working mode in the grid system, due to circumstances, the solar PV turns unsteady when the power grid is unavailable even if the sun is appearing. Likewise, in the islanded, SPV energy is chaotic due to its sporadic form is unexpected, and this is the logic behind the objective of battery storage which is fundamental to raising dependability. In [13] discussed grid and islanded modes are aforesaid, while these modes are detached control, intelligently switching among several modes is inapplicable. In the obscurity of auto-magical transformation, the energy extracted by SPV is muddled and thus does not charge continually. Due to conquer this, there is dialect mechanized switching was implemented as a result controller for inescapable switches in different operation modes. Consequently, at night solar PV stoppage from been generate power, and also its discontinuous nature of it, is essential to include BESS in order to preserve the power to supply the CS. Using solar PV and battery storage only, requires a massive storage range, to face the defiance, it demands multiple energy resources such as a combination of utility power and DG set in case of contingency. Only the case that utilizes the DG set is due to the unobtainable solar energy, utility grid, and BES being exhausted. The challenge faced by this procedure is its finite current harmonic distortions [19].

The CS is non-linear, and thus due to interference of the rectifier, buck converter, and filters.

The converter has a great effect on the operation of the DG set and the DC-DC converter (Step-down) acts as non-linear due to that causing harmonic current. Moreover, harmonics' current requirements, for the working of DG set in this paper are commonly when loaded not lesser than 80%.

Generally, CS is planned to work without any cut-off by being supplied from solar PV, BESS, DG set, and grid power. This assists jointly with AC / DC Electric Vehicle charging. The combined domination guarantees fluidly functioning in both off-grid mode and power grid. It also increases the performance and efficiency of power transfer through vehicles and vehicles to the grid system. The ANFIS controller has been replaced in VSC, this outcome is a quick response and less THD.

The implemented CS scheme shown in figure (1), uses a DG set, a power grid, BESS, and Solar PV. The system in addition to charging the electric vehicle is also connected to energies local demand. The power from BESS and solar power, are in form of DC, and for the AC are DG set, a single-phase grid. Therefore, the power link to AC is concurrent at PCC and modified into DC form by the intermediary of a bi-directional converter and vice versa. PCC main duty is to terminate the harmonics produced by the grid and currents gained by the diesel generator, in order to turn them into sinusoidal. The AC or DC loads are directly supplied by their respective source. the DC-DC converter, which is the EV2 charger, takes its power from the general DC power source.

CHAPTER TWO

SYSTEM DESCRIPTION

2.1 Diesel Generator Set

Diesel engines are commonly employed in electric-power generator sets, which are widely used for backup power supply in various applications, such as industrial facilities, commercial buildings, and homes.

The Features of Diesel Generator in Terms of:

1. Working Principle:

   Diesel generators work based on the principle of internal combustion engines, where diesel fuel is burned in the engine to generate mechanical energy. Then it transformed to electricity power.

2. Power Output Range:

   Different sizes and power output ranges, from small portable generators with a few kilowatts (kW) of power capacity to large industrial generators with megawatts (MW) of power capacity.

3. Fuel Consumption:

   Diesel generators are known for their fuel efficiency compared to other types of generators. The fuel consumption of a diesel generator depends on its size, load capacity, and operating conditions, but typically ranges from 0.25 to 0.6 liters of diesel per kilowatt-hour (kWh) of electricity generated.

4. Maintenance:

   Regular maintenance is essential for diesel generators to ensure optimal performance and longevity. This includes routine checks, servicing of engine components, fuel system, electrical system, and emission control devices, as well as periodic oil and filter changes.

5. Emission Control:

   Emission control technologies, such as exhaust after treatment systems, are used to reduce these emissions and comply with emission regulations.

6. Cost:

   The cost of a diesel generator depends on its size, power output, brand, features, and additional accessories. Diesel generators can have higher upfront costs compared to other types of generators, but their durability and reliability can offset the initial investment over the long term.

7. Safety:

   Diesel generators require proper installation, ventilation, and operation to ensure safety. They produce exhaust gases, generate heat, and involve electrical components, which need to be managed carefully to prevent any hazards.

8. Noise:

   Diesel generators can produce noise during operation, and the noise level depends on the size, design, and make of the generator. Some generators come with noise reduction features, such as soundproof enclosures or mufflers, to minimize noise pollution.

Diesel generators play a crucial role in India's electrical network, providing reliable backup power supply in various sectors. They have their benefits, including reliability, flexibility, and availability of fuel, but also face challenges related to emissions, fuel cost, and maintenance. Proper usage, adherence to emission regulations, and regular maintenance are important for responsible and efficient use of diesel generators in India's electrical network.

They provide a reliable source of power during power outages or load shedding, ensuring uninterrupted operations in industries, commercial establishments, and critical facilities. Diesel generators also serve as a primary source of electricity in remote areas where grid connectivity is limited or non-existent, enabling basic services such as lighting, healthcare, and education. diesel generators in India have varying technical specifications, including capacity, fuel consumption, efficiency, emission control, maintenance requirements, cost, and advancements in technology.

The regulations related to diesel generators in India:

1. Installed Capacity:

   As of 2021, the total installed capacity of diesel generators in India was estimated to be around 90,000 Megawatts (MW), accounting for a significant portion of the country's power generation capacity.

2. Emission Standards:

   The Central Pollution Control Board (CPCB) in India has implemented stringent emission standards for diesel generators to curb air pollution. As of April 2021, the emission limits for diesel generators in India are set at 250 mg/Nm3 for nitrogen oxides (NOx) and 100 mg/Nm3 for particulate matter (PM) for diesel generators with a capacity of 800 kilovolt-ampere (kVA) and above.

3. Noise Regulations:

   in India has also set noise regulations for diesel generators to control noise pollution. For diesel generators in residential areas during daytime are 55 decibels (dB) and 45 dB during nighttime.

4. Subsidies and Incentives:

   The Indian government provides various subsidies and incentives to promote the use of diesel generators that comply with emission norms and are equipped with advanced emission control technologies. These incentives include subsidies on the purchase of diesel generators, tax benefits, and other financial incentives to encourage the adoption of cleaner and more efficient diesel generators.

5. Import and Export:

   India is one of the major importers of diesel generators, with several domestic and international manufacturers catering to the demand. However, there has been a growing emphasis on domestic manufacturing and 'Make in India' initiatives to promote local manufacturing of diesel generators and reduce dependence on imports.

Furthermore, diesel generators are commonly chosen for their reliability and durability in demanding environments. They are often used in remote locations or in situations where a stable power supply is critical, such as in hospitals, data centers, and industrial facilities. In recent years, advancements in technology have led to the development of more sophisticated diesel generator systems that incorporate features such as electronic controls, automatic transfer switches, and remote monitoring capabilities.

These enhancements have made diesel generators even more efficient, reliable, and user-friendly. However, selecting the appropriate size and configuration of a diesel generator can be challenging due to the complex requirements of modern power systems. Factors such as load demands, runtime requirements, fuel availability, and environmental considerations must all be taken into account during the sizing process to ensure optimal performance and cost-effectiveness.

Despite the availability of alternative power sources such as renewable energy systems, diesel generators continue to play a crucial role in many industries and applications. Their versatility, reliability, and efficiency make them a preferred choice for a wide range of power generation needs, especially in areas without a reliable power grid connection or during emergencies when backup power is essential.

2.2. Solar Power Generation

Solar energy is generated when sunlight hits photovoltaic solar panels.

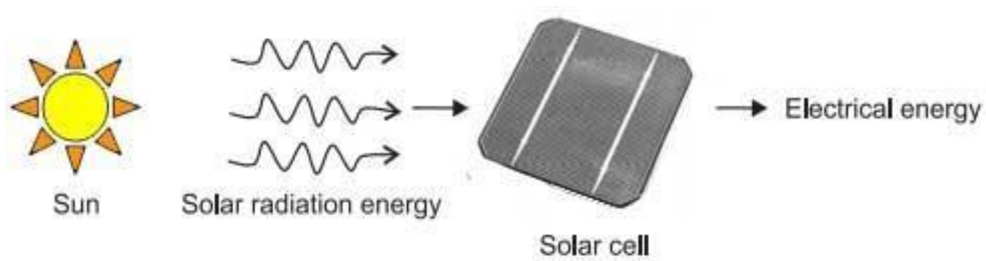

Fig 2.1: Power Generation from PV

2.2.1 The Fundamentals of Solar Energy

Solar energy can be harnessed for power generation through the utilization of the photovoltaic effect in specific materials. When these materials are exposed to intense sunlight, they exhibit the phenomenon of generating an electric charge. This phenomenon occurs when two layers of are combined, where one layer undergoes electron depletion. Upon exposure to sunlight, photons from the sun's rays are captured by this layer, resulting in the energization and movement of electrons.

The solar cell, which is a component of this semiconductor material mixture, is responsible for generating an electric potential difference in the presence of sunlight. Typically, silicon is used as the semiconductor material in the fabrication of solar cells, as it possesses the necessary properties for efficient solar energy conversion. Silicon is commonly employed in the construction of solar cells due to its favorable characteristics for photovoltaic applications. The use of silicon as a semiconductor material allows for the efficient absorption of sunlight and the generation of electrical energy through the photovoltaic effect.

Solar cells made from silicon are widely used in solar panels, which are commonly used for harnessing solar energy in various applications, such as residential and commercial power generation, remote area electrification, and powering electronic devices. Solar cells based on silicon technology have been extensively researched and developed, resulting in highly efficient and durable solar panels. Silicon solar cells can be fabricated using different types of silicon, including monocrystalline, polycrystalline, and amorphous silicon, each with its unique advantages and disadvantages.

Monocrystalline silicon solar cells, for example, are known for their high efficiency and uniform appearance, while polycrystalline silicon solar cells are more cost-effective due to their simpler fabrication process.

In addition to silicon, there are also other semiconductor materials being explored for solar cell applications, such as thin-film materials like cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and perovskite materials. These materials offer the potential for higher efficiency and lower production costs compared to silicon, but they are still in the early stages of development and commercialization.

The substance is thinly sliced into wafers. Impurities have been inserted into some of these chips. After that, the un-doped and doped crystals are joined together to form a solar cell. To collect the generated current, a metallic strip is connected to the two terminal points of the solar cell. The conductive metal strips are used to transport the electric current from the cells. However, a single solar cell or photovoltaic cell is incapable of generating the desired amount of electricity on its own, as it produces only a minute amount of electric current. Therefore, multiple cells are interconnected in parallel and series configurations to create a solar module or photovoltaic module. This arrangement allows for the generation of the desired amount of energy.

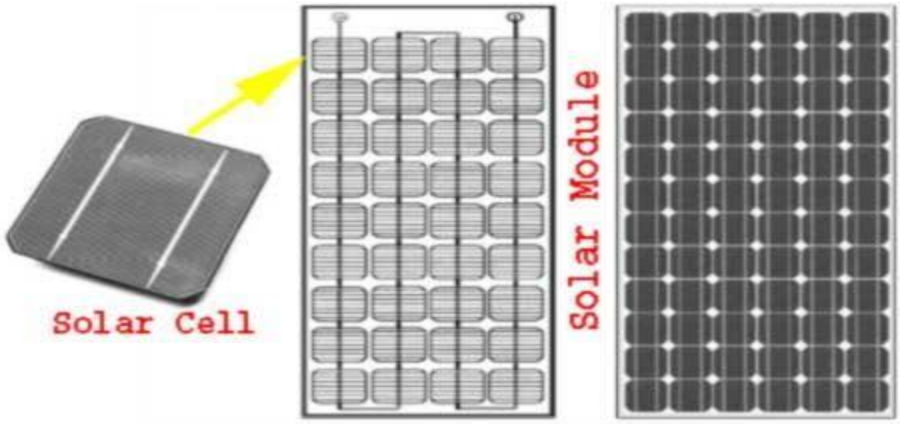

Fig 2.2: Solar Cell

2.3 The System Elements of Solar PV

2.3.1 Solar Panels

A solar panel is an interconnected, which are semiconductor devices that utilize the photovoltaic effect to convert sunlight directly into electrical energy. These cells are arranged in a grid-like pattern on the surface of the solar panel, allowing them to collectively generate electricity when exposed to sunlight. Solar panels come in various sizes, shapes, and configurations to suit different applications, ranging from small residential installations to large-scale commercial and utility-scale projects. They are typically mounted on rooftops, ground-mounted structures, or integrated into building facades.

The efficiency of solar panels, or their ability to convert sunlight into electricity, has improved significantly over the years, with modern solar panels achieving efficiencies of over 20%. Higher efficiency panels are capable of generating more electricity per square meter of surface area, making them more desirable for installations with limited space. Solar panels are designed to possessing resilience and weather resistance, solar panels are designed to endure diverse climatic conditions, including precipitation such as rain, snow, hail, and extreme temperatures. They are typically covered with a protective glass or plastic layer to prevent damage from environmental factors. Proper installation, maintenance, and cleaning are important for ensuring the longevity and optimal performance of solar panels. Solar panels are connected in series or parallel configurations to form solar arrays, which are used to generate electricity for various applications. Solar panels are considered a clean and renewable source of energy, as they do not produce any harmful emissions during operation and do not deplete

natural resources.
They have a relatively long lifespan, typically ranging from 25 to 30 years or more, and can provide a reliable and sustainable source of electricity for homes, businesses, and communities. Solar panels are also commonly used in remote areas where access to electricity is limited or unreliable, providing an independent and environmentally friendly source of power.

Overall, solar panels are a promising technology that can play a significant role in addressing energy challenges, reducing greenhouse gas emissions, and promoting sustainable development. With ongoing advancements in solar panel technology and increasing affordability, solar panels are becoming an increasingly popular and viable option for generating clean, renewable electricity.

The potential difference, or voltage, generated across a single solar cell is typically around 0.5 volts. In order to charge a standard 12-volt battery, a series connection of solar cells is required to achieve a total voltage of 14 to 18 volts. This series connection allows the individual voltages of each solar cell to add up, reaching the desired level for battery charging. A solar array, which is a collection of interconnected solar cells, is designed to generate higher current and voltage levels for practical applications.

To achieve this, solar cells are linked together in both parallel and series configurations. In parallel connections, multiple solar cells are connected side by side, allowing the current generated by each cell to flow independently. It's worth noting that the optimal configuration of solar cells in a solar array may vary depending on factors such as the size and efficiency of the solar cells, the desired output voltage and current, and the environmental conditions at the installation site. Proper design and installation of the solar array, taking into consideration these factors, is crucial for ensuring optimal performance and maximum power generation from the solar panels.

2.3.2 Batteries

Solar panel batteries are designed to store the surplus electricity generated by solar panels during periods of high production, so that it can be used during times when the panels are not generating electricity, such as at night or on overcast days. These batteries are rechargeable energy storage devices that help ensure a consistent and reliable supply of electricity from solar energy.
These batteries are typically installed in conjunction with solar panel systems and can be connected to the solar panels through a charge controller, which regulates the charging and discharging of the batteries.

The connection of a solar panel battery with a solar photovoltaic (PV) system typically involves the use of a charge controller. The charge controller monitors the state of charge of the battery and adjusts the charging rate accordingly to prevent overcharging, which can reduce the lifespan of the battery.

Once the battery is fully charged, the charge controller can also prevent any further charging from the solar panels to avoid overloading the battery. The charge controller manages the discharge of the battery, providing a steady supply of stored energy to power electrical devices or feed into the electrical system of the building.

The connection of the solar panel battery to the solar PV system typically involves proper wiring and connectors. These components should be installed according to industry standards and guidelines to ensure efficient and safe transfer of electricity between the solar panels, charge controller, and battery.

Lead-acid batteries are relatively inexpensive but have a shorter lifespan and lower energy density compared to lithium-ion batteries, which are more expensive but offer higher energy density, longer lifespan, and faster charging and discharging capabilities. Flow batteries are another type of battery used in solar panel systems, offering long cycle life, high energy capacity, and scalability, but they are currently less common due to their higher cost and complexity.

The inverter controls the output power and frequency. The electricity from the solar system is always maintained at the same amount as the power from the grid. The connection to the grid can help maintain a consistent voltage level and power quality in the system. Grid power is typically stable and regulated, providing a reliable source of electricity even during periods of low solar production. This ensures that the electrical devices supplied by the system receive a consistent and stable power supply, minimizing the risk of fluctuations that could impact their operation.

While a solar panel system connected to an external grid power delivery system can provide consistent voltage levels and power quality, it's important to ensure proper system design, sizing, and maintenance to minimize any potential impact on the operation of electrical devices, especially in stand-alone or grid fallback systems that are not connected to the grid.

Variation in energy quality caused by variations in sunlight strength can thus be prevented in a solar power system, while kept a continuous demand. Deep cycle lead acid batteries mainly are used for this reason. solar panel batteries are designed to endure multiple charging and discharging cycles and are available in different voltage configurations. They can be connected in series or parallel to increase the overall voltage and current capacity of the battery system, providing flexibility in designing efficient and effective solar power systems with adequate energy storage capacity. Ensuring proper battery configuration and maintenance is crucial for optimal performance and longevity of the battery system.

2.3.3 Charge Controller

A charge controller is a device that regulates the charging process of the solar panel batteries. It prevents overcharging or over-discharging of the batteries, which can lead to reduced battery lifespan or even damage.

There are several important functions of a charge controller:

1. Overcharge protection:

   Charge controllers prevent overcharging of the batteries, which can cause damage to the batteries and reduce their lifespan. They monitor the voltage of the batteries and regulate the charging process to prevent the batteries from being overcharged, ensuring that they are charged to their optimal capacity.

2. Over-discharge protection:

   Charge controllers also prevent over-discharging of the batteries, which can lead to deep discharge and damage the batteries. They monitor the voltage of the batteries and disconnect the load from the batteries when the voltage drops to a certain threshold, protecting the batteries from over-discharge.

3. Load control:

   Some charge controllers also have load control features, allowing them to manage the power output to the load or electrical appliances connected to the system. They may have timers, voltage regulators, or other settings to control the power output based on the needs of the system or user preferences.

4. Monitoring and diagnostics:

   Charge controllers may have built-in monitoring and diagnostics features that provide information about the charging status, battery health, and system performance. This allows users to monitor the performance of the solar power system and diagnose any potential issues.

Charge controllers come in different types and sizes are generally less expensive and suitable for smaller systems with lower power requirements, while MPPT charge controllers are more efficient and recommended for larger systems with higher power requirements. The charge controller relies on factors such as size, of the solar power system, battery capacity, load requirements, and budget

2.3.4 Inverter

Solar power systems often include inverters, which are responsible for converting the DC electricity from solar panels into high-quality AC electricity that is compatible with household appliances and devices. This ensures that solar energy is effectively utilized to power various electrical loads, thereby maximizing the performance of the solar power system.

Inverters provide sophisticated grid synchronization capabilities. This means that the AC electricity generated from the solar panels and batteries is seamlessly integrated with the electrical grid system, allowing homeowners to take advantage of net metering and other grid-tied incentive.

May have different kinds, but her the grid-tied inverters. They are utilizing in PV power and they are integrated to the power grid. The surplus power generated by the solar PV can returned into the grid, resulting in net metering or credit on the electricity bill. Off-grid inverters, on the other hand, are used in standalone solar power systems that are not connected to the grid. They are responsible for providing AC electricity directly from the batteries to power electrical appliances and devices in off-grid locations. Hybrid inverters are capable of both grid-tied and off-grid operation, offering flexibility in using solar power with or without grid connection.

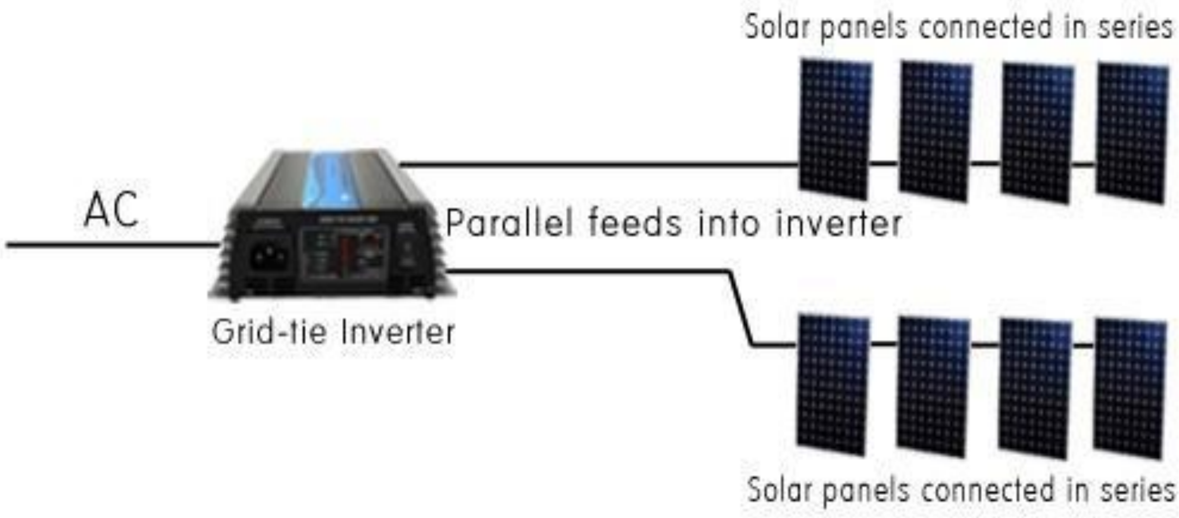

Fig.2.3.1 Connection in series

Each solar module in an upgraded grid tie device is linked to the grid via an single micro-inverter to obtain peak-voltage alternating electricity from each solar screen.

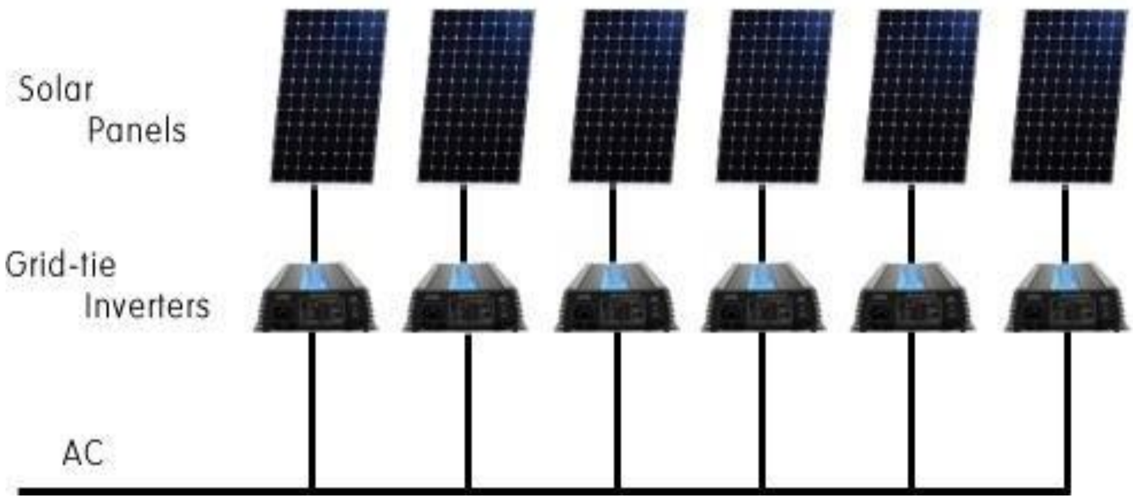

Fig 2.3.2: Inverter Connection in parallel

2.4 Battery Energy Storage Systems

It is a cutting-edge technological solution that enables energy to be stored in a variety of methods for later use. include energy economy, cost savings, and sustainability through reduced usage. Given the chance of fluctuations in an energy source due to weather, blackouts, or geopolitical causes, battery systems are critical for utilities, companies, and residences to maintain a continuous power flow.

Energy storage devices are no longer an afterthought or an afterthought. They are especially successful when coupled with solar energy, because solar energy is free. Energy storage reduces the intermittent character of renewable energy and ensures a consistent flow of electricity. The batteries in a solar energy storage device fill during the day and then discharge electricity when the sun is not shining.

They can also balance micro-grids to ensure that production and demand are in sync. The batteries used in these systems are usually lithium-ion batteries, although other types of batteries such as flow batteries, lead-acid batteries, and solid-state batteries are also being explored for energy storage applications. One of the key advantages of battery storage systems is their ability to provide frequency regulation, which helps to maintain a stable power supply.

Frequency regulation refers to the ability of the system to respond quickly to changes in electricity demand or supply, helping to balance the frequency of the alternating current (AC) power grid. This is crucial for grid stability, as maintaining the right frequency is essential for ensuring that electrical appliances and devices function properly.

The battery storage systems are a promising and rapidly growing technology that has the potential to revolutionize the electric power industry. They offer frequency regulation, reliable power supply, integration of renewable energy sources, and environmental benefits. However, there are still challenges to overcome, such as limited energy storage capacity and environmental considerations, as battery storage systems continue to evolve and become more widespread.

2.5 Stand Alone or Off Grid Solar Station

A standalone solar station, or off-grid solar power station, is a self-sustained solar energy system that operates independently from the traditional electricity grid. It typically contains of solar panels, a BESS, electronic devices, and control systems that work together to generate, store, and manage electricity for local use without relying on external power sources.

The electricity produced is then directed to a battery storage system. Power electronics, including inverters and charge controllers, play a crucial role in a standalone solar station. Inverters transformed the DC power produced by the PV and kept in the batteries to AC electricity, which is the standard form of electricity used in most homes and businesses.

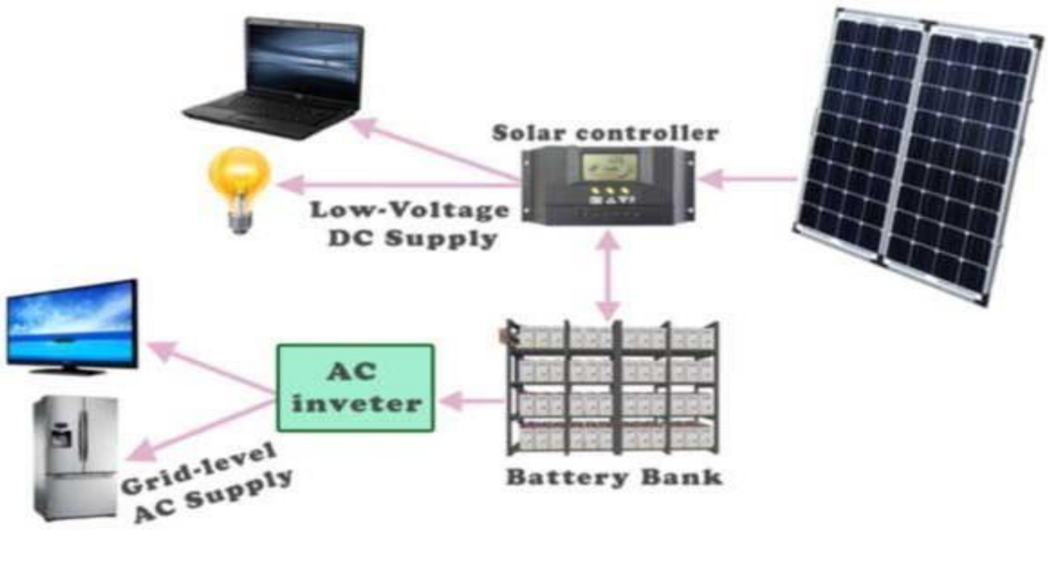

Fig 2.5: Stand-Alone or Off Grid Solar Power Station

The basic structure is illustrated in the provided diagram. It begins with the solar panel generating electrical power, which is then directed to the solar controller.

One of advantages of a standalone solar station is its ability to provide electricity in remote locations where unavailable. This makes it an ideal solution for powering remote homes, cabins, farms, or other off-grid applications. Standalone solar stations can also be used as a backup power source during power outages, providing electricity for critical loads, such as lighting, refrigeration, and communication devices

2.6 Components of Grid Tie Solar System

There are many kinds of grid-tied solar systems, and for this system used a shared central converter called a grid tie inverter in the first sort of solar system, as shown below.

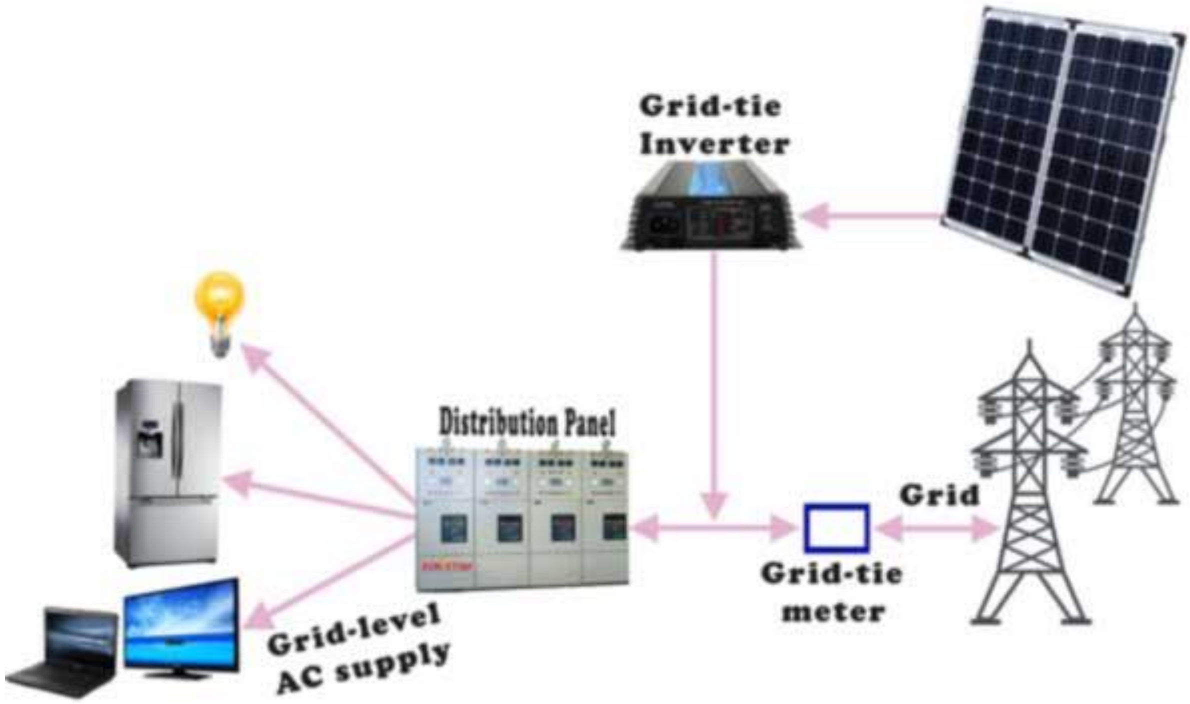

Fig 2.6.1 Station Scheme of Grid Tie Solar Energy

The micro-inverter technology integrates the inverter directly with each individual photovoltaic module, providing DC-AC conversion and Maximum Power Point (MPP) tracking capabilities. This means that each photovoltaic module is equipped with its own inverter module, allowing for direct conversion of the power generated by the module into AC for local consumption or for transmission to the grid. One of the key advantages of micro-inverters is that they offer module-level optimization. If one photovoltaic module encounters an issue or malfunctions, only that particular module is affected, while the rest of the system continues to operate at optimal performance, ensuring higher overall efficiency and power generation capacity. In contrast, with traditional combined inverters, a fault in one module can significantly impact the performance of several kilowatts of panels.

In practical applications, the impact of a micro-inverter fault is minimal compared to a combined inverter fault, as it only affects the specific module it is connected to. The energy meter serves as a crucial component in grid-tied solar systems, providing valuable data on the amount of energy that is exported to the grid when the solar panels generate excess electricity, and the energy that is imported from the grid during times when the solar panels are not generating enough power. This information is essential for tracking the performance of the system, monitoring its efficiency, and calculating net energy usage. Also, in systems that utilize micro-inverters, each solar module is connected to its micro-inverter. This individualized connection allows for independent control and optimization of each module's performance.

This means that if one module experiences shading, dirt, or any other issue that may reduce its output, it will not negatively impact the performance of the entire system. Instead, only the affected module's output will be affected, while the rest of the modules continue to generate power optimally. This approach of connecting each solar module to its micro-inverter can result in improved overall system performance, as it minimizes the impact of partial shading or other issues that may affect individual modules. Additionally, it provides more flexibility in system design, allowing for scalability and ease of maintenance.

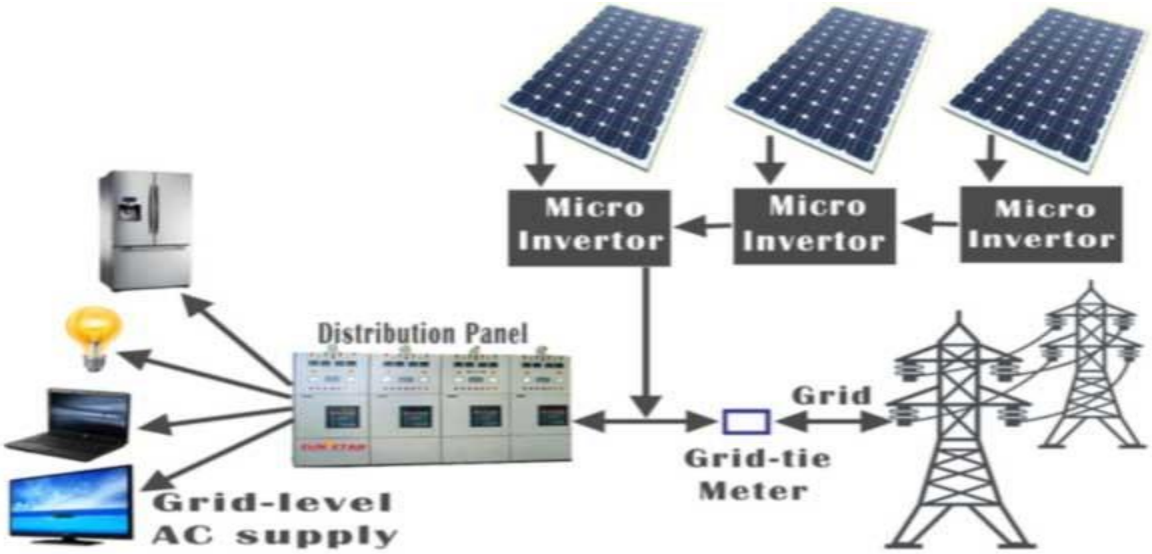

Fig 2.6.2: Various Micro Systems Grid Tie

2.7 Photovoltaics Cell

They are devices that can harness the sun power and convert it into electricity through a process called the photovoltaic effect. The basic structure of a solar cell consists of several layers of different materials. The top layer, known as the front contact, that allows sunlight to pass through while facilitating the flow of electricity.

Beneath the front contact is the semiconductor layer, which is responsible for capturing the solar energy and generating an electric current. The most commonly used semiconductor material in solar cells is silicon, although other materials such as gallium arsenide, cadmium telluride, and copper indium gallium selenide are also used in certain types of solar cells.

In addition, a solar cell may also include other components such as an anti-reflective coating on the front surface to minimize reflection of sunlight, and a protective encapsulation layer to shield the cell from environmental factors such as moisture and dust.

When sunlight strikes the front surface of the solar cell, it is absorbed by the semiconductor material, generating an electric current due to the movement of charge carriers towards the respective contacts. This electrical current can be harnessed and utilized for various applications, such as powering electrical devices, charging batteries, or feeding electricity into the grid.

The construction of a solar cell involves the use of semiconductor materials, doped to create a p-n junction, along with front and back contacts and additional layers for anti-reflective coating and encapsulation. This complex structure allows solar cells to effectively convert sunlight into electrical energy, making them a key component of solar power systems for renewable energy generation.

2.8 Construction of Solar Cell

The use of Silicon (Si) or Gallium Arsenide (GaAs) for a junction diode is a common practice in semiconductor devices. Si is the most widely used semiconductor material due to its abundance and well-established manufacturing processes, while GaAs is known for its higher electron mobility and ability to operate at higher frequencies compared to Si.

In the described configuration, an n-type semiconductor is used as the base material, onto which a thin coating of p-type material is formed. This creates a p-n junction, which is the heart of the diode and is responsible for its electrical behavior. The p-n junction acts as a barrier to the flow of charge carriers under reverse-biased conditions, while allowing current flow under forward-biased conditions.

The top of the p-layer is supplied with a few finer electrodes, which are likely used to create contacts for external electrical connections as well as to allow light to reach the narrow p-layer. This configuration suggests that the diode may be used as a photodiode, a type of diode that is sensitive to light and can convert light energy into electrical energy.

A current gathering conductor is installed at the bottom of the n-layer, which is likely used to collect the majority of the current flowing through the diode. This conductor serves as an electrical contact for the diode and allows the generated current to be extracted for external use.

Overall, this configuration suggests a specific type of diode known as a photodiode, which is designed to detect and convert light into electrical signals. The choice of Si or GaAs as the semiconductor material depends on, operating frequency, sensitivity to light, and manufacturing considerations.

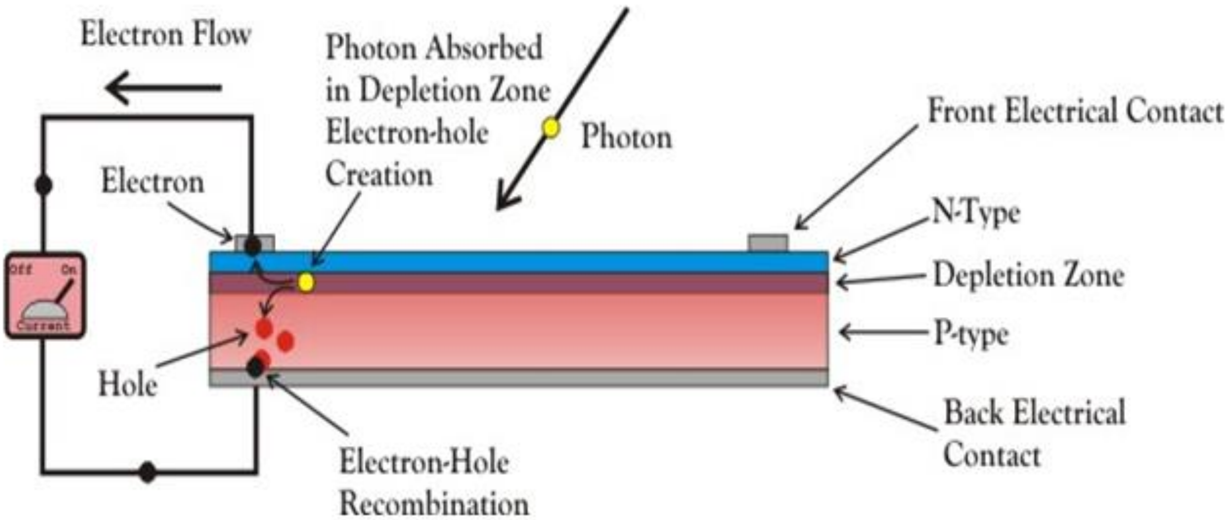

Fig 2.8: Structure of PV cell

2.8.1 Implementation Principle of PV Cell

The photovoltaic effect, which involves the absorption of sunlight by the semiconductor material of the solar cell. The absorbed photons excite electrons within the semiconductor, causing them to move and generate an electric current. The electric current is then collected and used as electricity. This process is fundamentally based on the interaction between light and matter and the semiconductor components used in the PV cell.

2.8.2 Solar Cell Accessories

The components used for this reason must have a band gap of less than 1.5eV. 1. Silicon is a commonly used substance. 2. GaAs. 3. CdTe. 4th. CuInSe2

Material Selection Criteria for Solar Cells

1. A band difference of 1eV to 1.8eV is required.

2. It must have a significant level of optical absorbance.

3. It must be electrically conductive.

4. The raw material must be plentiful, and the substance's expense must be cheap.

2.8.3 V-I Characteristics of a Photovoltaic Cell

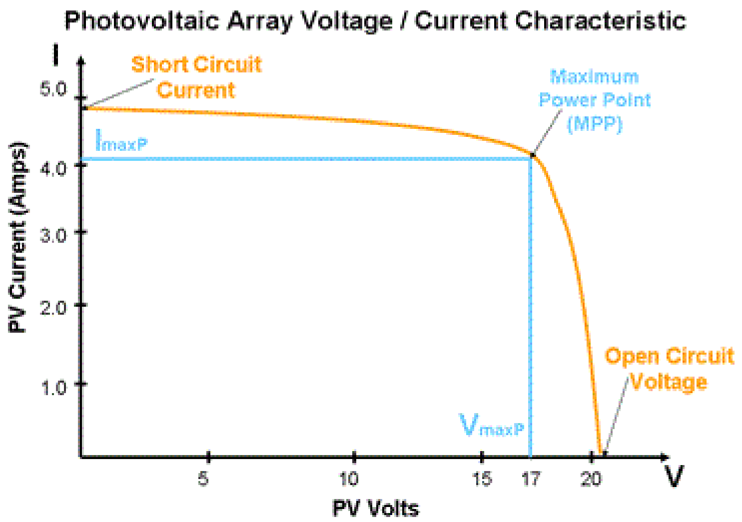

Fig 2.8.3: The Characteristics of PV cell

The Advantages of Solar cell:

1. Renewable and clean energy:

   Solar cells harness the power of sunlight. Solar energy is clean, produces no zero emissions.

2. Low operating costs:

   Once installed, solar cells have relatively low operating costs as they do not require fuel or ongoing maintenance. This makes solar energy an economically viable option for generating electricity, especially in the long run.

3. Energy independence:

Solar cells can provide electricity to remote or off-grid areas where access to electricity may be limited or expensive. This can help promote energy independence and improve the quality of life for communities without reliable access to electricity.

4. Scalable and modular: Solar cells can be easily scaled up or down depending on the energy needs of a particular application. They can be installed on rooftops, ground-mounted, or integrated into buildings, making them highly versatile and adaptable to different environments.
5. Long lifespan: Solar cells typically have a long lifespan, with warranties ranging from 20 to 25 years, and can continue to generate electricity beyond their warranty period. This makes them a durable and reliable source of electricity.

Disadvantages of solar cells:

1. High upfront costs:

   The initial cost of installing solar cells can be relatively high. This can be a barrier to adoption for some homeowners or businesses, although the costs have been decreasing over time.

2. Weather-dependent:

   Solar cells rely on sunlight to generate electricity, which means their performance can be affected shading, and geographic location.

3. Energy storage challenges:

   Solar cells generate electricity during daylight hours, and energy storage is often required storage excess energy for non-sunny periods or at night.

4. Manufacturing and disposal considerations:

   The production of solar cells requires the use of certain materials, some of which may have environmental or social impacts, such as mining of rare earth elements. Additionally, the disposal of solar panels at the end of their lifespan requires proper recycling or disposal methods to minimize environmental impact

2.9 Short Circuit Current of Solar Cell

A higher intensity of sunlight results in a higher short circuit current, assuming all other factors remain constant. However, it's important to note that the short circuit current is typically specified at (STC) of 1,000 watts (W/m^2) of solar irradiance, at a temperature of 25 degrees Celsius, and with an air mass of 1.5 (AM1.5) spectrum.

The short circuit current is influenced by several factors, including:

1. Material properties:

   It is used in the solar cell, such as its bandgap, carrier mobility, and carrier lifetime, can affect the short circuit current. Different materials have different abilities to absorb and convert sunlight into electrical current, which can impact the short circuit current of the solar cell.

2. Cell design:

   The design including its structure, thickness, and surface texturing, can also affect the short circuit current. Optimized cell designs can enhance the extracting of sunlight, resulting in higher short circuit currents.

3. Temperature:

   As the heat raise, the electrical resistance of the solar cell typically decreases, which can result in a higher short circuit current.

4. Incident angle of sunlight:

   The angle at which sunlight strikes the surface of the solar cell, can also affect the short circuit current. Solar cells are typically designed to perform optimally when sunlight strikes the surface perpendicular to the cell. If sunlight strikes the cell at an angle, the effective light absorption and conversion may decrease, resulting in a lower short circuit current.

5. External factors: Other external factors such as shading, dirt, and aging can also impact the short circuit current of a solar cell. Shading of a portion of the solar cell, even a small area, can significantly reduce the short circuit current as it reduces the amount of sunlight reaching the cell.

A higher short circuit current indicates a more efficient solar cell that can generate more current for a given level of sunlight intensity. However, it's important to consider other parameters such as the open circuit voltage, fill factor, and overall efficiency, as they are also critical in determining the performance of a solar cell. Manufacturers typically provide specifications for solar cells, including the short circuit current, as part of their datasheets, which can be used for designing and evaluating solar power systems.

The fill factor (FF) of a solar cell is a dimensionless parameter that quantifies the efficiency of the cell's power conversion. It is mathematically expressed as the ratio of the maximum power output (Pmax) that the solar cell can generate to the product of its short-circuit current (Isc) and open-circuit voltage (Voc), represented as:

$$FF = \frac{P_{max}}{I_{sc} * V_{oc}} \qquad (2.1)$$

where Pmax is the maximum power output of the solar cell, Isc is the short-circuit current, and Voc is the open-circuit voltage. The fill factor is an important parameter that indicates how effectively the solar cell can convert sunlight into electrical power, with a higher fill factor indicating a more efficient cell

It is a measure of how close a solar cell comes to achieving its maximum theoretical efficiency. Overall, understanding these parameters and how they affect the performance of a solar cell is crucial when selecting a solar cell for a specific project or application. By evaluating these parameters, one can determine how efficiently a solar cell can convert light to electricity, which is essential for maximizing the output of a solar energy system.

$$J_{sc} = \frac{I_{sc}}{A} \qquad (2.2)$$

Where, I_{sc} is short circuit current, J_{sc} maximum current density and A is the area of solar cell.

2.10 Open Circuit Voltage of Solar Cell

The open-circuit current (Ioc) is a critical parameter of a solar cell that represents the maximum current that the cell can produce when there is no external load connected to its output terminals, creating an infinite resistance load. It is one of the key factors that determine the power output of a solar cell. The open-circuit current is primarily determined by the intensity of sunlight falling on the solar cell and the efficiency with which the cell can convert the incident sunlight into electrical current. A higher intensity of sunlight results in a higher open-circuit current, assuming all other factors remain constant. However, it's important to note that the open-circuit current is typically specified at standard test conditions (STC) of 1,000 watts per square meter (W/m^2) of solar irradiance, at a temperature of 25 degrees Celsius, and with an air mass of 1.5 (AM1.5) spectrum.

2.11 Maximum Power Point of Solar Cell

The MPPT of a solar cell refers to the voltage and current at which the solar cell or panel operates to achieve its maximum power output. The MPPT can vary depending on various factors, such as the solar cell technology, temperature, irradiance (amount of sunlight), and electrical load connected to the panels.

characteristics of a solar cell. Pm's V-I properties of photovoltaic cells demonstrate this.

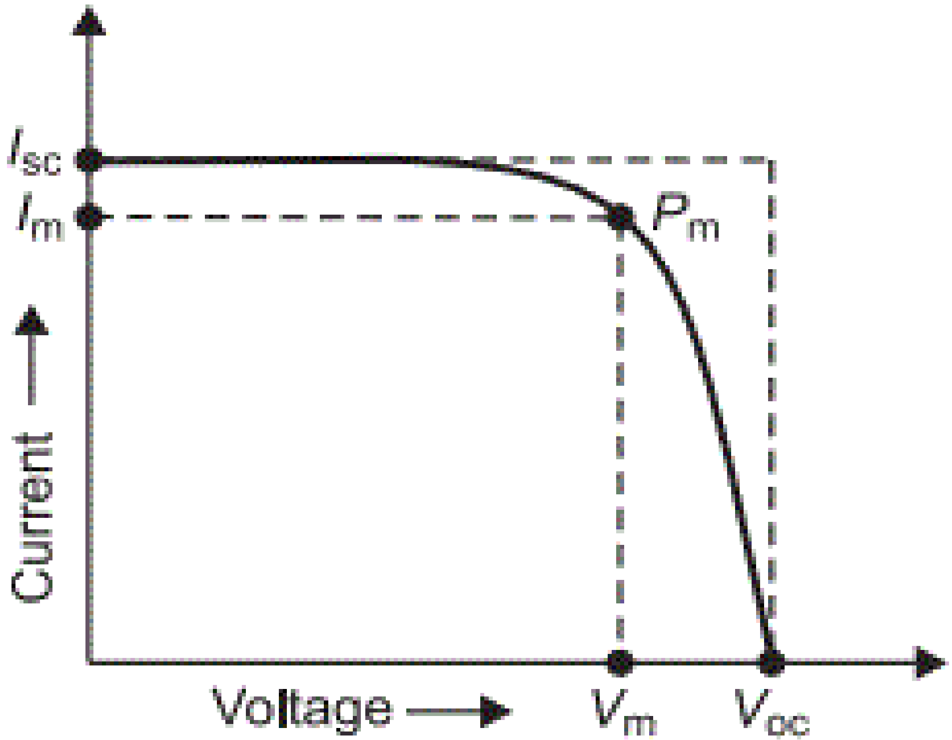

Fig 2.11: V-I characteristics of solar cell by P_m

2.12 Efficiency of Solar Cell

Is a sizing that showing effectively it converts sunlight into electricity. It is typically expressed as a percentage, representing the ratio of the electrical power output of the solar cell to the power of the sunlight that falls on the solar cell. Higher performance of PV panels has ability to transform a larger proportion of sunlight into electricity, which makes them more desirable for solar power systems as they can generate more electricity for a given amount of sunlight.

Mathematically, the efficiency (η) of a solar cell is given by the equation:

$$\eta = \left(\frac{P_{out}}{P_{in}}\right) * 100\% \quad (2.3)$$

The performance of PV panels is a crucial performance metric, as it directly impacts the amount of electrical power that can be generated from a given amount of sunlight. Because the radiation power on the planet is estimated to be 1000 watts, if the exposed surface area of the cell is A, the overall radiation power on the cell will be 1000A watts. Hence it may be expressed as:

$$Efficiecy\ (\eta) = \frac{P_m}{P_{in}} \approx \frac{P_m}{1000\ A} \tag{2.4}$$

2.13 Energy Storage Systems

The electric power sector has a unique trait where the generation of electricity remains relatively constant in the short term, despite fluctuating demand throughout the day. Achieving the technological advancement of storing electrical energy for on-demand availability would be a significant milestone in the field of electricity distribution.

Electricity storage devices play a crucial role in meeting this objective by effectively managing power supply during peak load periods when demand is at its highest.

Additionally, these devices can enhance the reliability of renewable energy sources by mitigating their variable power output, which is beyond the control of grid operators, and making it more consistent and manageable.

Recently, the demand for energy storage devices has been boosted by the mass production of lithium secondary batteries with lowered costs, driven by the widespread use of mobile IT devices and electric vehicles. Lithium secondary batteries, along with other electrochemical technologies like lead storage batteries and sodium-sulfur batteries, convert electric energy to chemical energy.

2.14 Maximum Power Point Tracking

MPPT, or Maximum Power Point Tracking, is a pivotal technology employed in solar energy systems to optimize the efficiency and output of photovoltaic (PV) panels. PV panels generate DC power, and to fully harness the available solar energy, it is crucial to operate them at their maximum power point (MPP), where they can generate the highest amount of electricity. MPPT is a technique that enables solar power systems to track and maintain the optimal operating point, leading to increased power production, improved efficiency, and enhanced overall performance.

Implementing Maximum Power Point Tracking (MPPT) in a solar energy system typically involves several steps:

1. Selection of MPPT Algorithm:

   The appropriate algorithm should be chosen based on the specific requirements of the system, including the type of solar panels, environmental conditions, and desired performance.

2. System Modeling:

   The solar energy system, including the solar panels, inverter, and battery (if applicable), needs to be modeled mathematically to simulate its behavior under different operating conditions. This involves obtaining the relevant parameters, such as the solar panel characteristics (voltage-current curve), inverter efficiency, and battery characteristics (if used), and using them to create a mathematical model of the system.

3. Sensor Measurement:

   Appropriate sensors, such as voltage and current sensors, need to be installed in the system to measure the actual values of solar panel voltage and current, as well as other relevant parameters, such as ambient temperature and solar irradiation.

4. MPPT Algorithm Implementation:

   The selected MPPT algorithm is then implemented in the system's control software or hardware. This may involve coding the algorithm in a microcontroller or using a software-based approach, depending on the system architecture and requirements.

5. Performance Evaluation and Fine-tuning:

   After implementing the MPPT algorithm, the system needs to be thoroughly tested and evaluated under different operating conditions to assess its performance. This may involve measuring the power output of the solar panels, tracking efficiency, response time, and other performance metrics. Based on the evaluation results, the MPPT algorithm may need to be fine-tuned or optimized to further improve its performance.

6. System Integration:

   Once the MPPT algorithm is successfully implemented and optimized, it needs to be integrated into the overall solar energy system, including other control strategies, energy storage systems (if used), and communication interfaces for monitoring and control. The integration process may involve hardware and software integration, as well as system-level testing and validation.

7. Maintenance and Monitoring: Finally, regular maintenance and monitoring of the MPPT system are essential to ensure its continued performance and reliability. This may involve periodic calibration of sensors, software updates, and monitoring of system performance and power output to detect any potential issues and take appropriate corrective actions.

2.15 The I-V Curve

Is an illustration of the relationship between current and voltage in an electrical component or circuit. It is commonly used in electrical engineering, physics, and electronics to understand the behavior and characteristics of various electronic devices such as resistors, diodes, transistors, and solar cells. In an I-V curve, the current (I) is plotted on the y-axis and the voltage (V) is plotted on the x-axis. The curve shows how the current changes with respect to the voltage across the component or circuit, and it can provide insights into the device's performance, efficiency, and operating conditions.

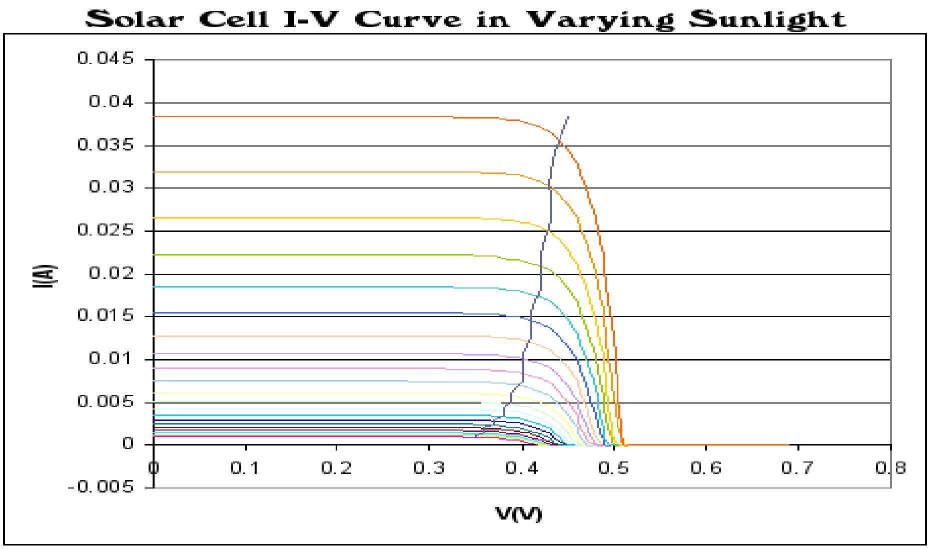

Fig: 2.15 Photovoltaic Solar Cell I-V curves

Photovoltaic (PV) cells, also known as solar cells, are influenced by their operating environment, which affects their maximum power output. One important parameter that characterizes the electrical behavior of PV cells is the fill factor (FF), and it's used in tabulated data to estimate the maximum power that a cell can provide under specific conditions, expressed as P=FFVocIsc.

Understanding the relationship between FF, Voc, Isc, and other parameters is crucial for optimizing the performance of PV cells in real-world applications. PV cells have a specific operating point. The MPP is determined by the current and voltage values that result in the optimal load resistance.

This MPP corresponds to the "knee" of the curve, where the power output is optimized.

Load resistance (R) plays a critical role in extracting the maximum power from a PV cell. The load resistance that draws the maximum power from a PV cell is equal to the reciprocal of the characteristic resistance of the cell, i.e., R=V/I. The characteristic resistance is a dynamic quantity that depends on various factors such as illumination level, temperature, and cell age. Deviating from this optimal load resistance value can result in less power being drawn from the cell, leading to inefficient utilization of the cell's potential.

To optimize power extraction, maximum power point trackers are used in PV systems. By continuously adjusting the load resistance to track the MPP, these trackers ensure that the PV cell operates at its maximum power output, maximizing the system's overall efficiency.

The fill factor, along with Voc, Isc, and characteristic resistance, plays a crucial role in the electrical behavior of PV cells. Understanding the relationship between these parameters and the MPP is essential for optimizing the power output and efficiency of PV cells in real-world applications. Load resistance and the use of maximum power point trackers are key factors in achieving maximum power extraction from PV cells and ensuring efficient utilization of their potential.

2.16 The Proposed Algorithm

2.16.1 Perturb & Observe MPPT Algorithm

P&O is also known for its real-time performance, making it suitable for real-world applications. It does not require complex calculations or large amounts of computational resources, making it well-suited for implementation in embedded systems or microcontrollers with limited processing capabilities.

This makes P&O a cost-effective and practical choice for MPPT in solar energy systems, especially in remote or off-grid installations where resources may be limited.

The P&O MPPT algorithm is a widely used and simple method for tracking the maximum power point of a solar panel. It involves measuring the power output, comparing it with

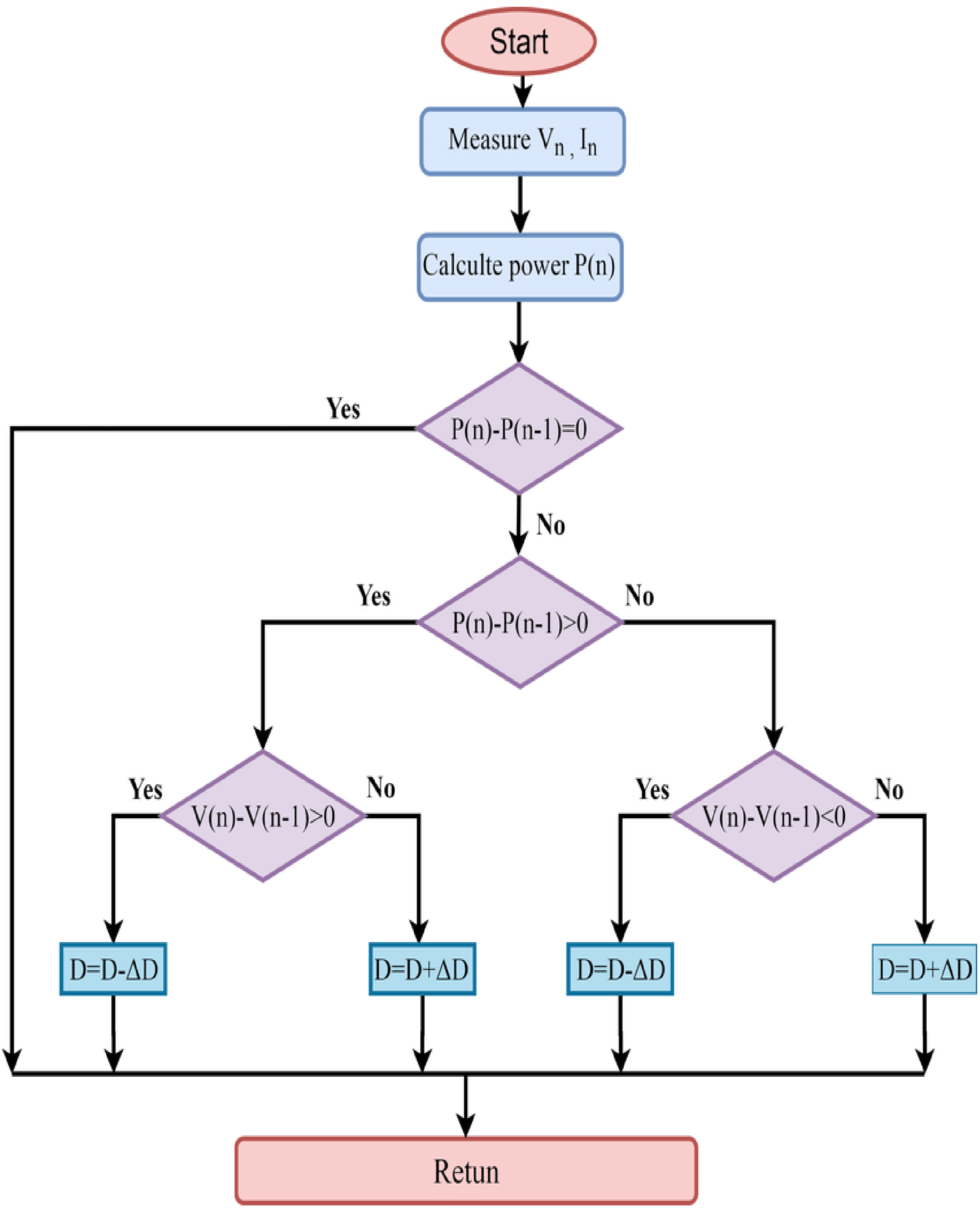

Fig. 2.16.1: P&O Flow Chart

previous values, determining changes in power and voltage, adjusting the duty cycle, and repeating the process until the MPP is reached. While it has some limitations, it remains a popular choice for many PV systems, and there are various variants that can be used to enhance its performance.

The P&O MPPT flow chart is a continuous loop that is repeated in real-time to continuously track the MPP of the solar panel and optimize the power output of the PV system. It is a simple and widely used MPPT algorithm that is suitable for many PV applications due to its simplicity and effectiveness. However, it may have some limitations, such as slow tracking speed and sensitivity to environmental conditions, and may not always be the most efficient MPPT algorithm for all PV systems.

This technique is the simplest method for implementing MPPT. It solely measures voltage, making it straightforward to implement. The system's power output is tested by adjusting the voltage provided. If increasing the voltage results in increased power, then continue increasing the voltage; otherwise, start reducing it. Likewise, if power increases while decreasing voltage, the duty cycle is decreased. This process is repeated until the maximum power point (MPP) is reached, with the reference point being the voltage at which MPP is achieved (Vref). The complete P&O algorithm is illustrated above.

2.17 The Topology of Charging Station

The implemented CS scheme shown in figure (1), uses a DG set, a power grid, BESS, and Solar PV. The system in addition to charging the electric vehicle is also connected to energies local demand. The power from BESS and solar power, are in form of DC, and for the AC are DG set, a single-phase grid.

Therefore, the power link to AC is concurrent at PCC and modified into DC form by the intermediary of a bi-directional converter and vice versa. PCC main duty is to terminate the harmonics produced by the grid and currents gained by the diesel generator, in order to turn them into sinusoidal. The AC or DC loads are directly supplied by their respective source. the DC-DC converter, which is the EV2 charger, takes its power from the general DC power source.

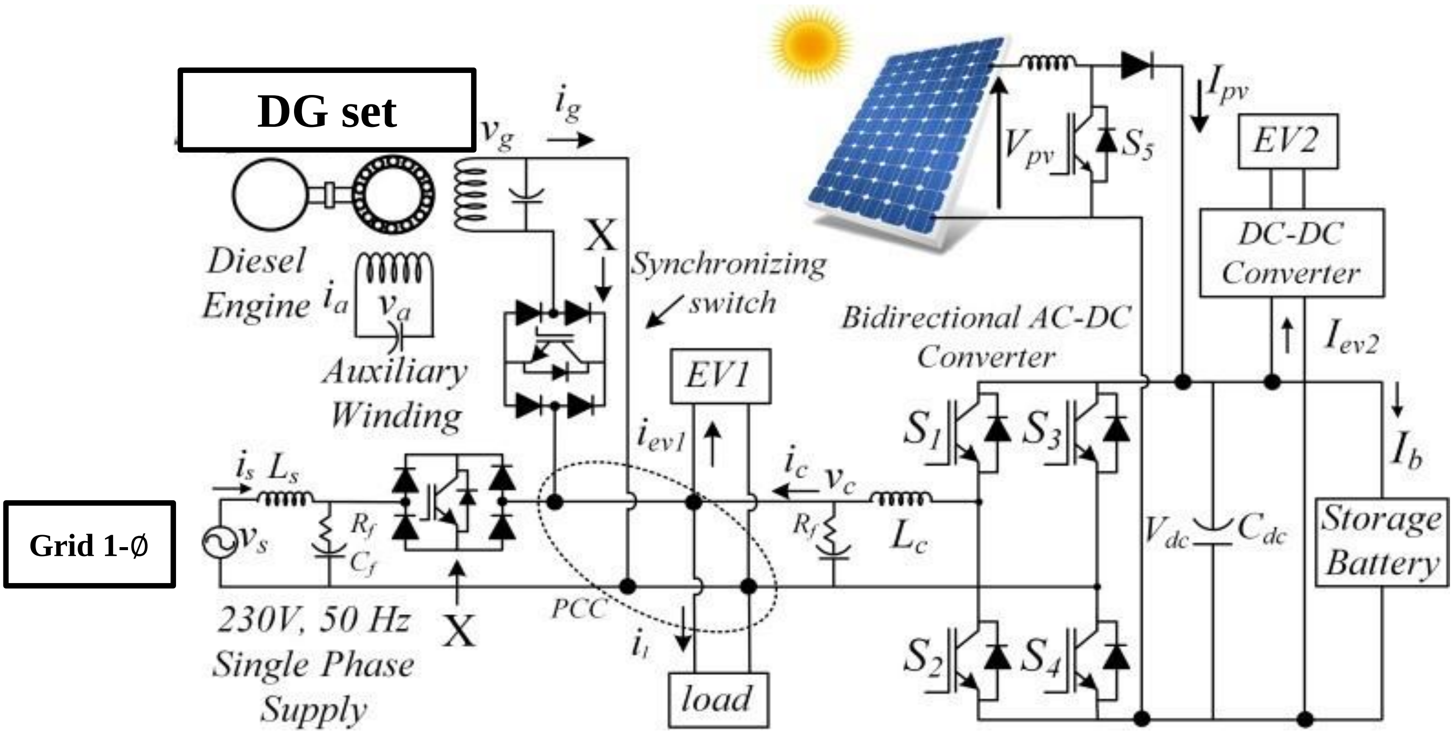

Fig 2.17: Topology of Charging Station

2.18 The Various Kinds of Control

VSC Control in the Islanded Mode Only

The islanded VSC control mode provides a stable supply to EVs without the power grid. AC and DC power is supplied by solar / BES through power converters. This mode faced the challenge of the shortage of a convenient voltage signal reference in the obscurity of the power utility. Thus, a producer of a voltage local reference is to ensure the conversion of the source voltage converter in order to secure the process. In the comparison of the reference signal with the produced feedback, the error signal comes through the PI controller. The error voltage is reduced, then the current reference is produced, this formula as mentioned equation (2.5), which can be expressed as:

$$i_c^*(s) = i_c^*(s-1) + x_{pv}\{v_{ce}(s) - v_{ce}(s-1)\} + x_{iv}v_{ce}(s) \qquad (2.5)$$

By comparing the current reference and actual current converter as it crossed the hysteresis current controller, these signals are produced and sent from the converter gate.

Utility Grid Mode or DG set Under VSC Control

A control system's primary responsibility is determining quantity of energy interchange among EVs and the power grid. In other words, power reciprocity from vehicle to grid, or grid to the vehicle, the controller determines the suitable amount to transfer it.

suitable amount to transfer it. To preserve fuel competency, DG set has to operate in fixed generation form, to realize high efficiency. Even so, the control part in both ways requires recompensing the current reactive and harmonic distortion which is the EVs needful, acquired by performing it from the computation of current reference of utility power or DG by considering to EV current. This equation (2.6) shows total currents, and it can be expressed as:

$$I_{sp} = I_p - I_{ef2} - I_{pf} \tag{2.6}$$

$$I_{sq} = 0$$

equation (2.7) encloses the working at UPF in the power grid, by counting only active power. But in the DG set estimation both active and reactive currents are used, and equation explains the expression of active and reactive currents respectively.

$$I_{sp} = I_p - I_{ef2} - I_{fp} - I_{pf} \tag{2.7}$$

$$I_{qp} = I_{vq} - I_q$$

A control system's primary responsibility is determining quantity of energy interchange among EVs and the power grid. In other words, power reciprocity from vehicle to grid, or grid to the vehicle, the controller determines the grid, by counting only active power. But in the DG set estimation both active and reactive currents are used.

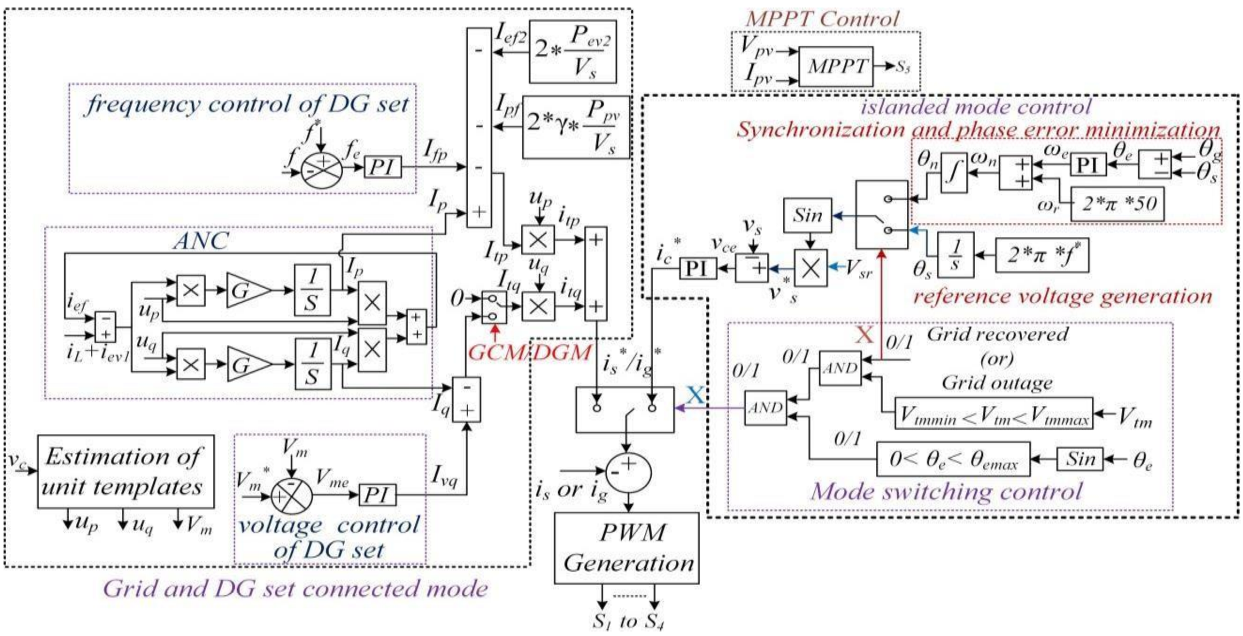

Fig.2.18.1:VSC Control of the three modes

Therefore, the reference current of DG set or power grid is calculated in the below equation, and it can express as:

$$i_s^* \ or \ i_g^* = I_{tp} \times u_p + I_{tq} \times u_q \tag{2.8}$$

The contemporary signals of the DG set can shape them as u_p and u_q and the power utility voltage (v_g or v_s). By using reference currents and sense of DG set or the power network, this process will produce switching signals, and that is due to the PWM control viewed in above schematic.

The Diesel Generator set Regulation of Frequency and Voltage

Principle working of the DG-set requires the decoupling between frequency and voltage control signals. Using this method will direct the frequency control real power and the voltage for apparent power. Mathematically can express the PI control voltage as shown by equation (5), thus, there are two controllers used for voltage and frequency control.

$$I_{vq}(s) = I_{vq}(s-1) + x_{vp}\{V_{ze}(s) - V_{ze}(s-1)\} + x_{vi}V_{ze}(s) \qquad (2.9)$$

$V_{me} = V_m^* - V_m$ represent error voltage, x_{vi} and x_{vp} gains of the proportional integral controller.

The PI control frequency can be expressed in a similar manner looks like this:

$$I_{fp}(s) = I_{fp}(s-1) + x_{fp}\{f_e(s) - f_e(s-1)\} + x_{fi}f_e(s) \qquad (2.10)$$

x_{fp} and x_{fi} refers to PI gain, and f_e the error in the frequency. The end outcome of the controllers of frequency and voltage will gather them in the controlling of the power grid as in figure. Yet, the result of the O/P will be zero in grid power, as keep controlled the voltage and frequency.

EV2 Control

The operation of EV Battery charging goes through either, the current constant or voltage. Therefore, For EV.

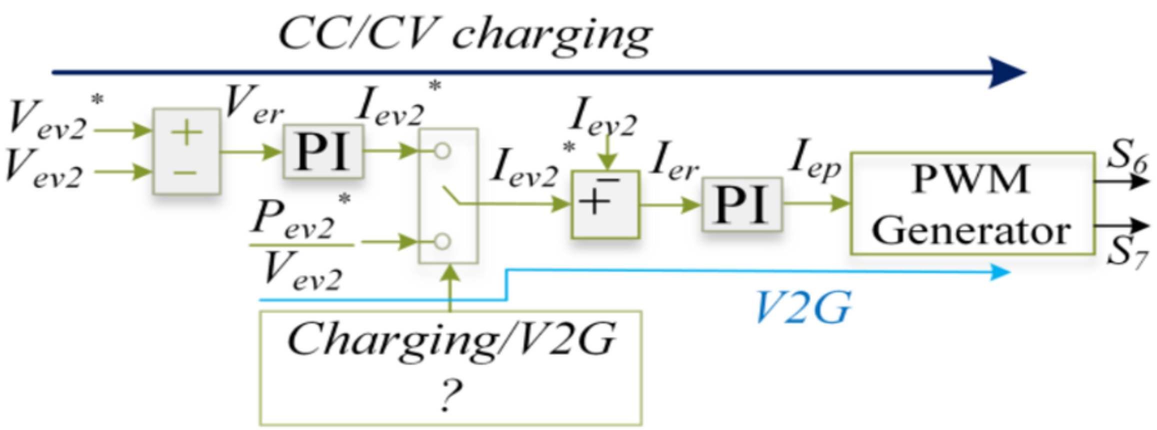

Fig.2.18.2: Power transferring vehicle/grid and the EV2 control for CC or CV charging

charging in dominant CC/CV, DC-link is used with a converter DC-DC until the storage battery attains the demand voltage charged status. When the CC mode is about to maximum charge, CC will adjust to CV mode by using two PI controllers, Figure (3) performs the CV/CC scheme of charging control.

The charging current reference is performed such:

$$i^*_{ev2}(s) = i^*_{ev2}(s-1) + x_{evp}\{V_{er}(s) - v_{er}(s-1)\} += x_{evi}V_{er}(s) \qquad (2.11)$$

In equation (2.11), the voltage error of the Vehicle storage battery is given, V_{er} and the controller gains by z_{evp} and z_{evi}.

By using the battery-sensed currents and the reference, the switching signals are obtained, using the pulse width modulation generator (PWM) with the controller PI.

The duty cycle (D) of PI is implemented as:

$$d_{ev}(s) = d_{ev}(s-1) + x_{ep}\{I_{er}(s) - I_{er}(s-1)\} + x_{ei}I_{er}(s) \qquad (2.12)$$

The current error of the battery is expressed by I_{er} and the PI gains as x_{ep} and x_{ei}.The transfer power in V-2-G, the electric vehicle 2 battery exhausted, controller keeps the various route-based power reference as in figure. By using power reference of feed-forward, in the same figure the control of EV2 achieved.

The Control of Synchronizing and Switching Logic

The design plan of control is needful for the power production and charging requirements, due the changing from one process to other, results streamline and the charging stay undisturbed. Therefore, islanded-to-DG sets, and off-grid to grid power, are considered as limitations where the demonstrated of switching logic.

In this fact, basically the difference of phase voltages is obtained, and the aim of synchronization of the two voltages are gained from the controller. Therefore, the voltage source converter's frequency is adjusted by the proportional integrator controller in off-grid case, layout in fig 2.

$$\Delta\omega(s) = \Delta\omega(s-1) + x_{pa}\{\Delta\theta(s) - \Delta\theta(s-1)\} + x_{ia}\Delta\theta(s) \qquad (2.13)$$

In equation (9) the difference in phase is express by $\Delta\theta$, the regulating elements x_{pa} and x_{ia}. The figure (2) offers an obvious view in the CS works in off-grid, also it relies on under which status the switchover of the mode can be obtained. To satisfy the demands of sources concur, the algorithm strategy bring an operate signal $\mathrm{Z} = 1$

CHAPTER THREE

CONTROL PROCEDURES

3.1 Basic Control Types

3.1.1 The Existing Model Controller

In control systems, the PID controller, is commonly used and highly effective control strategy that builds upon the principles of the proportional controller.

The PID controller extends the capabilities of the proportional controller by incorporating additional control actions to address some of its limitations. Kp, which controls the response of the controller based on the current error, the PID controller includes two additional parameters: the integral gain, Ki, and the derivative gain, Kd. These parameters allow the PID controller to consider the history of past errors and the rate of change of the error, providing a more comprehensive and adaptive control approach

P Controller:

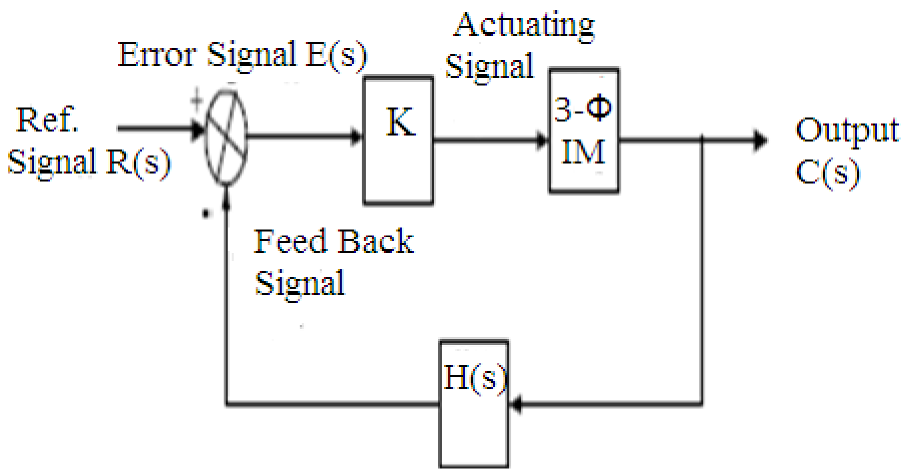

Fig 3.1: Scheme of P Controller

A P-controller, is a fundamental component that plays a crucial role in regulating processes and ensuring stability. With its simple yet effective design, the proportional controller is widely used in various industries, ranging from manufacturing to robotics, to maintain desired set points and achieve accurate control.

At its core, it is kind of close loop control mechanism that uses a continuous error signal to adjust the output of a system in proportion to the error. The proportional controller then calculates the control signal by multiplying the error by a gain factor, denoted as Kp, which determines the strength of the controller's response. Mathematically, the output of a proportional controller can be represented as:

$$u(t) = K_P * e(t) \tag{3.1}$$

where:

u(t) is the control signal at time t, Kp is the proportional gain, and e(t) is the error at time t. One of the key features of the proportional controller is its ability to respond to changes in the error signal in real-time. When the error is large, the controller responds with a higher output, providing a stronger corrective action. Conversely, when the error is small, the controller adjusts the output proportionally, resulting in a smoother response. This property makes the proportional controller well-suited for controlling systems with relatively simple dynamics and small disturbances.

PD Controller:

the derivative mode in a PD controller has a phase lead of 90° and is used in specific situations where it can enhance control performance or stabilize the system. Calculating the derivative from the system's output variable, and designing it to be proportional to the change in the output, can help mitigate issues associated with sudden changes in the reference input. PD controllers are commonly utilized in the controlling of dynamic purpose due to their stabilizing effect on heading variables, and rate gyros are often used as sensors to provide input for PD controllers in these applications.

PI Controller:

It is combines P and I action to enhance the efficiency of a control system. It adds a pole at the origin (integrator) and a finite zero to the feedback loop, allowing for precise tracking and regulation of a desired set-point.

The zero location and pole-zero pair can be adjusted to achieve desired system response characteristics, making PI controllers commonly used in applications where accurate and stable control is required, such as servomechanisms. Then the equation as shown below:

$$u(t) = K_P * e(t) + K_i \int e\,(t)dt \tag{3.2}$$

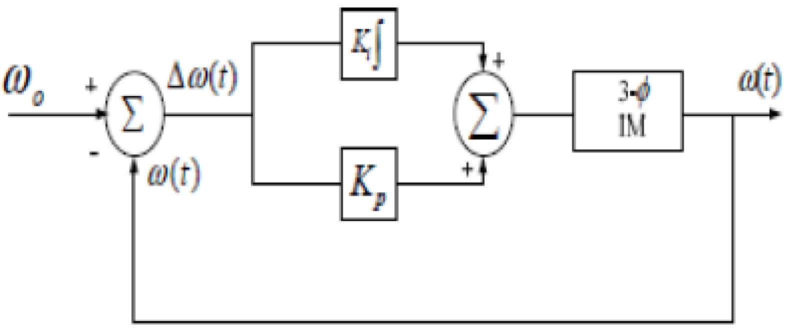

Fig 3.2: Scheme of PI Controller

One of the key features of a PI controller is the integrator. This means that a PI controller is capable of eliminating steady-state errors in the system, making it commonly used in applications where precise tracking or regulation of a desired set-point is required. Servomechanisms, which are systems used for precise position or velocity control, often utilize PI controllers to achieve accurate and stable performance.

PID Controller:

The derivative (D) mode in a PID controller plays a crucial role in improving the stability of the system and enhancing the overall performance. It provides fast reaction to changes in the controller input, allowing the system to respond quickly to sudden changes in the error. This can help prevent overshooting and oscillations, leading to a more stable control response.

Furthermore, the D mode enables an increase in the gain (K) and a decrease in the integral time constant (Ti) of the controller, which can result in faster response times. By providing predictive capabilities, the D mode helps the controller to anticipate the future behavior of the error, allowing for quicker adjustments to be made in the control signal to bring the error towards zero. The proportional (P) and integral (I) modes of the PID controller also play important roles. The P mode provides control action based on the current error, while the I mode integrates the past errors over time to eliminate steady-state error.

The combination of the three modes provides a comprehensive approach to control, with each mode contributing to the overall stability, responsiveness, and performance of the system. It's worth noting that tuning a PID controller, i.e., selecting appropriate values for the gains (Kp, Ki, and Kd), is essential to achieve optimal control performance. Proper tuning ensures that the controller responds, leading to stable and accurate control.

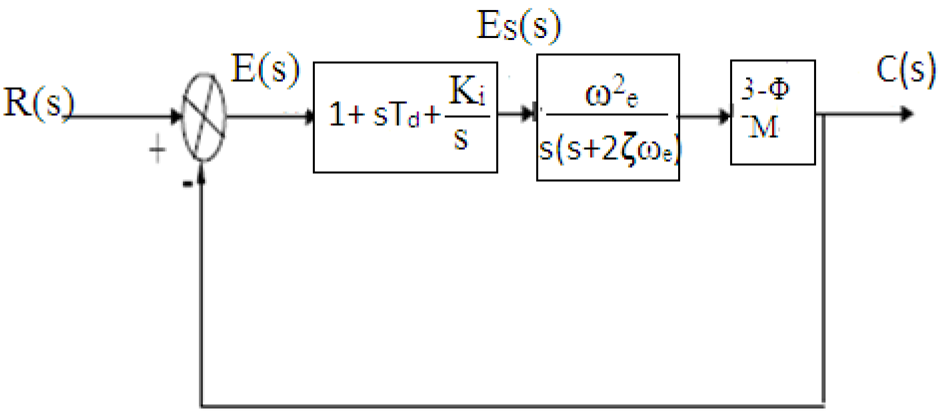

Fig 3.3: Scheme of PID Controller

Controller output is:

$$u(t) = K_p * e(t) + K_i \int e(t) * dt + K_d \frac{de(t)}{dt} \quad (3.3)$$

These processes may not exhibit dynamics similar to that of a pure integrator, making the PID controller a suitable choice for providing stable and accurate control. PID controllers are capable of providing precise reference following and stability, which are critical in applications where accurate trajectory or course tracking is required.

Conventional autopilot systems often utilize PID type controllers due to their ability to provide stable and reliable control performance. PID controllers can be tuned to meet the specific requirements of the mobile object's dynamics and environmental conditions, allowing for precise control of the object's movement, heading, and trajectory.

It's worth noting that while PID controllers are widely used and can provide effective control in many applications, they are not always the optimal choice for every control problem

Parameter	Speed Response	Stability	Accuracy
Increase K_p	Increase	Deteriorate	Improves
Increase K_i	Decrease	Deteriorate	Improves
Increase K_d	Increase	Improves	No impact

Table 3.1: Parameters Response

Parameters	Raise Time	Overshoot	Settling Time	S.S Error	Stability
K_p	Decrease	Increase	Small Change	Decrease	Worse
K_i	Decrease	Increase	Increase	Significant Decrease	Worse
K_d	Minor Decr.	Minor Decr.	Minor Decr.	No change	If Kd small, Better

Table 3.2: Impact of Parameters Change

3.2 The Proposed Model Controller

3.2.1 ANFIS Controller

ANFIS Controller: An Advanced Fuzzy Logic-Based Control Technique. In recent years, the field of control systems has seen significant advancements in various control techniques aimed at improving system performance and robustness.

One such technique is Adaptive Neuro-Fuzzy Inference System (ANFIS) control, which combines the strengths of fuzzy logic and neural networks to achieve effective control in complex and dynamic systems.

ANFIS controllers have gained popularity due to their ability to adapt and learn from system behavior, making them suitable for a wide range of applications, including industrial processes, robotics, and autonomous vehicles.

ANFIS, as the name suggests, is a hybrid control approach that integrates fuzzy logic and neural networks. Fuzzy logic is a mathematical framework that mimics human reasoning and deals with uncertainty in system behavior.

It uses linguistic variables and rules to represent and manipulate uncertainty in system inputs and outputs. Neural networks, on the other hand, are powerful computational models that can learn and generalize from data. They are capable of capturing complex patterns and relationships in data through training.

The ANFIS controller structure as shown in below Figure consists of five main components: fuzzifier, fuzzy rule base, fuzzy inference engine, defuzzifier, and learning algorithm. Let's discuss each component in detail:

1. Fuzzifier: The fuzzifier is responsible for converting crisp (numerical) inputs into fuzzy (linguistic) variables. It maps the system inputs to appropriate membership functions (MFs), which represent the degree of membership of a value to a particular linguistic term. The membership functions are defined based on expert knowledge or extracted from data using techniques such as clustering.

2. Fuzzy Rule Base: The fuzzy rule base contains a set of IF-THEN rules that describe the relationship between fuzzy inputs and fuzzy outputs. These rules are created based on expert knowledge or extracted from data. Each rule consists of antecedent and consequent parts. The antecedent contains fuzzy conditions, which are expressed in terms of linguistic variables and their corresponding membership functions. The consequent contains fuzzy actions, which are also expressed in terms of linguistic variables and their membership functions.

3. Fuzzy Inference Engine: The fuzzy inference engine performs the inference process to determine the fuzzy output based on the fuzzy inputs and fuzzy rules. It involves applying fuzzy operators such as AND, OR, and NOT to combine the fuzzy conditions in the antecedent of the rules and obtain a fuzzy output. Various inference methods such as Mamdani, and Sugeno, but in ANFIS Sugeno is used.

4. Defuzzifier: The defuzzifier is responsible for converting the fuzzy output obtained from the fuzzy inference engine into a crisp (numerical) value. It uses techniques such as centroid, mean of maximum (MOM), and weighted average to obtain a crisp output value.

5. Learning Algorithm: The learning algorithm in ANFIS controllers is responsible for updating the parameters of the membership functions and fuzzy rules based on the system's behavior. This allows the ANFIS controller to adapt and learn from the system in real-time. There are various learning algorithms used in ANFIS controllers, such as backpropagation, least squares, and hybrid algorithms.

3.3 Replacing PI Controller with ANFIS Controller: Role and Benefits

Replacing a conventional Proportional-Integral (PI) controller with an ANFIS controller can have several advantages in a control system. Some of the key benefits are:

1. Improved Control Performance: ANFIS controllers can provide better control performance compared to PI controllers in complex and dynamic systems. This is because ANFIS controllers are capable of capturing non-linearity's and uncertainties in system behavior through fuzzy logic and neural networks. They can adapt and learn from the system in real-time, allowing for more accurate and effective control actions.

2. Enhanced Robustness: ANFIS controllers are inherently robust

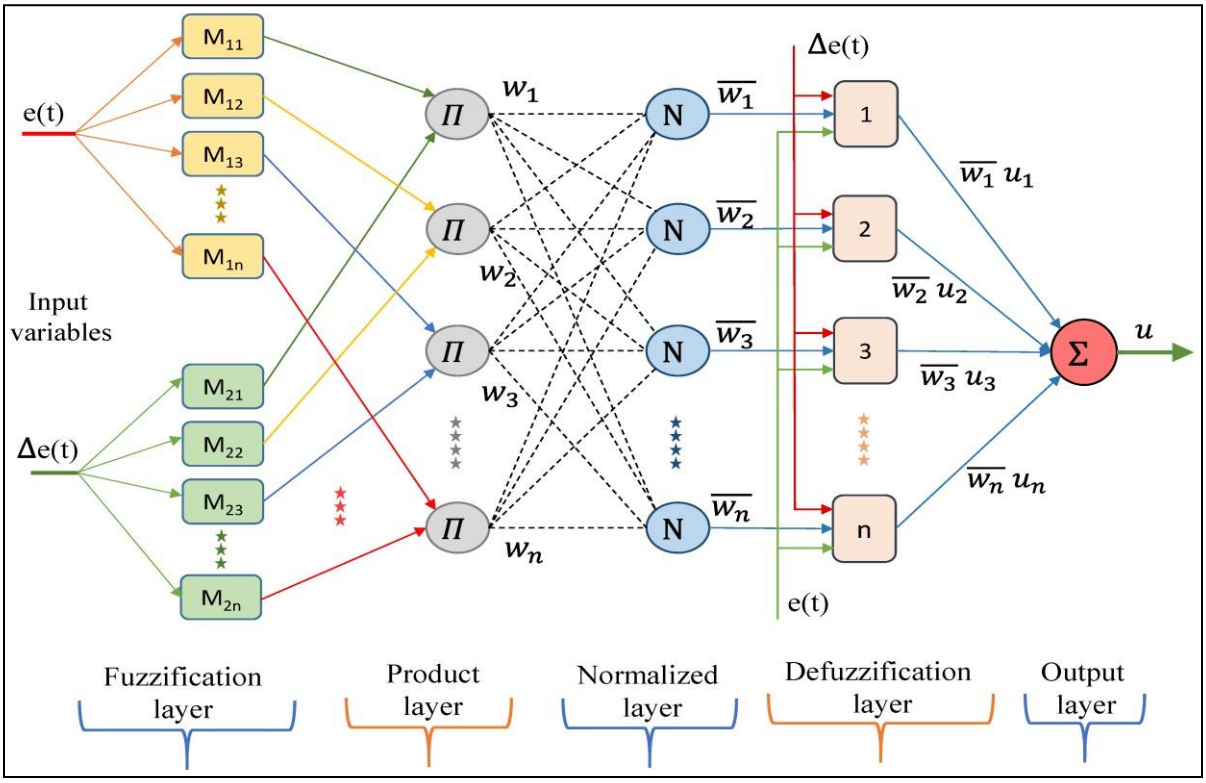

Fig 3.4: **ANFIS Structure**

ANFIS (Adaptive Neuro-Fuzzy Inference System) consists of five layers, each with its own set of equations. Here are the equations for each layer:

1. Layer 1 - Input Layer: In this layer, the input data is fuzzified, which involves calculating the membership values for each input variable based on the fuzzy membership functions.

The membership value for the i-th fuzzy set in the j-th rule for the k-th input variable can be calculated using the Gaussian membership function as follows:

$$u\_Aij(xk) = \exp(-((xk - cij) / dij)^2 \quad (3.4)$$

where xk is the k-th input variable, ci,j is the center of the membership function for the i-th fuzzy set in the j-th rule, and di,j is the width of the membership function for the i-th fuzzy set in the j-th rule.

2. Layer 2 - Rule Layer: In this layer, the fuzzy rules are fired based on the membership values obtained from Layer 1. The activation weight of each rule is calculated as the product of the membership values of all input variables associated with that rule.

The activation weight for the j-th rule can be calculated as follows:

$$wij = u\_A1ij(x1) * u\_A2ij(x2) \quad (3.5)$$

where μ_Aiij(xi) is the membership value of the i-th fuzzy set in the j-th rule for the corresponding input variable xi, and wij represents the activation weight of the j-th rule.

3. Layer 3 - Normalization Layer: In this layer, the activation weights from Layer 2 are normalized to ensure that they sum up to 1, which is necessary for defuzzification.

The normalized activation weight for the j-th rule can be calculated as follows:

$$wi.j = \frac{wij}{\sum wij} \quad (3.6)$$

where wij represents the activation weight of the j-th rule, and Σwij represents the sum of activation weights for all rules.

4. Layer 4 - Consequent Layer: In this layer, the output of the ANFIS system is calculated by combining the consequent part of each rule, which involves multiplying the normalized activation weight with the corresponding parameters of the consequent part.

The output of the ANFIS system can be calculated as follows:

$$y = \sum(wi.j * pi.j) \quad (3.7)$$

where wi,j represents the normalized activation weight of the j-th rule, and pi,j represents the parameters of the consequent part of the j-th rule.

5. Layer 5 - Output Layer: In this layer, the output of the ANFIS system is defuzzified to obtain a crisp output value, which is the final control signal for the system. The most commonly used method for defuzzification is the centroid method, which calculates the center of gravity of the fuzzy output.

The crisp output y can be calculated as follows:

$$y = \sum(wi.j * yi.j) \,/ \sum wi.j \tag{3.8}$$

where wi,j represents the normalized activation weight of the j-th rule, yi,j represents the crisp output value associated with the j-th rule, and Σwi,j represents the sum of normalized activation weights for all rules.

These are the equations used in the five layers of ANFIS controllers to perform fuzzification, rule firing, normalization, consequent calculation, and defuzzification, respectively. These equations collectively enable ANFIS controllers to perform.

CHAPTER FOUR

Design and Simulation Results

The Design's Main Description:

4.1. Diesel Generator

the diesel engine is responsible for generating mechanical energy through combustion of diesel fuel. This mechanical energy is then transferred to the generator, which converts it into electrical energy. The speed of the diesel engine is regulated by governor as shown, which ensures that the generator operates at the desired speed and frequency.

The efficiency of a DG set relies on the conversion of power from mechanical to electrical through the diesel engine and generator.

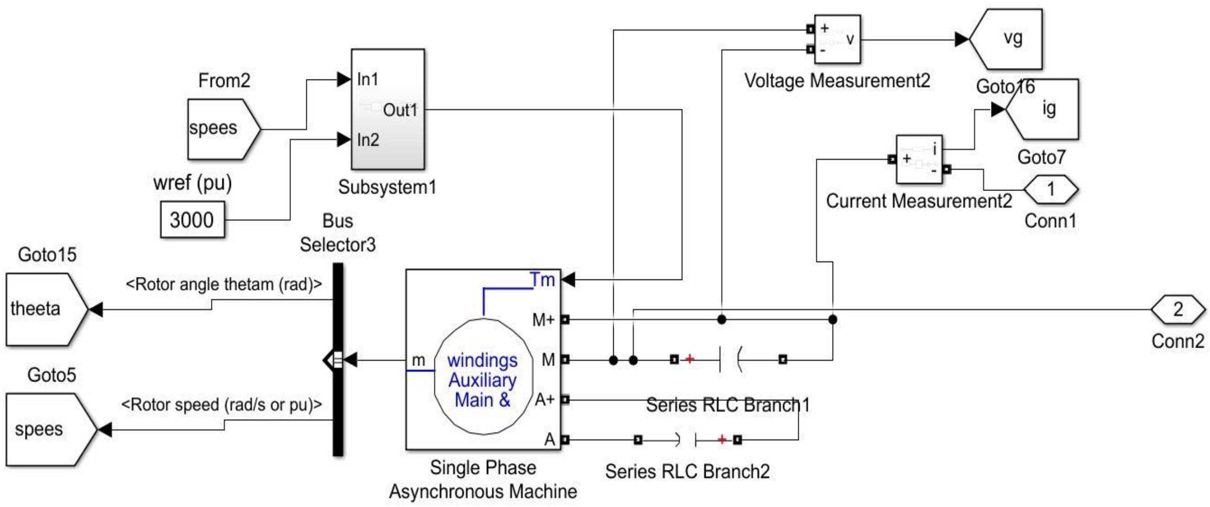

Fig. 4.1: Diesel Generator Block

4.2 Switchover of The DG and Grid Power

The synchronizing switch plays a crucial role in integrating the diesel generator set with the existing electrical power system. In a power system, it is important to maintain the frequency of the generated power in sync with the system frequency to ensure smooth and stable operation. The synchronizing switch is in-control for matching the frequency of the generator with the system frequency before the generator can start feeding power to the grid. If the frequencies are not matched, the generator cannot deliver AC power to the system due to the difference in the rotational speeds of the generator and the grid. This can result in disruptions and instability in the power system, potentially damaging electrical equipment.

To synchronize the generator, the speed setting of the generator is adjusted by providing additional energy to the generator axis. It’s achieved by boosting fuel oil to the engine combusting chamber, which in turn increases the rotational speed of the generator. Once the desired speed setting is reached, this speed will generate a field, and the voltage of generator is adjusted to match the other side. This is typically done using voltage regulators and other control systems.

The synchronization process ensures that the generator is operating in parallel with the grid, and the power generated by the generator is in phase and frequency with the existing power system. This allows the generator to supply power to the grid seamlessly without causing disruptions or instability.

It's important to note that the synchronization process should be performed carefully and by trained personnel to avoid any potential risks or damages to the generator or the power system.

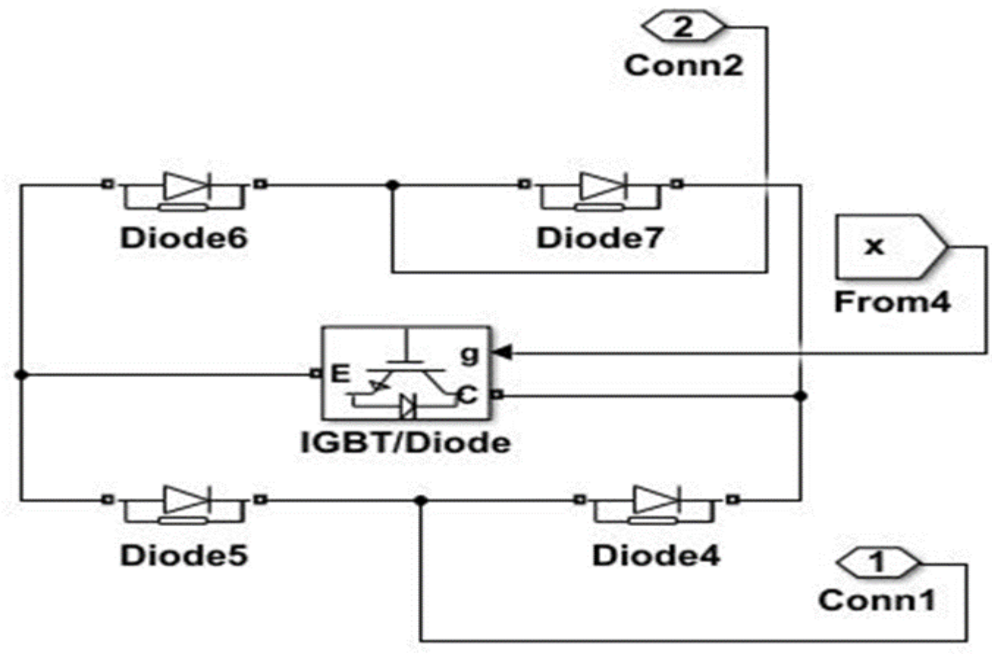

Fig 4.2: Sync Switchover

4.3 Power Grid System

A single-phase grid is kind of electrical power distribution network that consists of a 1- phase

AC voltage source, typically with a sinusoidal waveform, which is used to generate, transmit, and distribute electrical energy to consumers.

In this system, the voltage and current waveforms oscillate in a single direction, with one peak and one trough per cycle, and typically have a frequency of 50 Hz or 60 Hz, depending on the region.

In reality, an electrical grid system comprises a wide range of components such as transmission lines, transformers, switchgears, substations, generators, and various control systems. These components work together to generate, transmit, and distribute electrical energy from power generation sources to consumers.

The grid system is designed to handle a complex network of interconnected power generation sources, transmission lines, and distribution networks, and is subject to various operational constraints, regulations, and safety standards.

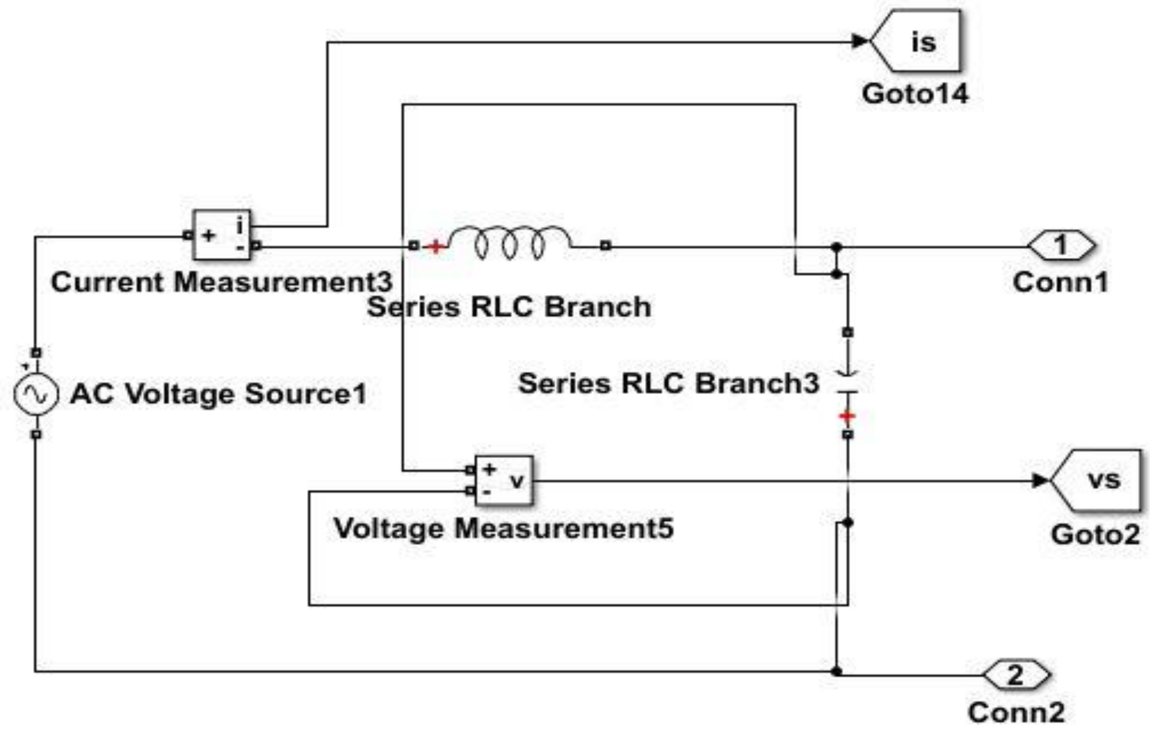

Fig 4.3: Grid Block

4.4 The Electric Vehicle

In an electric vehicle simulation, the battery is a critical component as it stores the electrical energy that powers the electric motor. Lithium-ion is commonly utilized in EVs due to their high energy density, long cycle life, and relatively light weight. The electric motor in an electric vehicle is responsible for converting the electrical energy from the battery into mechanical power for propulsion.

The motor controller, which manages the power flow to the motor based on the driver's input through the accelerator pedal. The controller adjusts the power delivered to the motor to control the vehicle's speed, acceleration, and other performance characteristics.

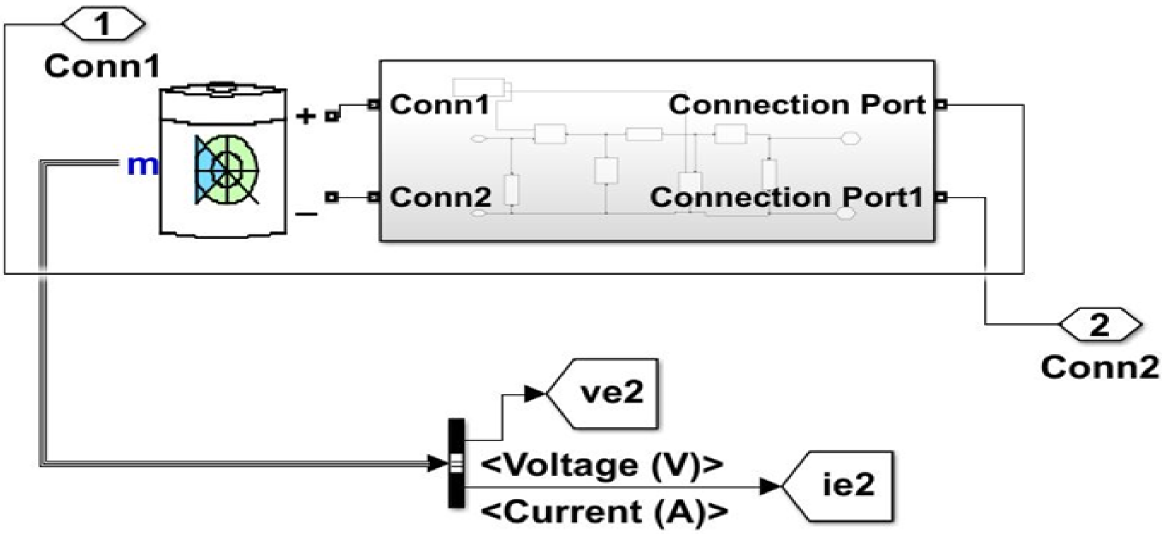

Fig 4.4: EV Block

4.5 The Voltage Source Converter (VSC)

The VSC typically consists of four IGBT diodes, connected to a series inductance on the AC side. These switches are controlled in a way that they can transform AC power into DC power, or vice versa, depending on the desired power flow direction.

The main goal of a VSC is to enable the integration of various power sources, such as energy storage devices, renewable energy sources (RES), and loads, into an electrical system with continuous power flow. The VSC can control the power flow direction, magnitude, and quality of the converted power, making it a versatile and efficient solution for power conversion in modern power systems.

In a single-phase VSC, the switches are typically operated using pulse width modulation (PWM) techniques, where the duration of the switch's ON and OFF states is controlled to achieve the desired output voltage or current waveform. The series inductance on the AC side helps in controlling the current and voltage in the converter, and it also provides impedance to the AC system.

The bidirectional capability of the VSC allows for energy transfer between the AC and DC systems, depending on the system requirements. For example, during periods of excess power generation from RES’s, the VSC can convert the surplus power into DC power and store it in energy storage devices, such as batteries or capacitors. Then, during periods of high power demand or when the renewable energy generation is low.

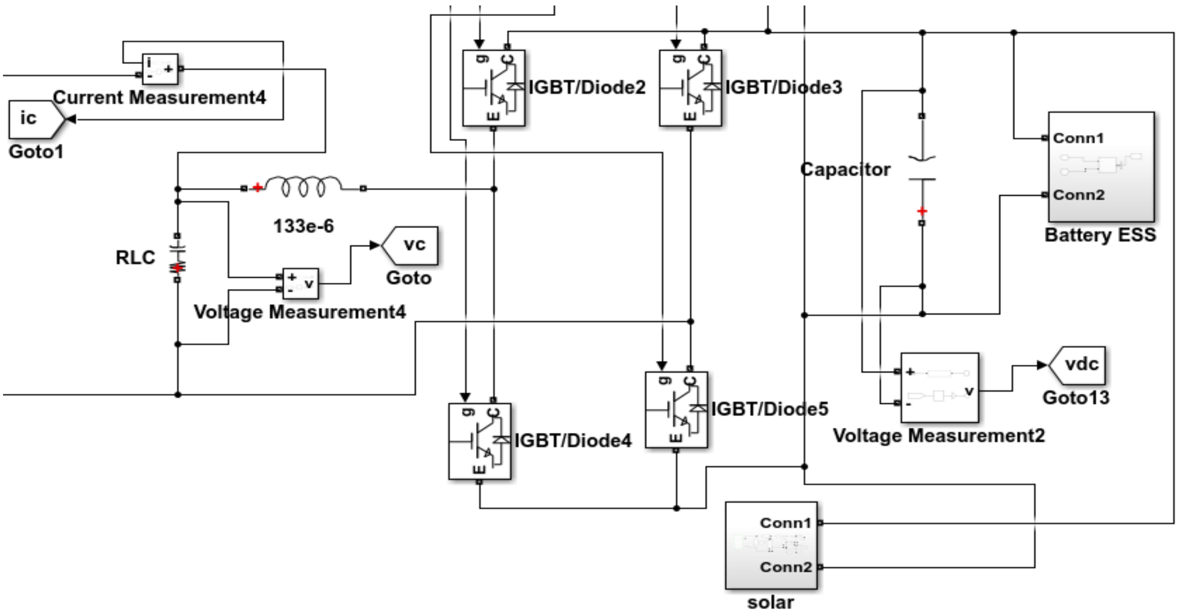

Fig. 4.5: VSC Block

4.6 The Energy Storage

They are used for stock piling the energy taken from various sources, such as solar PV panels, grid, and other renewable energy sources. It is typically consisting of batteries that store electrical energy in the form of chemical energy, which can be converted back into electrical energy when needed.

These batteries use improved battery technologies, such as lithium-ion batteries, which are widely used in modern energy storage systems due to their high energy density, long cycle life, and fast response times. One of the main purposes of this system is load shifting, ensuring that energy is available when needed and reducing the reliance on the grid during peak demand periods.

This can help to alleviate stress in the network and avert power outages, particularly when the electricity demand is high, such as hot summer days or sever weather events.

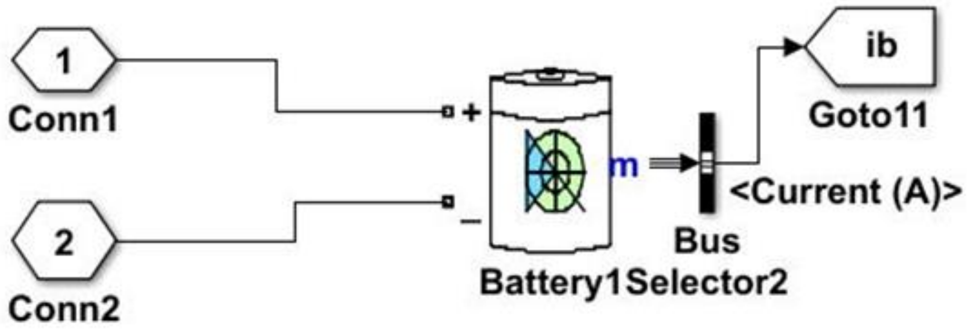

Fig 4.6: Battery Storage System Block

4.7 Model of Solar PV

In a solar PV system linked to a bi-directional converter, a boost circuit is often used to increase the voltage. The DC-DC converter is linked in series with the panels, allowing it to raise the DC voltage to a level suitable for the bi-directional.

The DC link is bind between the panel and the bi-directional converter, serves as a connection point for the energy flow between the two. It acts as a buffer, storing surplus power. The AC power can be used directly in the connected electrical system, or it can be stored in battery energy storage to utilized later on.

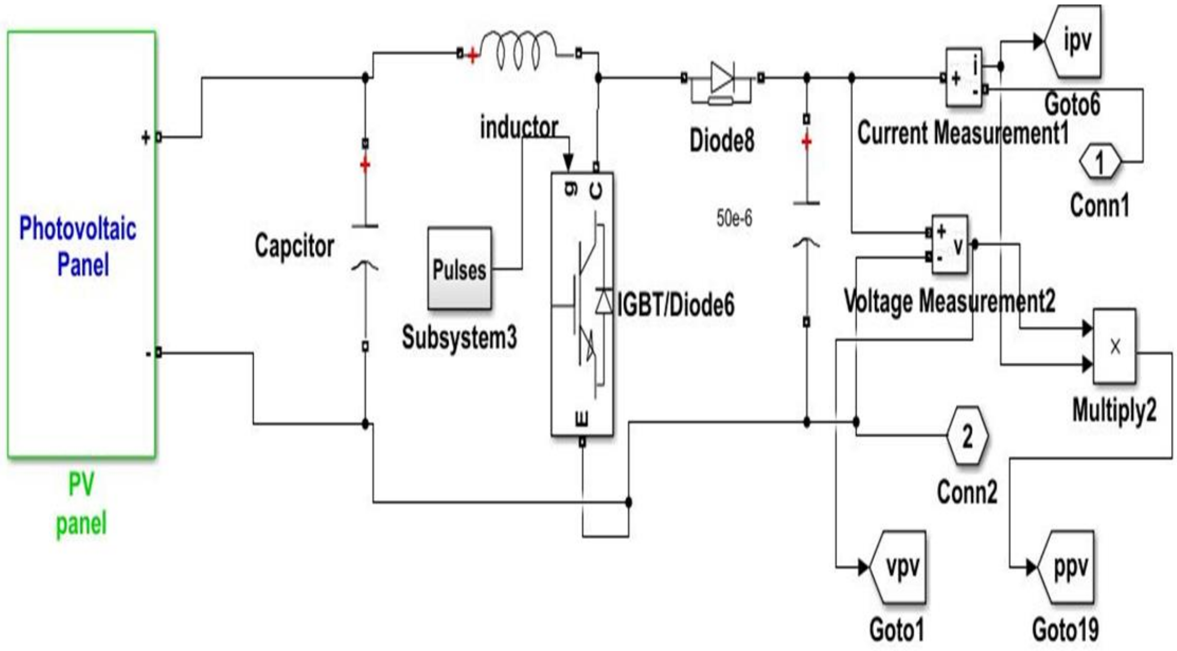

Fig 4.7: Solar PV Block

4.8 PWM Pulse Generations Using ANFIS

The applied pulse gate to the bi-directional converter in a system are typically dependent on frequency and voltage control of the diesel generator set. These control blocks work together to regulate the voltage output of the diesel engine, ensuring that it meets the desired voltage requirements.

One commonly used control strategy for regulating the voltage is the Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. In the case of the bi-directional AC to DC converter, the ANFIS controller takes in two inputs the constant voltage reference value and the error voltage.

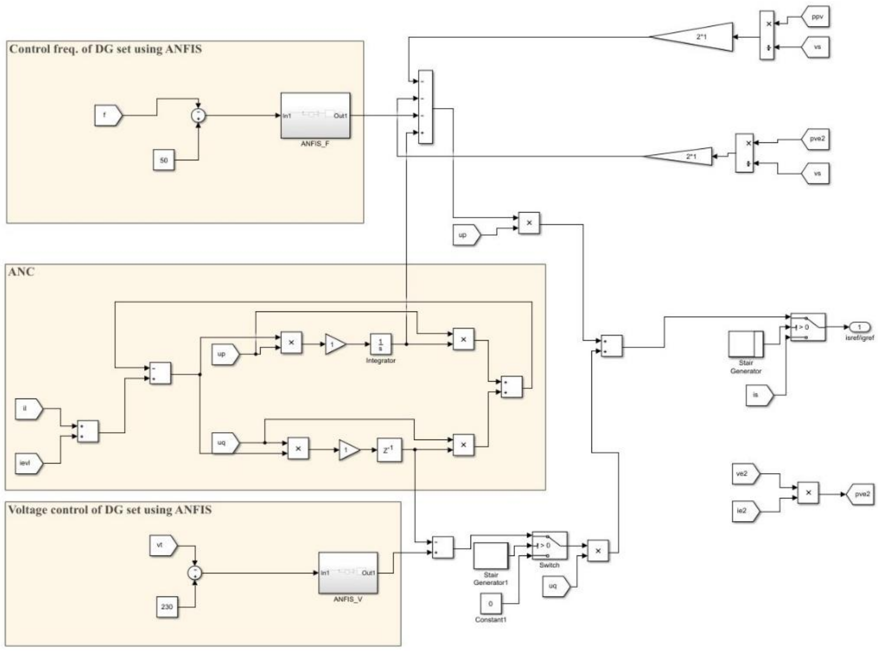

Fig.4.8: PWM Using ANFIS Block

4.9 The Combination Scheme of The EV Charging Station

The diagram illustrates how the vehicle and load are operated and controlled, utilizing diverse energy sources. On the alternative current side there VSC, the 1-phase grid are interconnected via an inductor, referred to as the PCC. The Filters elements are connected at this junction to mitigate distortions arising from the grid and generator set.

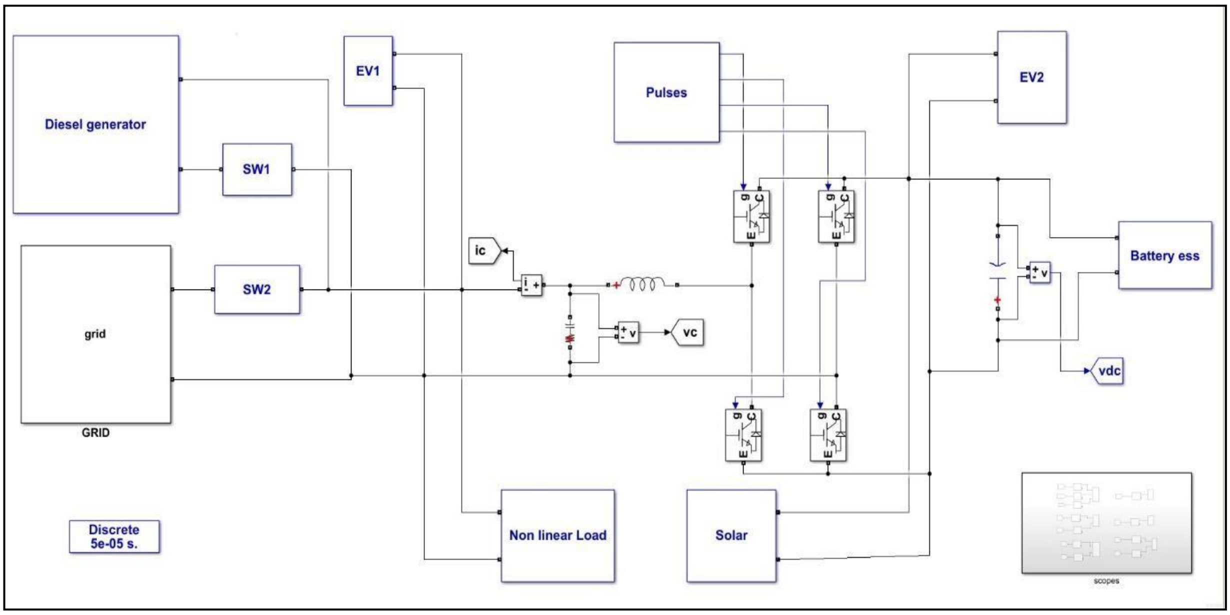

Fig 4.9: **The Combined Proposed Design Model**

4.10 Simulation Results

The below figures shown the simulation results, and it perform continues work of the CS, the operation in various modes. as in figures, with the PI and ANFIS controllers the CS performed. A persist power to CS working is accomplished in off-grid and power grid. In sufficient existence of solar energy, the CS utilize it with its maximum energy.

While the solar power is reaching the desire, and if the PV power in decay, then the BESS start discharging supports the CS. After a while, when the battery storage is exhausted, the charging station intelligently shifts from the battery storage power into the grid power to keep the CS uninterrupted. Worse case is when the solar power unavailable, the only alternative is to enable the DG to draw electricity while the BES is draining and the grid is shut down. Always, the DG set is running in the practical load to realize the preserved fuel efficiency, this done by regulating the battery system charging, and alimentation of the CS.

It is recognized that the charging station smartly shift between several modes according to it demands**.** The charging station (CS) operates uninterruptedly using different power sources. Initially, the CS operates in standalone, with power from the solar panels being used to charge the electric vehicles connected at the PCC.

Since the solar generates surplus energy that exceeds the charging demand of the EVs, the excess power is stored battery bank.

When the 0.32 seconds, the irradiance variation from 1000 W/m2 to 500 and then to 300, causing a reduction in the PV array power. As a result, the energy storage system starts discharging to ensure uninterrupted charging of the EVs. At 0.48 seconds, the storage battery is completely discharged as the solar power is low. Subsequently, the storage battery continues to support the charging process in smooth sync.

At 0.79 seconds, the charging station starts supplying energy, as the grid becomes available. However, due to the unavailability of grid power and battery power, the CS is supported by a diesel generator (DG) set. From the observation, it can be seen that the charging station automatically switches between different modes depending on the generation and demand conditions.

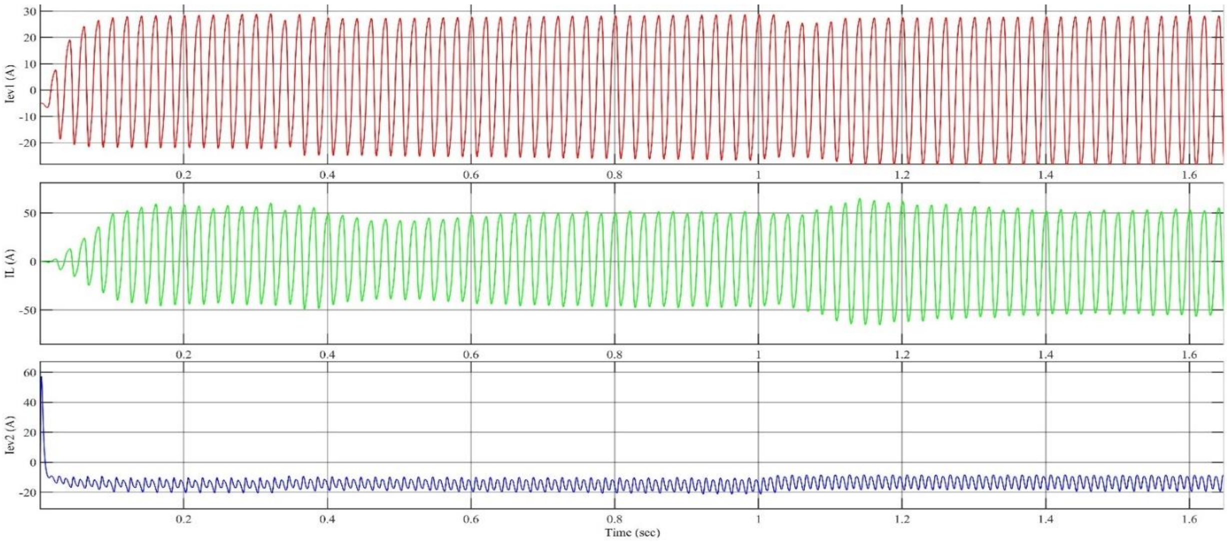

Fig.4.10.1: Current Waveform of EV1 and EV2 and Current Load

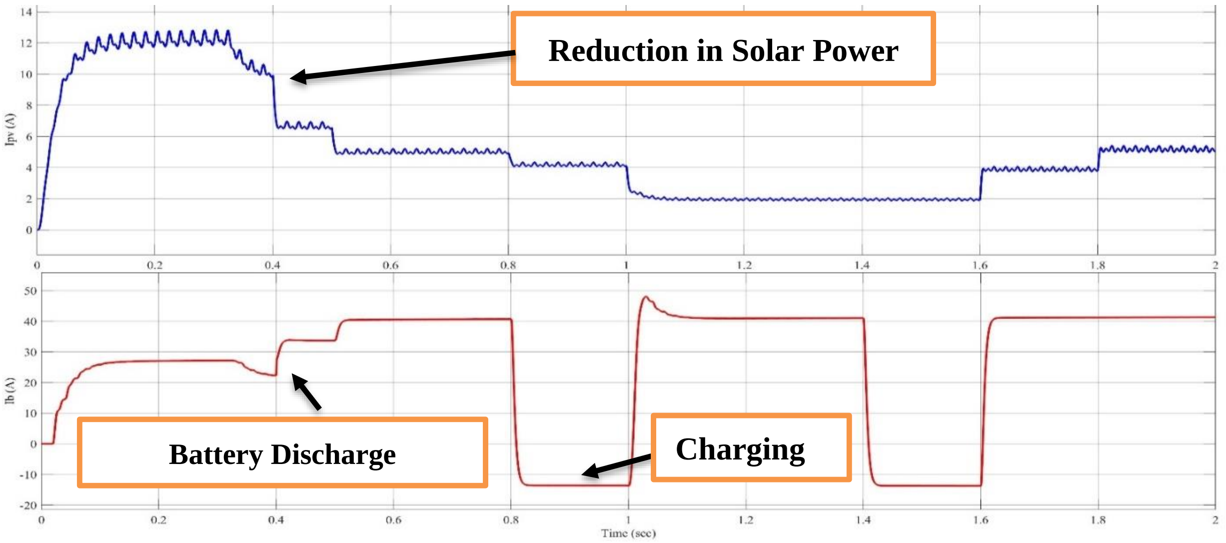

Fig. 4.10.2: Solar PV and Battery Currents

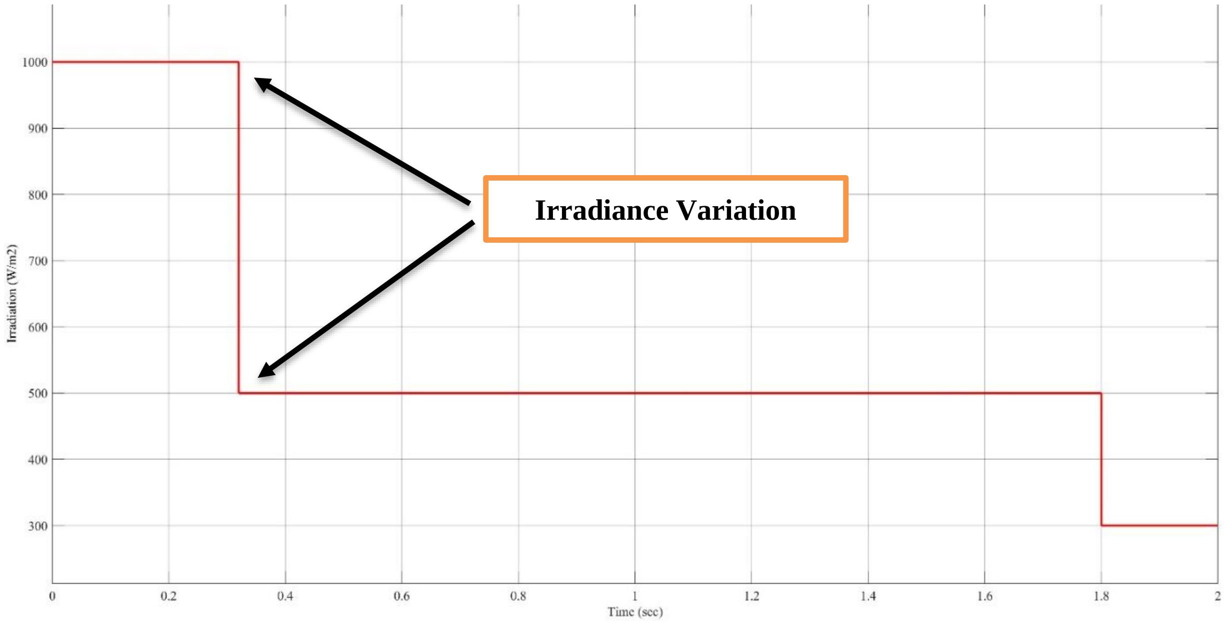

Fig. 4.10.3: Irradiation Change

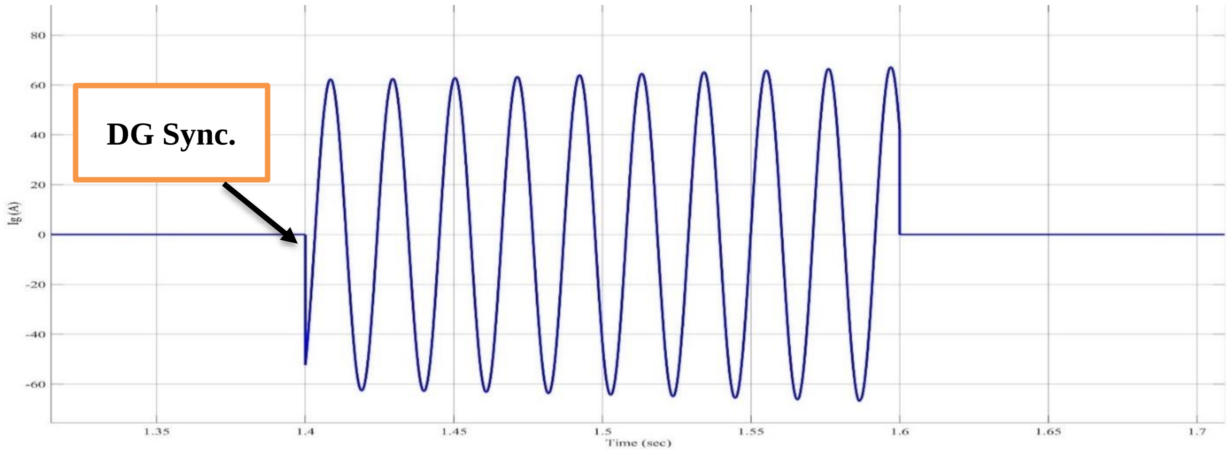

Fig. 4.10.4: DG Set Current

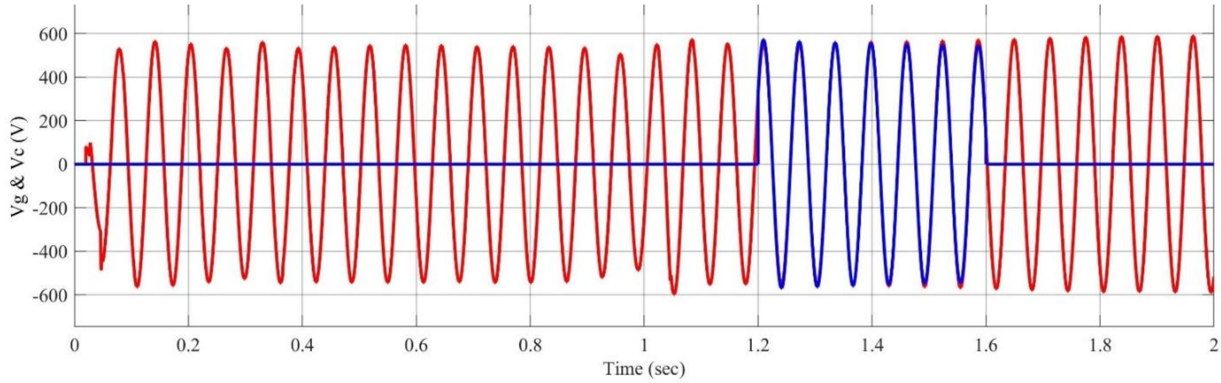

Fig. 4.10.5: DG Set Voltage and PCC Voltage

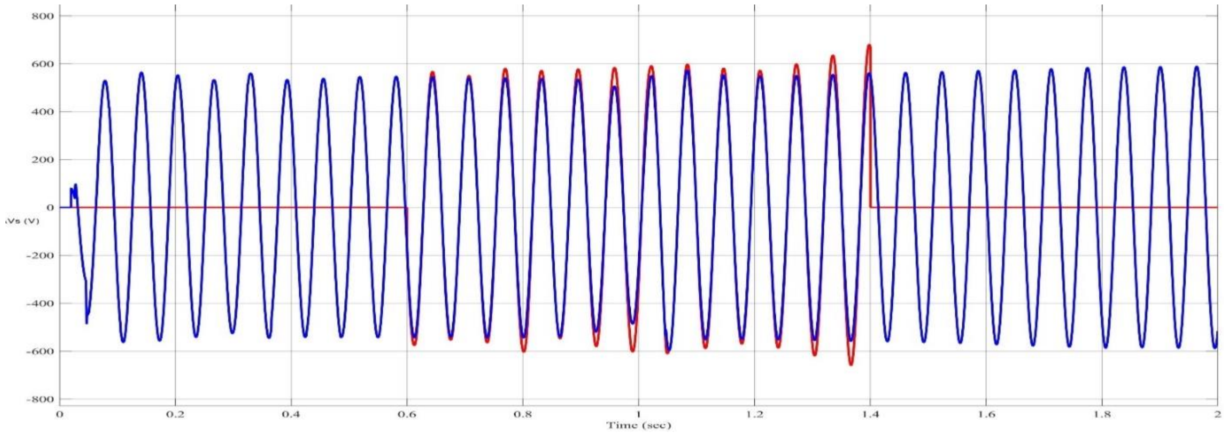

Fig.4.10.6: PCC Voltage and Grid Voltage

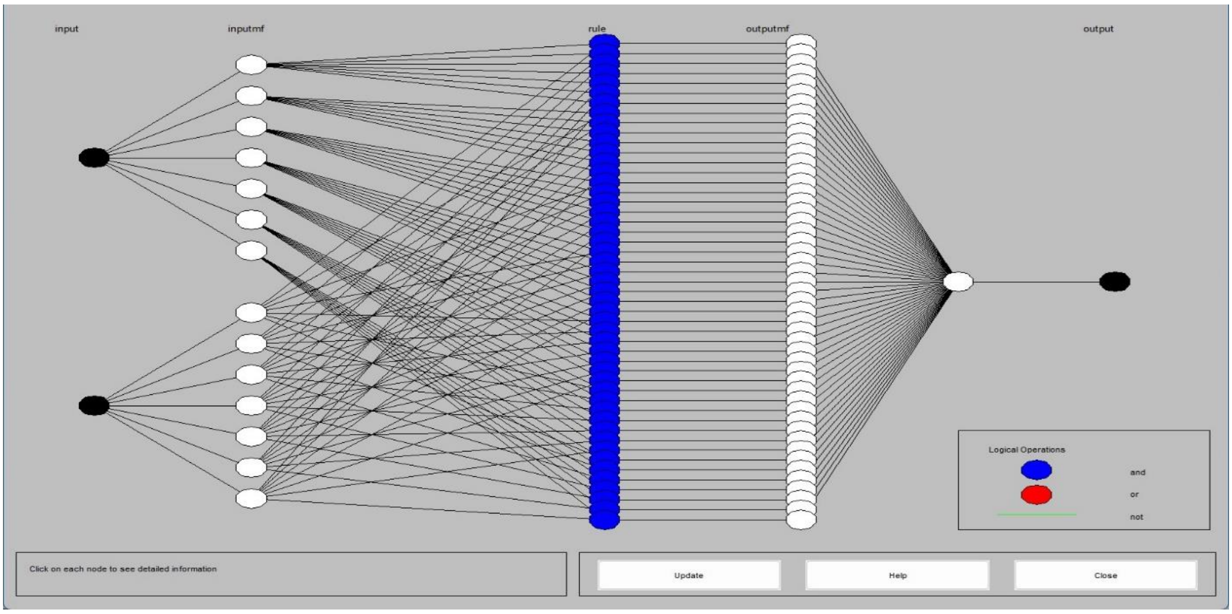

Fig. 4.10.7: ANFIS Structure

Fig.4.10.8: ANFIS Rules

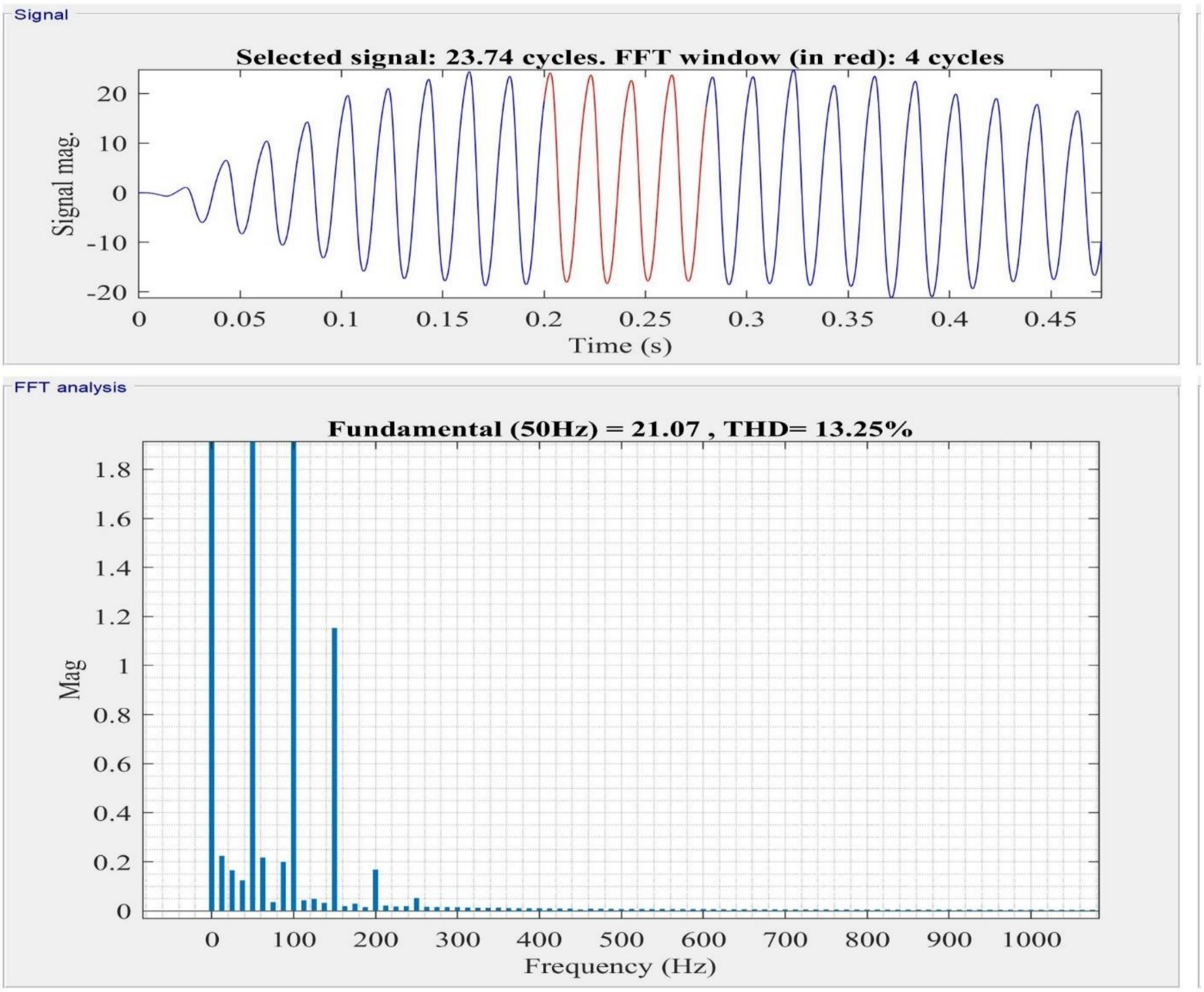

Fig.4.10.9: THD Using ANFIS Controller

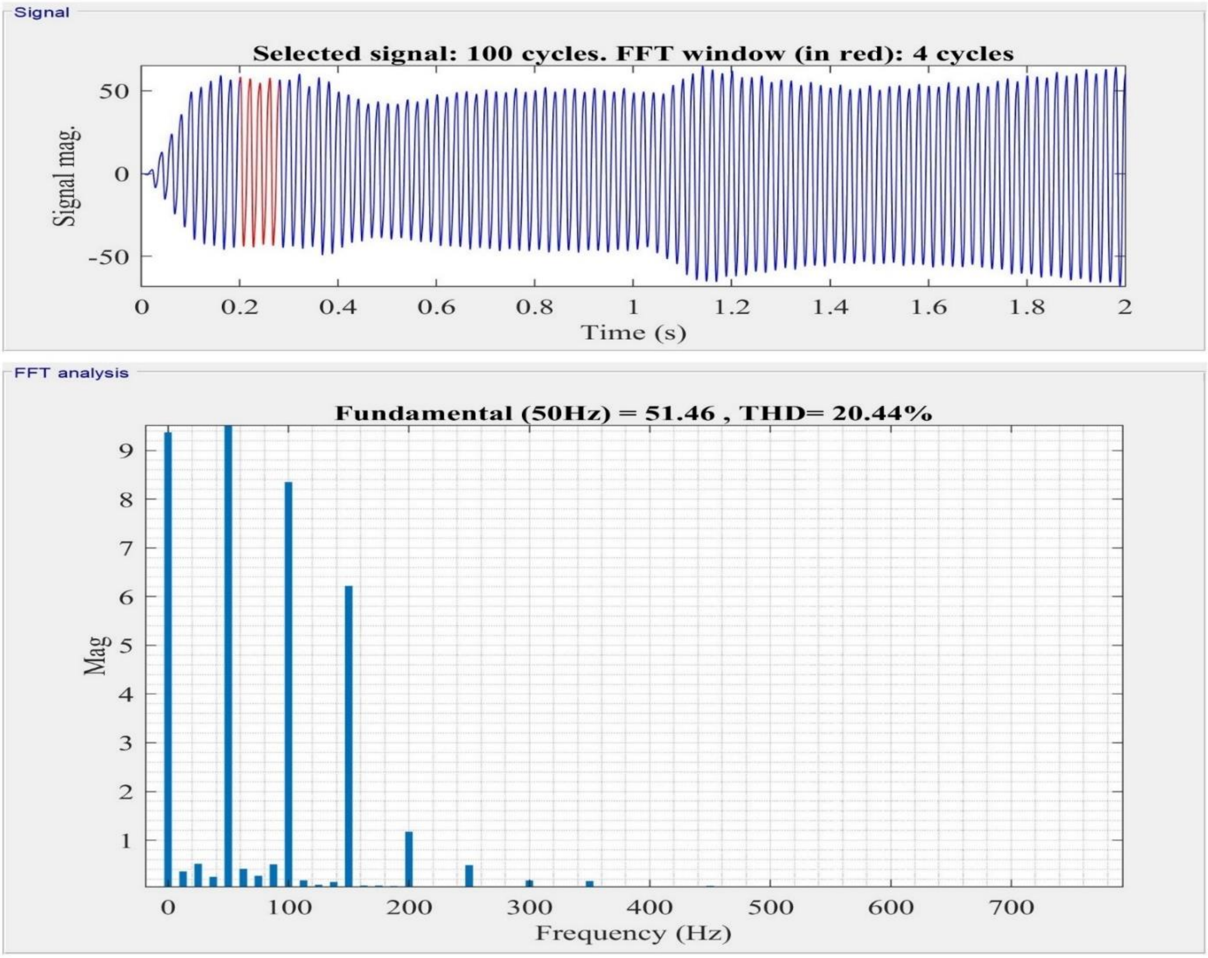

Fig.4.10.10: THD Using PI Controller

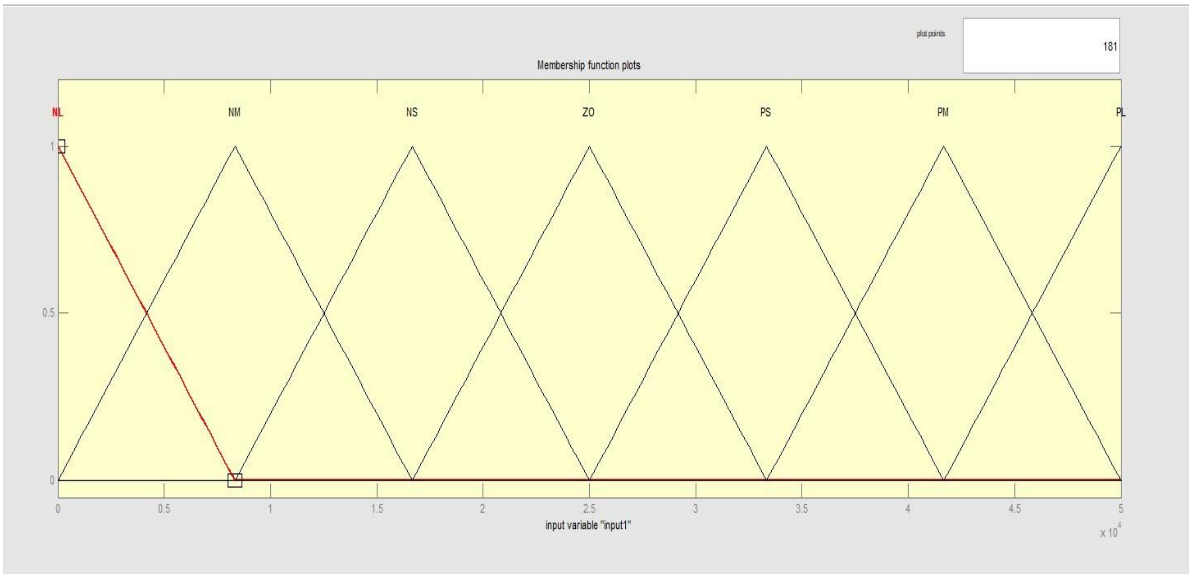

Fig.4.10.11: Membership Function of ANFIS

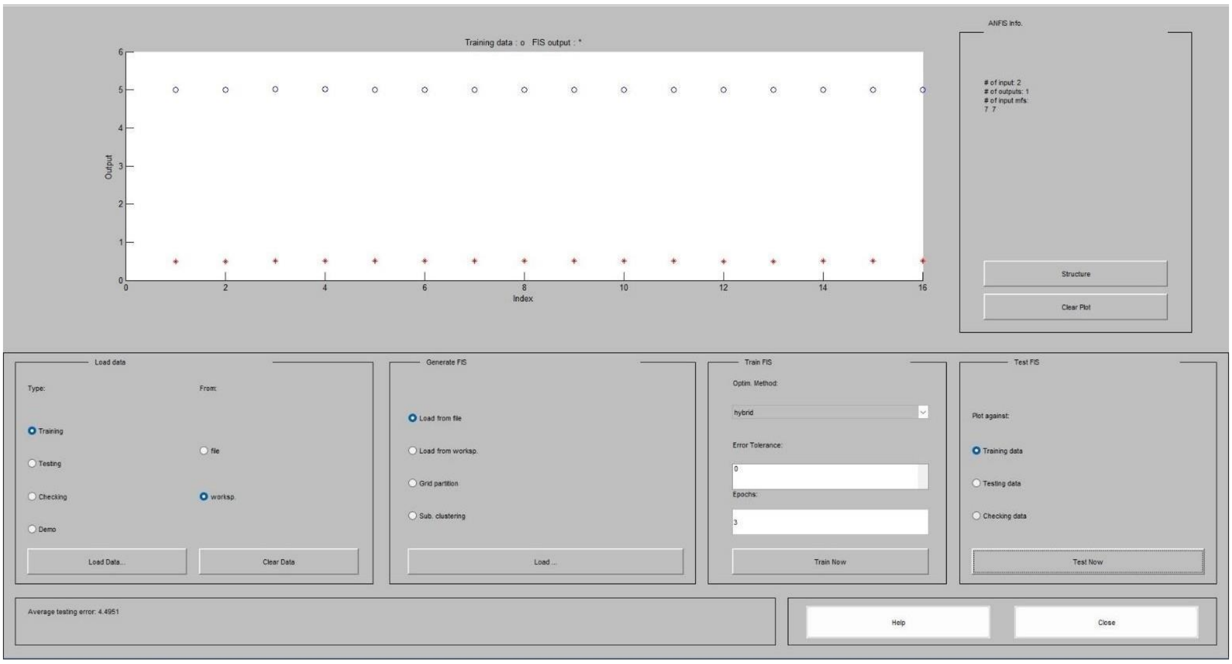

Fig.4.10.12: ANFIS Data Training

CHAPTER FIVE

CONCLUSION AND FUTURE RECOMMENDATIONS

5.1 Conclusion

The implementation of CS is linked to grid, a solar PV, battery system, and also the set DG setup purpose of charging EVs has been verified. The obtained outcomes have proved in the multi modes of operation. The single voltage source converter used the three modes in the charging station. The proven results also consider various running statuses, such as a change in load demand, the fluctuation in solar-generated during daylight due to irradiance level, and the availability/unavailability of grid power. The control configuration has the ability to automatically regulate the balance of the load and demand, the method of control used in power interchange preserved with grid or at maximum load of DG set. THD also was less than 15%, and it shows the efficiency of the controller. From the presented information we can conclude that the CS with this controller has achieved the capability and it can utilize different sources with high efficiency, and low cost, and continuously supply the CS

5.2 Future Recommendations

The current design uses an ANFIS controller and in the future can add more ANFIS controllers instead of PI controllers for different positions of control, and as well another source can be added such as wind turbine generator.

References

[1] International Energy Agency-Global EV Outlook 2017-Two Million and Counting. [Online]. Available:https://www.iea.org/publications/freepublications/publication/Global EVOutlook2017.pdf

[2] Musadg.Z, S.Anusha, M.Sirisha,''A Multi-Mode Operating Tri-Port Based Electric Vehicle Charging Station'', IJEEE,Vol 8,doi:10.14445/23488379/IJEE, Aug.2021

[3] G. R. Chandra Mouli, J. Schijffelen, M. van den Heuvel, M. Kardolus and P. Bauer, "A 10 kW Solar-Powered Bidirectional EV Charger Compatible with Chademo and COMBO," *IEEE Trans, Power Electron.*, vol. 34, no. 2, pp. 1082-1098, Feb. 2019.

[4] J. Ugirumurera and Z. J. Haas, "Optimal Capacity Sizing for Completely Green Charging Systems for Electric Vehicles," *IEEE Trans. Transportat. Electrificat.*vol. 3, no. 3, pp. 565-577, Sept. 2017.

[5] S. A. Singh, G. Carli, N. A. Azeez and S. S. Williamson, "Modeling, Design, Control, and Implementation of a Modified Z-Source Integrated PV/Grid/EV DC Charger/Inverter," *IEEE Trans. Ind. Electron.*, vol. 65, no. 6, pp. 5213-5220, June 2018

[6] V.onteiro, J. G. Pinto and J. L. Afonso, "Experimental Validation of a Three-Port Integrated Topology to Interface Electric Vehicles and Renewables with the Electrical Grid," *IEEE Trans. Ind. Informat.*, vol. 14, no. 6, pp. 2364-2374, June 2018

[7] Y. Zhang, P. You and L. Cai, "Optimal Charging Scheduling by Pricing for EV Charging Station with Dual Charging Modes," *IEEE Trans. Intelligent Transportat. Syst.*, vol. 20, no. 9, pp. 3386-3396, Sept. 2019.

[8] F. Kineavy and M. Duffy, "Modelling and design of electric vehicle charging systems that include on-site renewable energy sources," in *IEEE 5th Int. Symp. Power Electron. For Distributed Gene. Syst. (PEDG)*, Galway, 2014, pp. 1-8.

[9] N. K. Kandasamy, K. Kandasamy and K. J. Tseng, "Loss-of-life investigation of EV batteries used as smart energy storage for commercial building-based solar photovoltaic systems," *IET Electrical Systems in Transportation*, vol. 7, no. 3, pp. 223-229, 9 2017.

[10] A. Tavakoli, M. Negnevitsky, D. T. Nguyen and K. M. Muttaqi, "Energy Exchange Between Electric Vehicle Load and Wind Generating Utilities," *IEEE Trans. Power Sys.*, vol. 31, no. 2, pp. 1248-1258, 2016.

[11] Y. Shan, J. Hu, K. W. Chan, Q. Fu and J. M. Guerrero, "Model Predictive Control of Bidirectional DC-DC Converters and AC/DC Interlinking Converters - A New Control Method for PV-Wind-Battery Microgrids," *IEEE Trans. Sustain. Energy*, Early Access.

[12] P. Liu, J. Yu and E. Mohammed, “Decentralised PEV charging coordination to absorb surplus wind energy via stochastically staggered dual-tariff schemes considering feeder-level regulations,” *IET Gene., Trans. & Distri.*, vol. 12, no. 15, pp. 3655-3665, 28 8 2018.

[13] B. Singh, A. Verma, A. Chandra, and K. Al-Haddad, “Implementation of Solar PV-Battery and Diesel Generator Based Electric Vehicle Charging Station,” *IEEE Trans. Ind. Appl.*, vol. 56, no. 4, pp. 4007–4016, 2020, doi: 10.1109/TIA.2020.2989680

[14] N. Saxena, B. Singh and A. L. Vyas, “Integration of solar photovoltaic with battery to single-phase grid,” *IET Generation, Transmission & Distribution*, vol. 11, no. 8, pp. 2003-2012, 1 6 2017.

[15] H. Razmi and H. Doagou-Mojarrad, “Comparative assessment of two different mode’s multi-objective optimal power management of micro-grid: grid-connected and stand-alone,” *IET Renewable Power Generation*, vol. 13, no. 6, pp. 802-815, 2019.

[16] O. Erdinc, N. G. Paterakis, T. D. P. Mendes, A. G. Bakirtzis and J. P. S. Catalão, “Smart Household Operation Considering Bi-Directional EV and ESS Utilization by Real-Time Pricing-Based DR,” *IEEE Trans. Smart Grid*, vol. 6, no. 3, pp. 1281-1291, May 2015.

[17] H. Kikusato, K. Mori, S. Yoshizawa, Yu Fujimoto, H. Asano, Y. Hayashi, A. Kawashima, S. Inagaki, T. Suzuki, “Electric Vehicle Charge-Discharge Management for Utilization of Photovoltaic by Coordination between Home and Grid Energy Management Systems,” *IEEE Trans. Smart Grid*, Early Access.

[18] F. Hafiz, A. R. de Queiroz and I. Husain, “Coordinated Control of PEV and PV-based Storages in Residential System under Generation and Load Uncertainties,” *IEEE Trans. Ind. Applica.*, Early Access.

[19] R. W. Wies, R. A. Johnson, A. N. Agrawal and T. J. Chubb, “Simulink model for economic analysis and environmental impacts of a PV with diesel-battery system for remote villages,” *IEEE Trans. Power Systems*, vol. 20, no. 2, pp. 692-700, May 2005

[20] Kiran.K, Sumit.K, Lalit.M,’’ANFIS Controlled Grid Connected Electric Vehicle Charging Station Using PV Source’’, 2020.

[21] Jyh-Shing Roger Jang,’’Adaptive - Network -Based Fuzzy Inference System’’IEEE Trans. Sys.Cyber, doi:10.1109/21.256541 June 1993