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ANALYSIS OF RENEWABLE ENERGY-BASED HYBRID MICROGRID USING MPPT ALGORITHM

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ABSTRACT

Microgrids are gradually making their way from research labs and demonstration sites to the commercial markets, propelled by advancements in technology, declining costs, and expanding awareness of their advantages. This paper work proposes a Renewable energy based microgrid model with photovoltaic panels, and wind energy system as source, an energy storage system, and loads. In the proposed model to extract maximum power from solar PV cell and wind energy system MPPT algorithm is used. The voltage and current profile are maintained at a constant value by using low pass filters. DQ reference frame is used to design the inverter control for islanded and grid connected mode of operation. A LCL filter is placed at the output of inverter to reduce harmonics. The simulation profile is designed using "MATLAB 2021b" software. The proposed microgrid concept can run in an island mode or be connected to the main grid. The microgrid contains a DC bus to connect solar PV modules, WECS, and BESS elements. To connect the microgrid into grid, An DC-AC inverter is being designed. The simulation results are presented, and the results are discussed in detail which can help other researchers working on Renewable energy and microgrid control.

Keywords: Microgrid, Renewable Energy, Wind Energy Conversion System, Photovoltaic, Battery Energy Storage System.

I. INTRODUCTION

The deterioration of fossil fuels like coal, natural gas, and petroleum is a result of the world's exponentially growing energy consumption. The gases that cause the greenhouse effect then rise as a result. On global scale many small- and large-scale RE sources like wind energy, solar PV energy, biomass energy, tidal energy has merged to meet power demand. By 2040, when renewable sources should make up 40% of the world's energy mix, the demand for energy will have increased by more than a quarter globally. The imbalance between energy demand and supply is the fundamental factor posing a significant barrier to the reliability of RE sources. Energy is now produced close to where it is used because of rising energy demand and redesigning of power infrastructure [1]. Energy produced from renewable sources are becoming more and more competitive because of reduction in cost and technological advancement in the solar PV energy and wind energy power generation [2].

Because of the high dependence on climatic and meteorological circumstances, the ideal solution is frequently a hybrid RE system with BESS systems (considering one or more renewable sources)

Hybrid power systems are used to supply electricity for many purposes, including communication systems transmitters devices, and many other self - contained systems, as well as homes or farms in remote locations without electric grid. In comparison to systems that use only one energy source, hybrid solutions frequently offer the highest reliability and lowest prices. A MG is a collection of loads, energy storage system devices, and limited generation. A microgrid is made up of several loads, energy storage devices, and miniaturized power plants. In a broader sense, it is a moderate transmission grid with distributed generation, along with renewable and non - RE sources, and energy storage devices [3].

Energy Storage system increases the MG's dependability and is utilized to balance for the variable nature of the PV and wind output electricity. The storage is employed to balance for the intermittent nature of solar and wind energy output. For real-time management, these MG have the essential communication systems [11]. These MG can function both independently and when connected to a grid because they contain the communication protocols required for real-time management.

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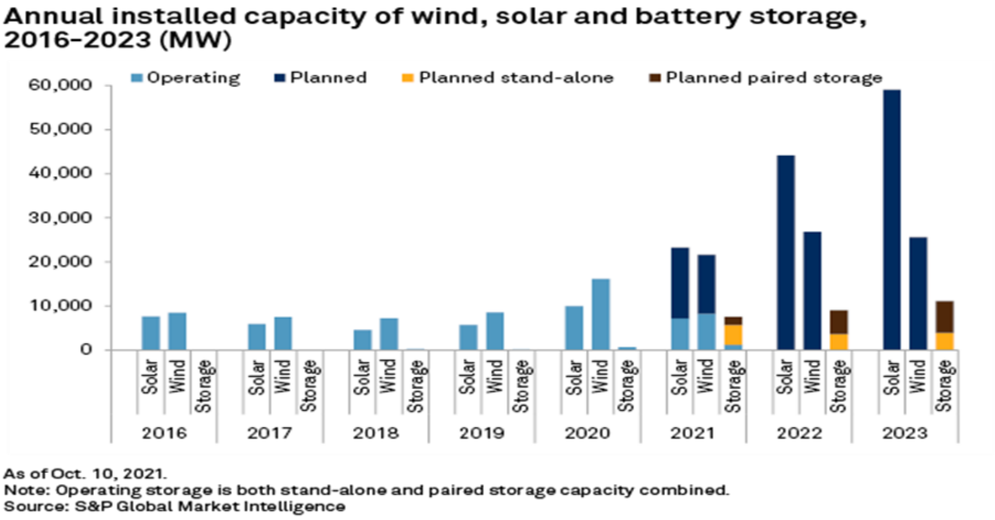

Figure 1: Annual installed capacity of wind, solar, and BESS

II. MICROGRID OPERATION MODES

Islanded Mode of Operation

The standalone power system is a suitable solution in distant areas where services, in specific transmission lines, are very costly to operate or problematic to create because of their high cost and/or challenging terrain, etc. Stand-alone systems can be divided into two categories: one with common DC buses and another with common AC buses. The two resources are combined into an ideal system, which partially mitigates the fluctuating character of the solar and wind energy and increases the system's dependability. For a brief time, the power of one source could outweigh the weakness of the other. The main economic problem for stand-alone systems continues to be storage costs. By combining wind, solar, and PV energy, it is possible to reduce the amount of storage needed and, ultimately, the system's overall cost.[13]

Expanding the number of PV panels and wind turbines might be preferable than increasing the number of batteries because batteries are more expensive and have a shorter lifespan than PV or WTs. However, for highly reliable systems, insufficient battery capacity makes it impossible to achieve reliability standards, which results in higher costs due to the need for an excessive number of PV modules or big WTs. It is becoming more and more affordable to address the issue of few usable RE throughout the year by integrating RE generation with BESS and DG backup systems. However, there is no mechanism to import energy if storage runs out. Consequently, combining fuel cells with solar and wind energy sources is a possible alternative back-up RE source for hybrid energy generation systems. Since the units of distributed generators will be close to the loads, they can help with power supply variations. Distributed generators will, however, necessitate an upgrade to the current protection plans [10] [31].

Grid Connected Mode of Operation

The cost of RE generation can be decreased, and its ability to reliably meet demand can be increased, by integrating combined solar energy power plant and WPP into the grid. The main grid purchases extra RE from RE sources and supplies it to the loads at the sites as where it is needed. The grid-connected common DC and common.

Hybrid Mode of Operation

Particularly for isolated applications, hybrid solar PV system and wind energy production systems offer a particularly appealing alternative. The hybrid energy system becomes more cost-effective to operate when the two energy sources—solar energy and wind energy —are combined since the weaknesses of each system can be made up for by the advantages of the other. The efficiency and dependability of RE generation to meet demand can be further improved with the grid integration of hybrid solar and wind power systems. Similar to this, the amount of energy storage required to provide continuous power can be decreased by incorporating hybrid solar PV and wind power into the islanded system. Either PV or concentrated solar power are used in solar electricity producing systems [6]. The sort of PV will be the main topic of this study. Many textbooks and papers, including, provide thorough explanations of the many technologies, physics, and fundamentals of PV. The amount of incident radiation heavily influences the outputs that PV modules produce. The photocurrent will increase, and the open-circuit voltage will decrease as the light intensity rises. Any photovoltaic cell's efficiency declines when temperature, which is unevenly distributed across the cell, rises. The spread of solar energy across various geographical locations can level out the solar output power [9]. To significantly penetrate the market, solar PV and concentrated solar power plants' electricity must either see a large cost reduction or a change in policy that either mandates or subsidizes the use of these technologies.

III. COMPONENTS OF MICROGRID

An MG is a local energy system in which includes three major components are Generation, storage, and Load demand. The generation unit comprises of different RE based source like solar PV module and Wind energy system. Major drawback of RE based generation unit is that production of power depends upon climatic condition which is always fluctuating.so, to provide a reliable power supply, we required Energy Storing System.in this paper there is a detailed study on a renewable energy-based hybrid microgrid is discussed [6]. The designed system can operate in both islanded and grid connected mode. To get the most power out of the PV module and wind energy combination, an MPPT algorithm is applied. In later chapters, the detailed analysis of each component is covered in detail. [14] [32]

Modelling of the Wind Energy Conversion System

The system includes the rectifier, DC DC boost converter, direct driven PMSG, and necessary control techniques for hybrid mode operation. To get the most power out of WECS, MPPT algorithm generates the duty cycle for the boost converter. [17][26]

Wind Turbine with PMSG Model

The amount of energy that the blades can capture and convert into mechanical power can be written as

$$P_M = \frac{1}{2}\rho A v_w^3 C_P \qquad (1)$$

where ρ represents the air density, A denotes the cross-sectional area which the wind flows through, speed of wind is denoted by Vw, and Cp represents the power coefficient of the blade. The power coefficient Cp is being calculated from β which is the pitch angle, λ is the tip speed ratio of wind turbine blades and λ_i can be written as

$$C_P = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{-21}{\lambda_i}} + 0.0068\lambda \qquad (2)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \qquad (3)$$

When the speed of wind is less than its rated value, the wind turbine operates in generator mode; when the rated speed of wind is more than its rated value, it operates in pitch control mode. To harness the full potential of the wind, an MPPT control mechanism is used in this study for the generator control mode. To control the pitch angle, a PI controller is used. The rate limiter and hard limiter are used to restrict changing rate of pitch angle and boundary values. The pitch control method states that when Pm is equal to or less than Pref, the negative error and must be maintained at its ideal value to harness the maximum amount of wind energy possible based on the MPPT control. When Pm exceeds Pref, a positive error results, and the wind turbine's output is limited to keep it from going beyond its designed capacity. indicating that the speed of wind is greater than the planned cut-off speed. If the speed of wind is greater than the planned cut off speed, Pm will change to pitch out of the turbine blade and the wind generator turbine will be shut down [25]. The model, which is accessible in Simulation, is the PMSG employed in this paper. It is a synchronous non-salient generator. There is no gearbox between the wind turbine and the generator [37].

PMSG Operation with Varied Speed of winds

The various speed of winds through the following equations to validate the modelling and control approach used in this paper. where Vw gives the speed of wind available to the turbine, Vm represents the average speed of wind, k is the change in the speed of wind as ramp function, t1 and t2 gives the starting and ending time resp. of the speed of wind ramping duration, VES gives the external speed of wind of the wind source.

$$V_w = \begin{cases} V_m & t < t_1 \\ V_m + k(t - t_1) & t_1 < t < t_2 \\ V_m + k(t_2 - t_1) & t > t_2 \end{cases} \quad (4)$$

$$v_{ES} = k(t_2 - t_1) \quad (5)$$

We are unable to maintain a steady output voltage as the speed of wind fluctuates when the PMSG is connected directly to different loads without any converters. Back-to-back VSCs are the complete capacitor converters are used in PMSGs the most frequently. Here, IGBT converters are used to maximise the output power from wind energy while maintaining a steady DC voltage.

Control strategies

WECS have the challenge of rapid fluctuation in speed of wind. Therefore, we require a control strategy to improve efficiency and power generation rate. Many research work is done to integrate wind energy system into the microgrid. The designed controller must be cost effective, design must be simple and reliable. Most importantly, the controller should be able to handle the fluctuation in speed of wind.

MPPT algorithm for Wind Energy Conversion Systems

Sources of clean energy, such as wind power are soaring in popularity due to the lower availability, rising costs, and growing demand for traditional fuels. It is also an environmentally friendly form of green energy. There has been a notable rise when installing wind energy facilities globally. The installed wind capacity will be 840 GW by the year 2022. To get the most energy output from WECS, the generator's ideal speed must be maintained because to the wind's fundamentally variable nature. To ensure the most possible energy extraction from the WECS for variable speed of winds, tracking the maximum power point is therefore very popular and crucial. The used control strategies have an impact on WECS performance. Therefore, when these MPPT methods are used for WECS, these advanced control techniques must cause the fewest possible disturbances. MPPT algorithms assist in monitoring and maximising power from WECS.[14]

There are many different algorithms available. The MPPT techniques used to estimate speed of wind are divided between techniques that need speed sensors and techniques that do not, based on the necessity of speed sensors for measurement of speed of wind [22]. Different Sensors like anemometers are used in the MPPT method that use speed sensors to measure speed of wind. The MPPT techniques perturb and observe (P&O) algorithm, optimal relation based (ORB) algorithm, and incremental conductance (INC) algorithm do not employ speed of wind sensors, whereas the MPPT method tip speed ratio (TSR) and power signal flow (PSF) are speed sensor based MPPT techniques [15] [21].

IV. PROPOSED ALGORITHM

In this research, a P&O-based multilevel inverter is suggested for maximising wind energy extraction.

Perturbation and Observation algorithm

Despite being unpredictable, wind energy is always changing as the speed of wind changes. This solution involves a smaller voltage adjustment by the P&O MPPT controller [18]. The maximum power can be found by looking at dc power, which is produced by converter voltage and current instead of external influences. [19]. The HCS is also known as perturbation and observation (P&O) since it monitors the power perturbation and delivers corrections as a result. A certain characteristic, such as the DC-DC duty cycle converter to adjust the current or dc voltage to alter the rotor speed and follow the MPP. This technique relies on affecting the control variable. small, random steps, and the subsequent disturbance is decided to monitor the changes in the power curve caused by before the disturbance. A popular approach is P&O. Because of its simplicity and lack of complexity, the MPPT algorithm anemometer or mechanical speed sensor for implementation. The following two shortcomings of this system must be mentioned: delayed response, especially for the small step sizes, and ineffective functioning under sudden wind fluctuations. The Flowchart of P&O method is shown in figure below.

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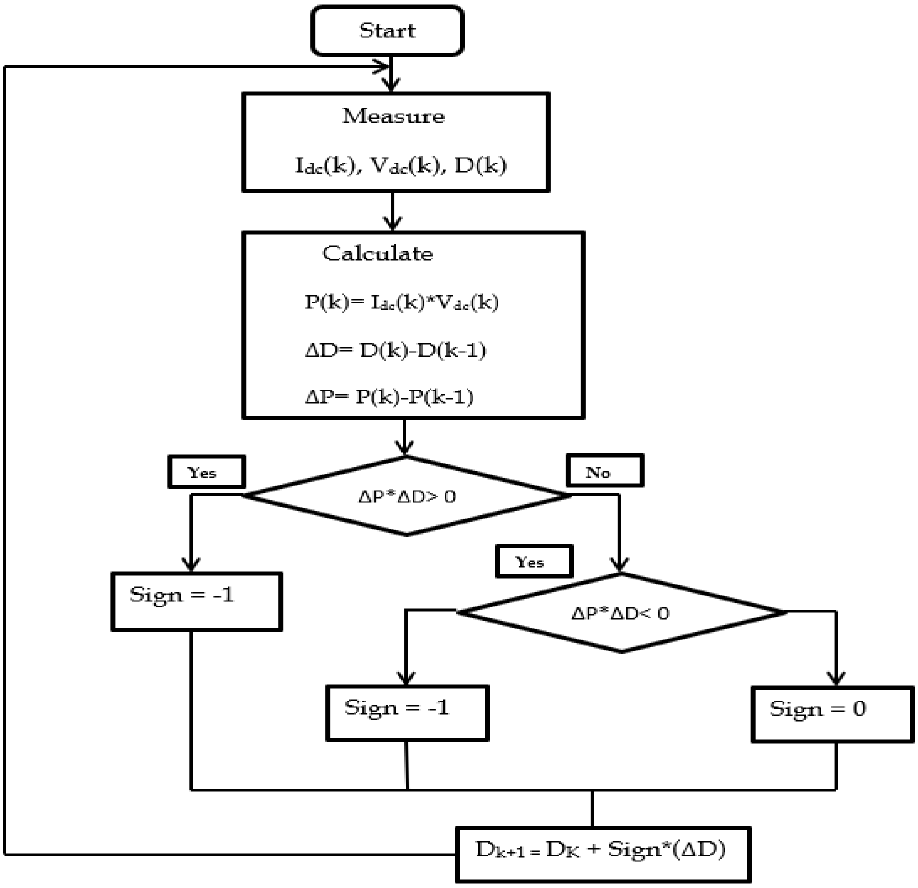

Figure 2: The Flowchart of P&O MPPT method

V. MODEL OF SOLAR PV CELL

Three categories are used to categorise its modelling, and they are discussed below

I – V characteristics and equivalent circuit of solar PV cell

The abbreviations PV are made up of two different words: photo, which signifies light, and voltaic, refers to generation of electricity. The word PV presents the importance of particularly harnessing solar energy. A sun-powered array was made up of different arrangements of sun-based modules, each of which contained a different type of solar cell [34]. p-n junction diodes made in a thin layer of semiconductor are what make up solar cells. They share the same characteristics with p-n diodes and are similar in design. The equivalent circuit of an ideal solar PV cell is shown in Figure 3. This ideal structure is detailed enough to understand the characteristics of PV and how the PV cell is dependent on changing environmental circumstances.

$$I_{PV} = N_P(I_{ph} - I_o\,[exp\left(\frac{qV_{PV}+R_SI_{PV}}{N_SAKT}\right) - 1] - \frac{V_{PV}+R_SI_{PV}}{N_SR_P} \quad (1)$$

The total amount of output power of solar PV cell connected in series and parallel is stated in equation no (1). I_{PV} represents magnitude of output current of Solar PV module. V_{PV} represents magnitude of output voltage of Solar PV module. N_P represents the no cells in series and N_S represents the no cells in parallel. R_S and R_P series and parallel resistances.

$$I_{ph} = [I_{SCC-STC} + K_i(T - T_{STC})]\frac{G}{G_{STC}} \quad (2)$$

T_{STC} (25°C) is the temperature of cell at standard rated test condition G_{STC} (in watts per square metres) is the solar cell irradiance on surface of it, G_{STC} (1000W/m2) is the irradiation at Standard Temperature Conditions, and Ki is the SCC coefficient, typically provided by the cell manufacturing company. The accompanying equation also shows that the temperature influences the saturation current, Io.

$$I_o = \frac{I_{SCC-STC}+K_i(T-T_{STC})}{exp\,[(V_{OC-STC}+K_V(T-T_{SC})/AV_{th}} \quad (3)$$

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Where Vth denotes cell thermic voltage, Kv denotes the open circuit voltage coefficient, and VOC-STC (in volts, V) is the voltage at open circuit condition at Standard Temperature Conditions; the values can be found on the data sheet provided by the manufacturer of the module. The amount of power produced by the solar PV cell is depicted using VPV and condensed IPV as

$$P_{PV} = V_{PV}\ X\ N_P\ \{I_{ph} - I_o\ exp\left(\frac{qV_{PV}}{N_S AKT}\right) - \frac{V_{PV}}{N_S}\} \quad (4)$$

Figure 4 shows the I-V and P-V characteristic curve of the solar PV cell. The curve shown in this picture demonstrates that the PV's operating point changes rather than staying at a constant value, ranging from zero to oc voltage. For a certain combination of solar insolation and temperature, there is position where maximum amount of power is possible [35]. The current and voltage that are discovered at that precise time are shown as IMPP and VMPP in Figure 4, and that point is designated as MPP.

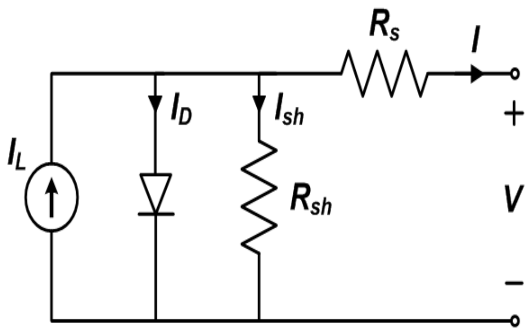

Figure 3: Equivalent circuit of an ideal PV cell

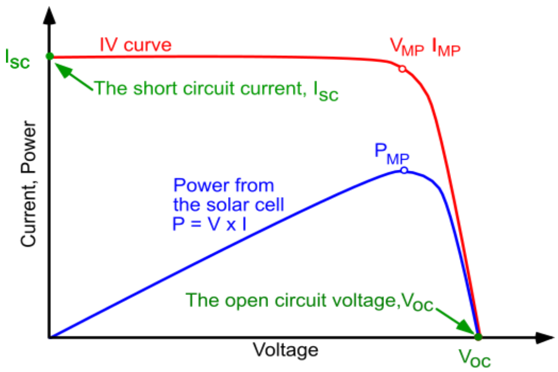

Figure 4: IV curve of solar PV module A solar cell must function at its PMP, or maximum power point, to produce the most power possible.

Effect of irradiance and temperature on solar PV cell

Because of the varying weather, PV production varies. The irradiance of the solar PV cell is determined by the angle of inclination of the rays of sun; hence, altering this parameter is directly influences the output via altering the P-V and I-V characteristics of solar PV module. A PV module's output current, IPV, is significantly influenced by different irradiance, G, but the output voltage, VPV, essentially stays constant. On the other hand, it is discovered that as the temperature changes, the voltage normally changes but the current essentially remains constant [27]. Its own heat produced during solar PV activity, energy radiated at the infrared wavelength, which warms the cell, and a rise in sunlight-based insolation are the three reasons that cause the temperature of the PV cell to increase. PV array at solar cell temperature and intensity.

$$V_{OC} = V_{OC}^{*} + a_1(T - T^{*}) - (I_{SC} - I_{SC}^{*})R_S \quad (5)$$

In (5) and (6), a1 and a2 are temperature coefficient of solar PV module respectively. $V_{OC}^{*}$and I_{SC}^{*} are the Open circuit and short circuit at standard sun intensity and temperature T^{*}.

$$I_{sc} = I_{SC}^{*}\left(\frac{G}{G^{*}}\right) + a_1(T - T^{*}) \quad (6)$$

The photo current, Iph, and consequently the SCC of the PV panel are dependent on temperature and insolation, implying that as radiation increases, the current increases and vice versa. The MPPT is presented as a solution for locating the MPP with the different temp. and irradiation.

Effect of PSC on PV cell

The partial shade has a notable impact on solar cell properties in addition to temperature and insolation. PSC refers to the situation in which different components of a PV module receive a different amount of radiation. Trees, nearby structures, and mists can all cast shadows. In context of this, obtaining MPP under PSC is the most crucial and difficult task for the MPPT controller. In a solar PV module, a cell that is covered and receives less or absent solar illumination a decrease in photocurrent (Iph). The Kirchhoff current law dictates that all series-connected solar PV array must have the same current, therefore the shaded cell's internal diode travels to the breakdown zone to make up for the reduced photocurrent. Therefore, instead of functioning as a generator, the covered PV cell now functions as a load.[16]

Control Strategy of the Hybrid System

The MPPT algorithm is the component that controls the PV to produce the maximum amount of electricity. If the controller consistently functions at MPP, no matter the weather, the PV system's efficiency is boosted. It should be feasible to legally match the solar PV source well with load in every climatic condition to generate the most amount of power. Either electrical tracking or mechanical tracking can be used to fully power the PV array. While MPP is identified using the I V curve in electrical tracking, the direction of the PV panels differs with the different seasons of the year in mechanical tracking. To guarantee that the max amount of power is delivered to the load, storage, rotors, and grid and islanded mode, respectively, modern power systems must have MPPT. Since solar radiation is not always uniform and PV arrays still have a less conversion rate of solar energy to electrical energy, the MPPT controller is commonly utilised in PV modules. [17] [28]

Need for an MPPT controller

Any ecological modifications place requirements on the generation of electricity from a self-sustaining source of energy. Particularly, the effects on solar and wind energy systems are particularly severe. The issues that wind and solar systems face includes (I) shifting weather conditions and (ii) grid integration. To provide a supportable power output, solar PV cell and wind turbine generation systems adopt MPPT techniques. Because of which, it is essential to confirm the existence of an MPP in the I-V and P-V with different temperature and irradiations of solar PV module. This MPP constantly changes its location in response to environmental changes. Therefore, MPPT controllers are a crucial component of the PV system because they are made to maintain the tracking of MPP. The panel is compelled to work closer to MPP because the controller's presence effectively affects the resistance it perceives. To change the load's operational point when it is connected to modifying the converter's duty cycle, efficient MPPT controllers are crucial.

Selection parameters of the MPPT controller

There are a variety of MPPT method that have been reported in the scientific research paper for tracking the solar PV system's actual MPP. The MPPT controller's selection parameters are crucial for determining which option is best among the alternatives. The selection factors offer crucial knowledge regarding which approach is superior for a specific application. These criteria are not used to categorise the methods; rather, they are used to compare the ways of each categorise MPPT method.

INC method

The incremental conductance algorithm uses two sensors in order to sense output voltage and output current of solar PV module. In the INC method, the terminal voltage is always adjusted to the MPP voltage level which is based on the incremental and instantaneous conductance of the solar PV module. In figure 5, it represents the slope of power curve of solar PV module is zero at maximum power point & towards the left side, slope is increased and towards right side slope is decreases.

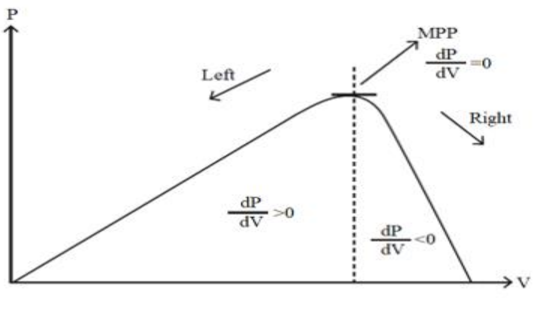

Figure 5: P-V array power curve

The basic equations of this method are as follows:

$$\frac{dp}{dv} = 0 => \frac{I}{V} = \frac{dI}{dV} \qquad \text{at the MPP}$$

$$\frac{dp}{dV} > 0 => \frac{I}{V} > -\frac{dI}{dV}- \qquad \text{left of the MPP}$$

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$$\frac{dp}{dV} < 0 => \frac{I}{V} < -\frac{dI}{dV} \quad \text{right of the MPP}$$

The solar PV module's output current and voltage are denoted by the letters I and V, respectively. The incremental conductance of a solar PV module is represented on the left side of the equation, and the instantaneous conductance is represented on the right side. The solar array will function at its peak power point when the ratio of change in output conductance equals the negative output conductance. The ratio of output conductance changes to output instantaneous conductance is assumed to be equal in this technique. P = VI is a fact. With the help of the chain rule for derivative goods, we can write

$$\frac{dP}{dV} = \frac{d(VI)}{dV} \quad (6)$$

At MPP, as $\partial P/\partial V$ = 0, the equation could be expressed as PV array voltage V and PV array current I as:

$$\frac{dP}{dV} = \frac{-I}{V} \quad (7)$$

The MPPT controls the controlling signal for PWM of the DC/DC boost converter until the following condition: $(\partial I/\partial V) + I/V = 0$ is satisfied

The Flow chart of incremental conductance MPPT algorithm is shown in figure 8.

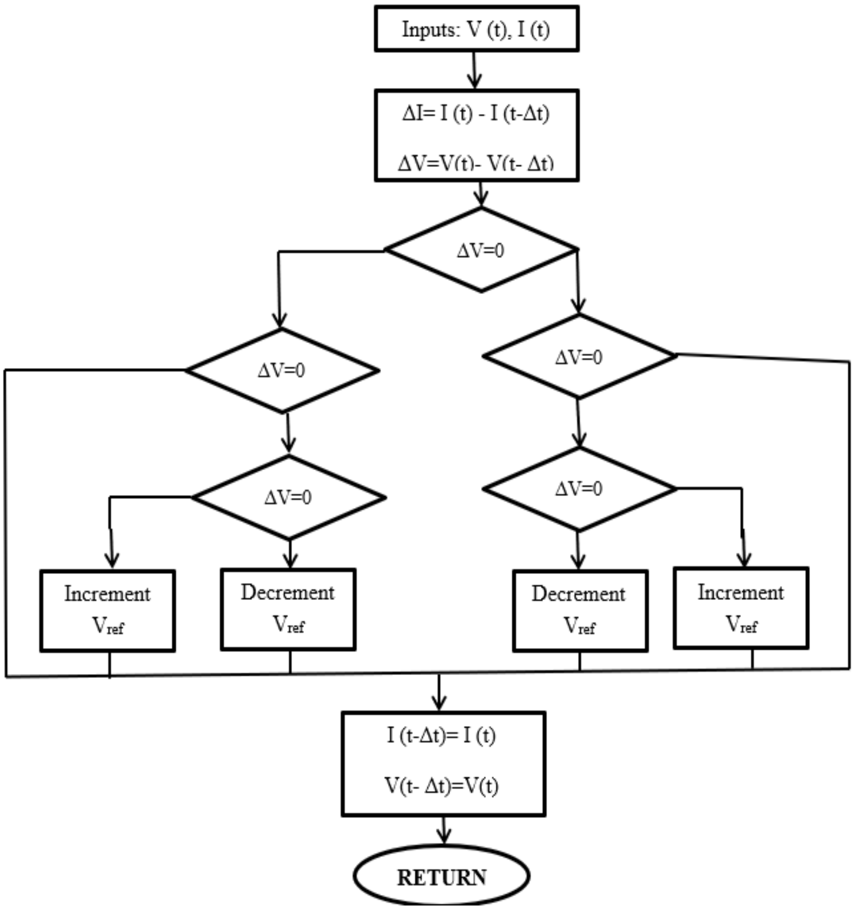

Figure 6: The Flow chart of incremental conductance MPPT algorithm

Energy Storage System of Microgrid

The energy storage system enables microgrids to respond to the loss of energy generation. Various factors must take into consideration before selecting the ESS and integrating of it with the microgrid [8]. For RES microgrid ESS plays a very important role as there is uncertainty in the availability of energy sources. Whether it's cloud blocking sun or fluctuations in speed of wind A MG should always have continuity in power supply. So, we need to store the energy for future use. ESS usually use batteries to store energy. With the rapid growth in technologies currently ESS uses supercharged capacitors. Although SC is costly and requires maintenance, therefore for a cost point of view many mg prefer a battery energy storage system [10].

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Battery Energy Storage System of Microgrid

Bess plays a key role in ensuring green energy even when the sun is not shining, or the wind has stopped blowing. Bess is the devices that enable to storage of energy from different sources like wind and solar to use whenever there is a shortage in power generation. BESS uses software algorithms to coordinate the production of energy and to decide when to charge or to release energy to the MG [16]. BESS also supplies energy during peak load demands keeping costs down and electricity flowing. The storage system for RES requires a battery system that will be long-lasting, it requires less maintenance and cost-effective [9]. Any microgrid's main goal is to provide its customers with reliable electricity. The primary utility grid, which is ageing and may experience power outages owing to unfavorable weather conditions where utility power is unavailable, may also experience power outages during these times [12] [33].

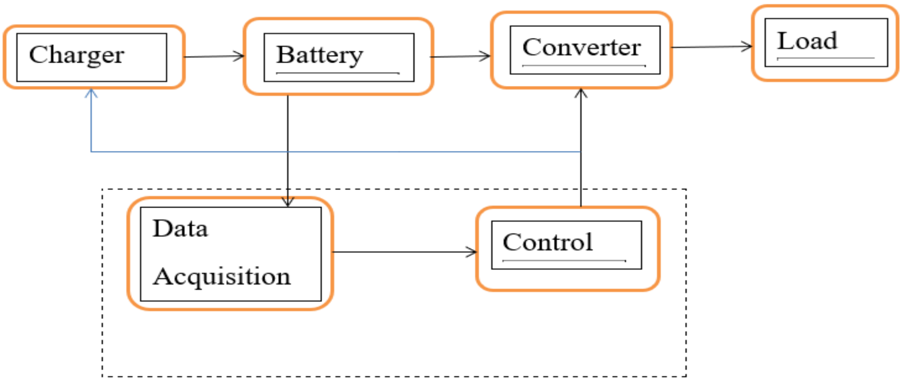

Figure 7: Basic block diagram of BESS

Anomalies in power quality caused by the ageing grid, such as voltage spikes and lulls and frequency regulation, can be seen and fixed by using a microgrid BESS. Instead of building massive MWh buildings on the fringes of cities, this infrastructure uses more compact, manageable storage systems that require less capital and are simpler to install, maintain, and monitor. The suggested arrangement also permits power sharing, lowering the danger of power loss during brownout or blackout circumstances.

The BESS system can be mounted outside and may resemble a small truck or a refrigerator in size. These modules' designs ought to fit in with the surroundings in which they are situated. These devices need to be installed such that they are crash safe in the event of collisions, water ingress safe in the event of flooding, or they need to be installed higher up. On a larger scale, there are various ways to store energy, such as flywheels, compressed air energy storage, advanced capacitors, etc. These technologies have been put in place and are successfully being used. Even if they continue to be successful, these systems need a lot of money, are large (2–10 MW), and cannot be recommended in smaller levels. With these restrictions, battery cell technologies might be a possibility for us as a source of stored energy. The battery cell technology employed in these Microgrid BESS is extremely important. This pattern determines which cell technology can be utilised most effectively, regardless of the size of the system or if it must be used to power substantial requirements as opposed to typical home consumption. Periodic servicing would be required for the microgrid BESS. Whether this procedure is carried out by an external agency, such as service providers, or is integrated within the system through firmware management. A system that can monitor and self-test to assure power delivery, when necessary, can take care of support. An external service would be alerted to address any alarms the system may raise. The cost of the system increases with the ability to have this feature incorporated in. In the long run, nevertheless, this feature makes debugging and repairs faster because the system doesn't have to be taken offline for maintenance or repairs.

VI. SIMULINK MODEL

The proposed microgrid model is thoroughly described in this section. MATLAB software is used to develop the simulation platform of the Renewable Energy based. The simulation is done with MATLAB version of "MATLAB 2021b". The single line diagram of proposed microgrid is shown in figure 10. All the generating units are designed to produce only active power at unity power factor. The system consists of Wind Energy conversion

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System, Solar PV cell, BESS, different DC & AC Load. The operational details about each unit have been discussed.

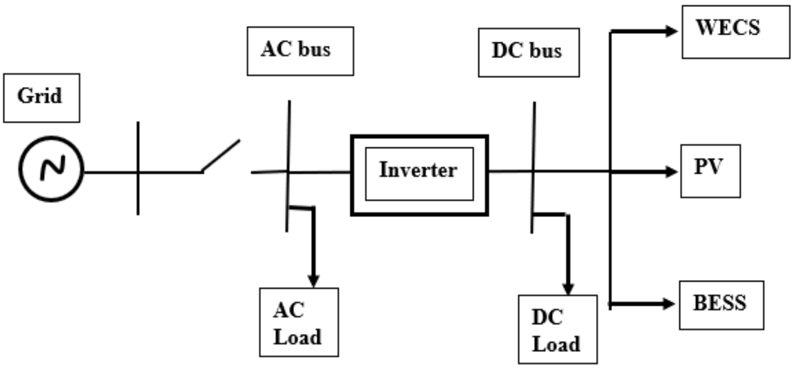

Figure 8: Single line diagram proposed microgrid

Modelling of WECS

The suggested model for the WECS consists of a wind turbine, diode rectifier, DC-DC boost converter, and permanent magnet synchronous generator. A P&O MPPT method is used to extract the most power possible. The MPPT approach will be used to produce the duty cycle for the DC DC boost converter. A 400V DC bus receives the boost converter's output. Depending on the wind speed, a wind turbine's output power varies. A variable wind function is built in this suggested model with a base speed of 12 m/s. After 2 seconds, the wind speed changed to 10.8 m/s, and as a result, the output power also changed. The figure below displays the range of wind speed utilised for WECS simulation.

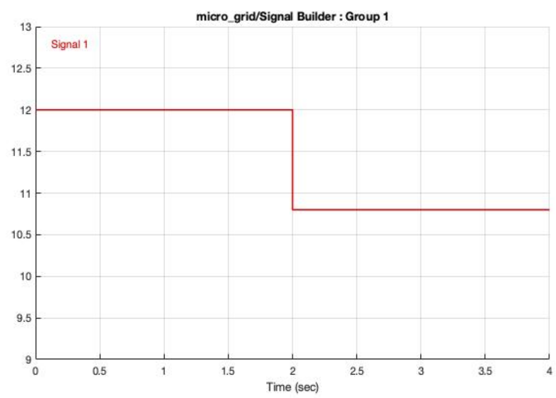

Figure 9: Variable speed of wind of WECS

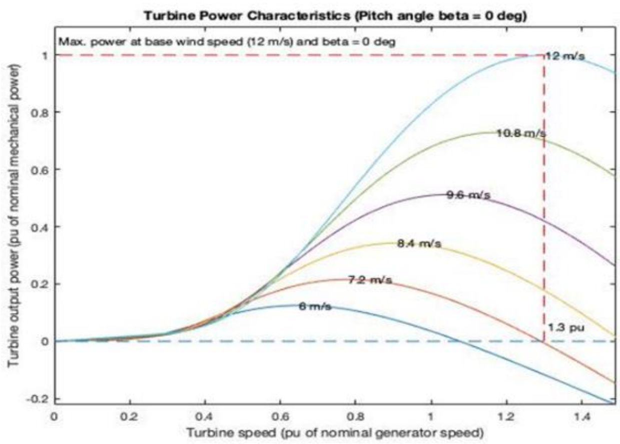

Figure 10: Wind Turbine Power Characteristics

Turbine power characteristics curve of a WECS provides the relation between output power and speed of wind and it is an important characteristics of wind generator turbine. From characteristics curve, we can evaluate the performance of a wind generator turbine. The figure 12 depicted below shows Turbine power characteristics curve of simulated wind turbine at a pitch angle of zero degree.

Modelling of SOLAR PV module

A PV module for monitoring the operation of the solar PV module is part of the system. The MPPT approach has been used to manage the DC-DC boost converter to acquire the maximum power production from the PV system. a collection of parallel-connected PV modules that make up a PV array. Each string is made up of modules that are joined in order. The solar PV module's maximum output is 2 KW at standard temperatures and radiation conditions, with an operating voltage of 250V. Duty cycle for the boost converter will be generated by the incremental conductance MPPT and sent through the PWM generator. User specified array types are utilised in simulation. The PV array voltage and power simulation characteristics at different irradiance are shown in Figure 13. Variation in irradiance effects the performance of PV module.

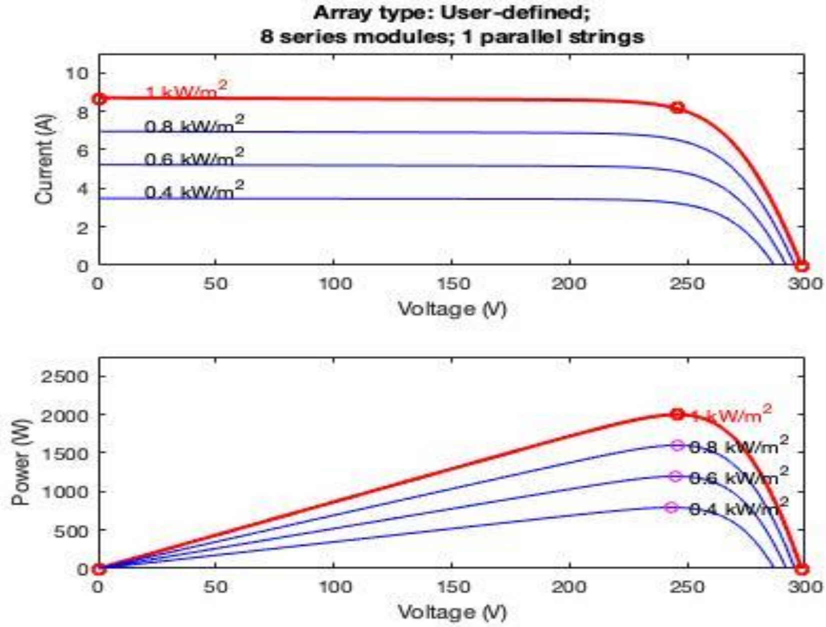

Figure 11: PV Array Power-Voltage Simulated Characteristic

The Table depicted below shows different Simulation parameters that has been taken for modelling of Solar PV module.

Table 1: Simulation Parameter Solar PV module

No. of Parallel string	1
Series connected modules per string	8
Maximum power	250 W
Cells per module	60
Open circuit voltage	37.5 V
Short circuit current	8.66 A

When a PV panel can produce power, the output voltage should always be constant, however this isn't always the case because of changes in input or load. As a result, a PV panel that was isolated needed a controller to maintain a steady voltage.

Control strategies

We measured the PV panel's voltage and current. It was afterwards processed through an Increment Conductance MPPT to generate duty cycle for the boost converter and extract the most power from the PV module. The produced duty cycle is then sent to a PWM generator, and the PWM generator will produce a pulse for the boost converter. for maximizing PV power with varying temperature and irradiation.

Modelling of Battery Energy Storage System

The DC-DC boost converter controls the BESS's charge-discharge cycle. The control system of BESS uses a PI controller to deliver the switching signal to the DC-DC converter. Based on the battery state of charge (SOC), a logic approach is developed to operate the battery system within its specified limit (SOCmin <SOC< SOCmax). Table shown below shows the Simulation parameters that has been taken for BESS.

Table 2: Simulation Parameters of BESS

Type	Lithium - ion
Nominal voltage	240V
Rated Capacity	48Ah
Initial SOC	50 %
Battery response time	100 microsec

The battery is connected to the DC Bus System via a bi-directional converter that is controlled by a voltage controller. Power can be transferred between two DC sources in both directions using a bidirectional DC to DC converter. For instance, the employment of these converters in situations like battery charging circuits and uninterruptible power supply is the result of the power flow being reversed and the voltage polarity being preserved. A bidirectional DC to DC converter is often used for applications involving power conversion. Two full bridge converters (inverter and rectifier), which are most suited for electrical applications, are employed in this converter power.

Control strategies

A bidirectional converter links the battery system to the DC bus. DC DC boost converter is used to control the bidirectional converter. The DC bus voltage must first be measured and compared to a 400 V DC bus voltage before being processed by a VI controller. The boost converter's IGBTs will be controlled by the PWM controller, whose output will produce duty cycle.

DQ Transformation

Direct Quadrature (DQ) synchronous reference frame transformation based current controller are used for the inverter control. Single phase inverter can operate in both the modes of operation. When the system operating in grid connected mode, power delivered to the load depending upon situation of microgrid. In the isolated mode of operation, there is no sharing of power and current between grid, and microgrid, as it works independently. During faulty condition, the inverter shares power by controlling methods. An LCL filter is connected at the output of inverter to reduce the harmonics. The major advantage of this method is that while performing with DC quantities, it achieves zero steady state error, & are highly compatible for single phase grid tied and isolated inverter operation.

Modelling of Single-phase inverter in islanded mode

The proposed concept for a single-phase inverter operating in an islanded mode is shown in the image. The inverter can work in bidirectional mode, allowing current to flow both ways from the grid to the microgrid. To lessen the presence of harmonics in current and voltage, an LCL filter is attached between the AC bus and the inverter. A PI current controller is linked to the current values in the relevant reference frame.

System Modelling

The modulating signal of Inverter for islanded mode operation is generated based upon the current and voltage of load. To compare load current with the reference current, we need to generate the reference current from converting DQ voltage into phase values. The actual load voltage is converted into DQ reference frame. The DQ reference voltage is generated from sine and cosine waveforms as shown in figure. Generation of reference voltage in DQ frame. The generated reference voltage is now compared with the actual DQ load voltage. Then it is going to processed by a voltage PI controller. The output of voltage PI controller is to generate two control output in DQ reference frame. Which then converted into abc form i.e., phase and neutral form by using abc to DQ conversion. The phase component of reference current is compared with the actual load current which going to be processed via a PI controller. Which will generate the modulating signal for inverter operation.

Modelling of Single-phase inverter in grid mode of operation

For sharing power with grid, the voltage and current waveform should be in phase with each other. To regulate grid power the current of grid connected inverter should synchronized with voltage of grid. Reference current should be changed to sinusoidal form. To convert phase values into sinusoidal form a Phase Locked Loop is used. A signal that is 90 degrees out of phase with the measured current is delivered by PLL. After the reference signal gets converted to sinusoidal form, it is now gets converted into DQ reference frame. Now the generated unbalance DQ frame reference current compared with actual load current and then processed via a PI controller. The output of PI controller is in DQ reference frame gets converted into abc form. The phase value of current is used as the modulation signal for the PWM generator.

Control of voltage and current

Two different types of control loops that the PI current controllers operate under are the inner current control loop and the outside voltage control loop. While an outside loop of current control governs the flow of active and reactive power, the inner loop can handle grid current control, power quality, and THD [18]. Also, the PWM

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generated signals are regulated by the PI controller. PWM controls the needed output current from the inverter & can be adjusted to produce a current waveform with better quality. The sine wave is combined as a carrier frequency wave through the PI controller transfer function. By adjusting the signals' phase and magnitude, the output voltage can be achieved. The beta input signal, which is a d-component in the DQ frame, governs the active power whereas the alpha output signal, which is a q-component, controls the system's reactive power. The presentation of the active current and reactive current components with a DQ frame is as follows.

$$i_d = Asin(\omega t + \delta)$$

$$i_q = Asin(\omega t + \delta - \frac{\pi}{2})$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos(\omega t) & sin(\omega t) \\ sin(\omega t) & cos(\omega t) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

With constant DC values and fixed amplitude, we will get ideally cases as mentioned in below equations: -

$$\mathrm{i_d} = \mathrm{A}\sin(\omega t + \delta)\sin(\omega t)\mathrm{A}\sin(\omega t + \delta - \frac{\pi}{2})(-\cos(\omega t)$$

$$\mathrm{i_q} = \mathrm{A}\sin(\omega t + \delta)\cos(\omega t)\mathrm{A}\sin(\omega t + \delta - \frac{\pi}{2})(\sin(\omega t))$$

Similarly,

$$\begin{bmatrix} \mathrm{V_d} \\ \mathrm{V_q} \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos\omega t) \end{bmatrix} \begin{bmatrix} \mathrm{V_\alpha} \\ \mathrm{V_\beta} \end{bmatrix}$$

$$\mathrm{V_{d1}} = \mathrm{V_{d1}} + \omega \mathrm{L_{i_q}} - \mathrm{V_d}$$

$$\mathrm{V_{q1}} = \mathrm{V_{q1}} + \omega \mathrm{L_{i_d}} - \mathrm{V_q}$$

i_d & i_q represents grid current

V_d & V_q represents grid voltage

V_{d1} & V_{q1} are the output grid DQ voltage

ω represents grid angular frequency

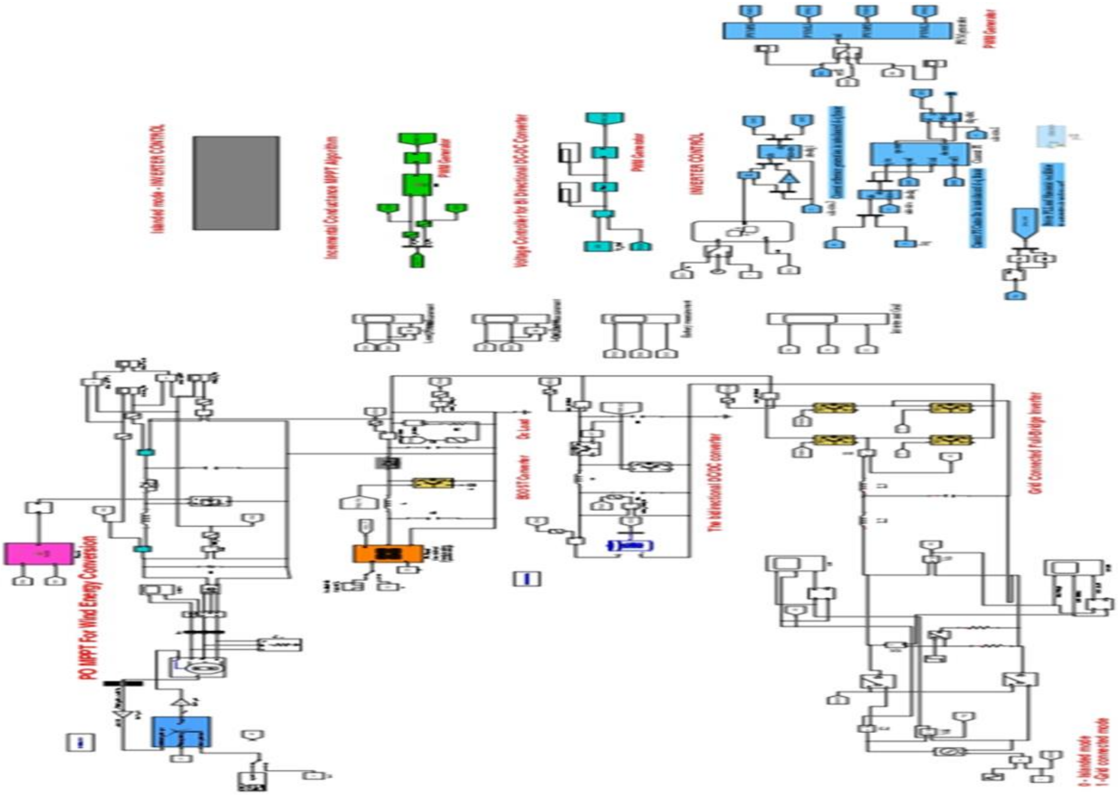

Figure 12: Simulink model of Renewable energy based Microgrid with MPPT algorithm

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VII. RESULT AND DISSCUSSION

The proposed microgrid system is simulated with MATLAB 2021b software. The simulation results of voltage, current and power characteristics of different components are discussed. The simulation model of WECS with varying wind speed, Solar PV module with variable irradiance is considered. The initial SOC of battery is considered at 50 percent. The microgrid's energy management system mainly focuses the measurements (the power produced by the two renewable sources, the battery's soc, and the load demand), correlates them, and regulates the battery's charging and discharging in accordance with the generating schedule. Through circuit breakers, the functioning of islanding and grid-tied systems can be chosen. For value 0, the microgrid will operate in Islanded mode & for value 1, the microgrid will get connected to the power grid. The proposed Simulink model of RE based microgrid is shown in figure 14. The rating of parameters taken during simulation in shown in the table depicted below.

Table 3: Rating of Proposed Model

Maximum power generated by WECS	2.8 KW
Maximum power generated by Solar PV module	2.2 KW
Power delivered to DC load	1 KW
Power delivered to AC load	2.4 KW
Peak Grid Voltage	325 V
Frequency of Grid	50 HZ
DC Bus Voltage	400V

The performance of different components of microgrid with different mode of operation are discussed in this chapter.

Performance of WECS in Islanded mode of operation

The figure 15 displays WECS's performance. Initially, when the speed of wind is 12 m/s, the boost converter's output achieves its maximum value of 2.8 KW. The output power of WECS drops as the speed of wind reaches 10.8 m/when the speed changed, there is a transition happened in the system because of which we can see that there is fluctuation in power curve.

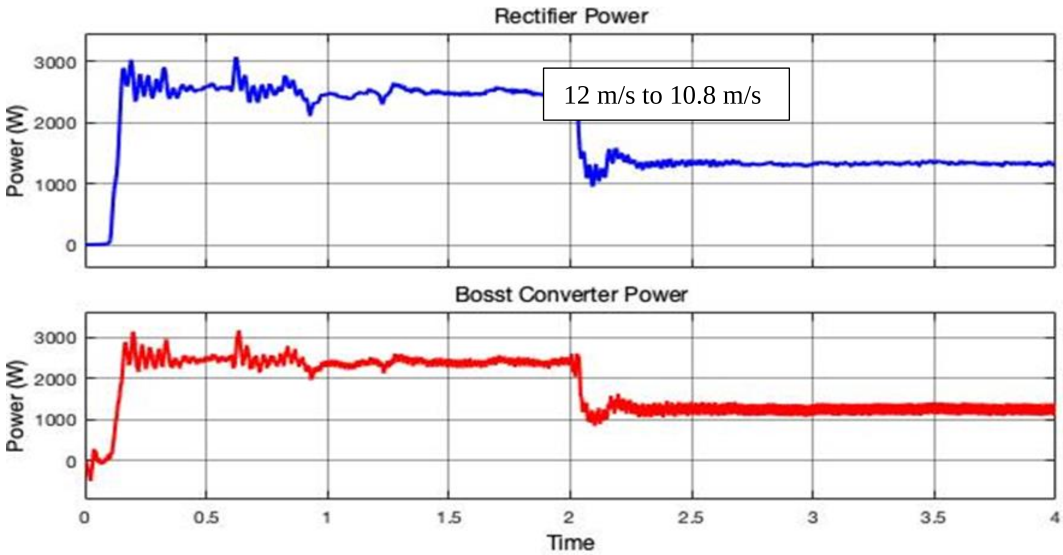

Figure 13: Output power from WTG and Boost converter in Islanded mode of operation

Performance of WECS in Grid connected mode of operation

The output power of WECS in grid coupled mode is depicted in the figure 16 below. V and f are managed by the grid, which is connected to the WECS. As we can see, the voltage level of WECS in grid linked mode exhibits far less volatility than islanded mode.

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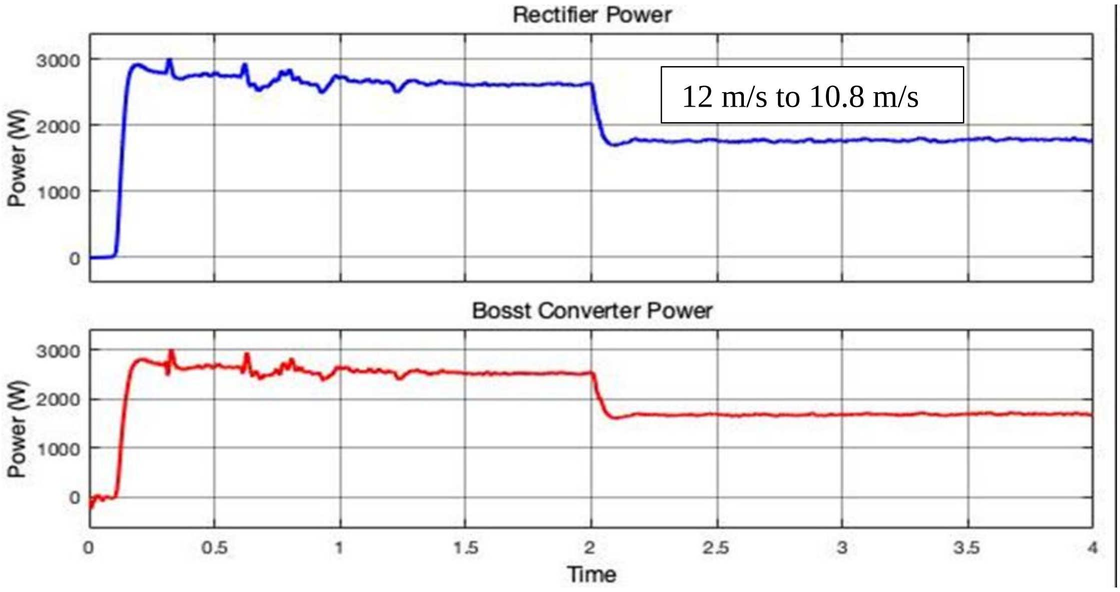

Figure 14: Output power from WTG and Boost converter in Grid connection mode

Performance of Solar PV module in Islanded mode

The controller's presence ensures that the system's output voltage is constant even when the input voltage fluctuates, and load disturbances happen while the solar PV module is running in the islanded mode. The output power of the inverter varies depending on the load power, and the output power of the PV module and the DC link voltage are regulated by a PI controller. The maximum power generated by a PV module is around 2 KW.

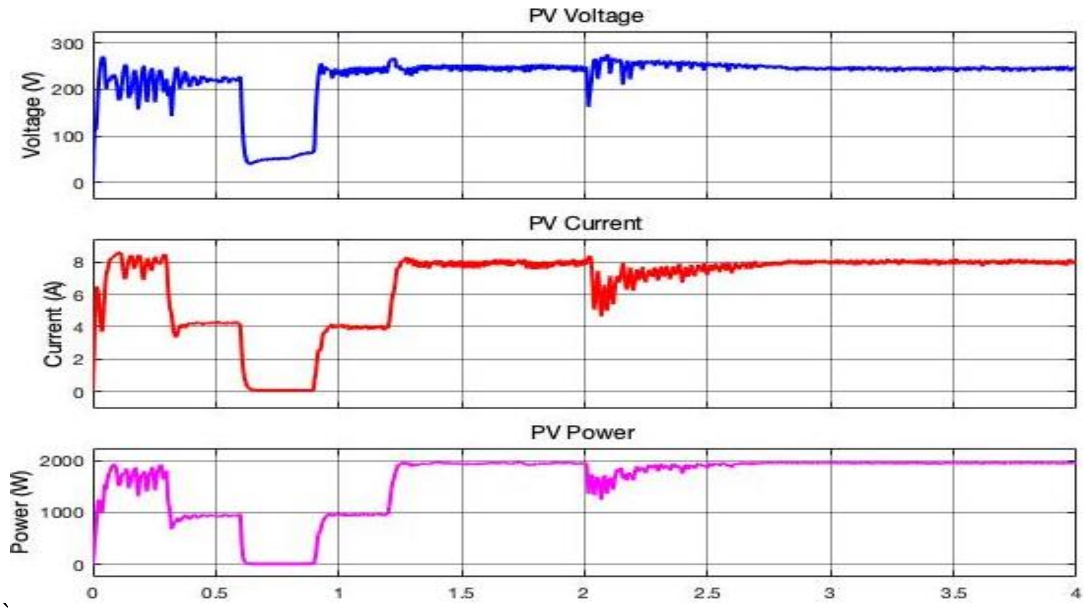

Figure 15: Solar power injected to DC bus in Islanded mode

The variation in current is because of change in irradiance. In the figure 13, it shows different magnitudes of current at different values of irradiance. The voltage level is maintained at constant magnitude, so output power of PV module changes with change in current. After 2 sec, the speed of wind is changed from 12 m/s to 10 m/s there is a transition occurred in system, which we can see in figure 11.

Performance of Solar PV module in Grid-connected mode

The figure 18 depicted below shows solar power injection to DC bus in grid connected mode. The inverter controls the dc-link voltage (Vdc) in grid-connected mode by using a reference set by the MPPT algorithm. In this operational mode, the inverter voltage loop is controlled by a PI controller. Constant voltage and frequency

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are being maintained by grid, because of which the current, voltage, and power profile of PV module has very less fluctuations.

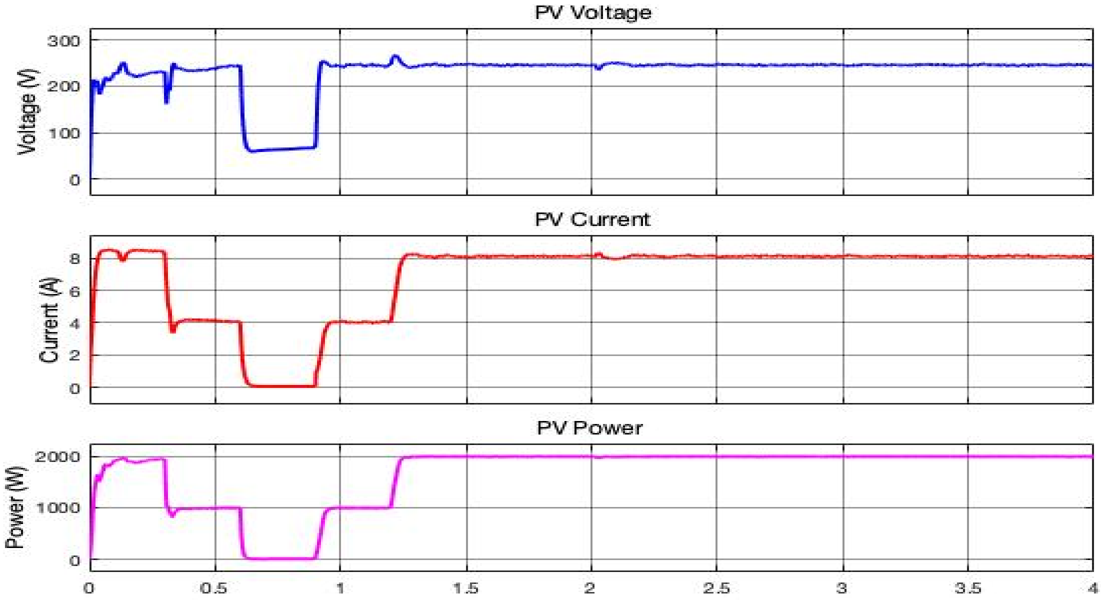

Figure 16: Solar power injected to the DC bus Grid-connected mode of operation

Performance of BESS in Islanded mode

The battery voltage has been maintained at a constant value of 250V.During Islanded mode the BESS supplies power to the load because of which there has been decrease of percentage of charge stored in battery is reduces. When magnitude of AC load is increased, BESS supports the continuity of power by discharging which can be seen in the figure 19 shown below

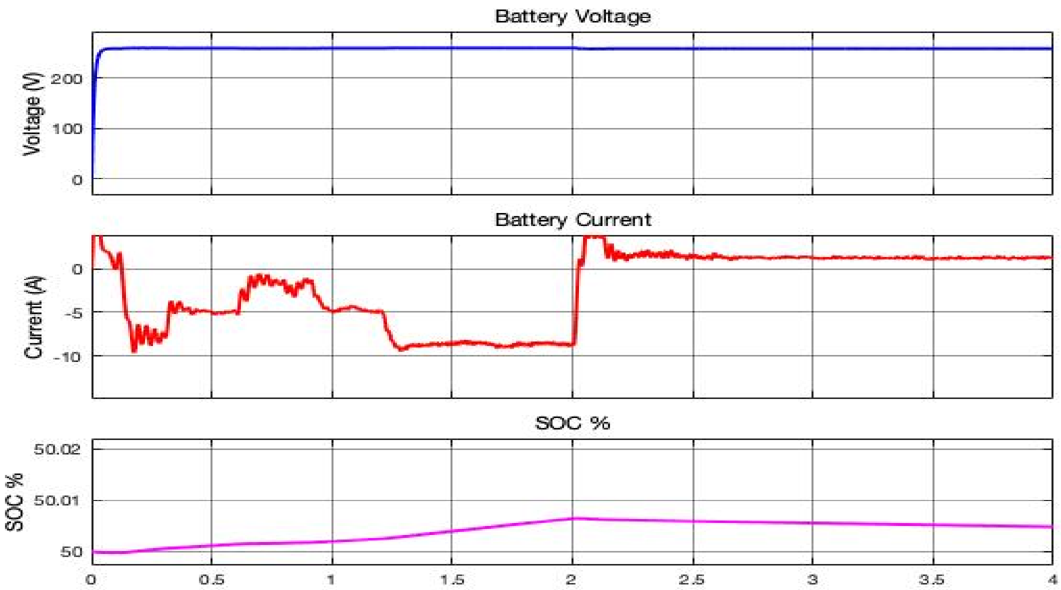

Figure 17: Battery power dynamics during Islanded mode of operation

Initially soc of the battery is 50%. when system undergoes islanded mode of operation it starts charging.at starting irradiance of 1000 w/m2, PV module produces its maximum power, so there is steady increase in amount of charging of battery. But after o.5 sec when the irradiance of PV is changed to 500 w/m2, the charging sped of battery is decreased. After 2 sec the speed of wind has been changed to 12 m/s with irradiance of PV module is maintained at 1000 w/m2, load in the system increases to maintain the continuity in supply, battery starts discharging, which can be seen in figure 19.

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Performance of BESS in Grid connected mode

During the grid connected mode of operation, the additional power is being supplied from the grid, Because of which battery gets to charge fully. The below mentioned figure 20 shows the state of charge of battery is increases steadily.as we can see in figure 20 that magnitude of current is negative value. Which signifies that the battery is constantly being charged. charging current magnitude keeps on changing because of the variation in irradiance of PV module and speed of wind.

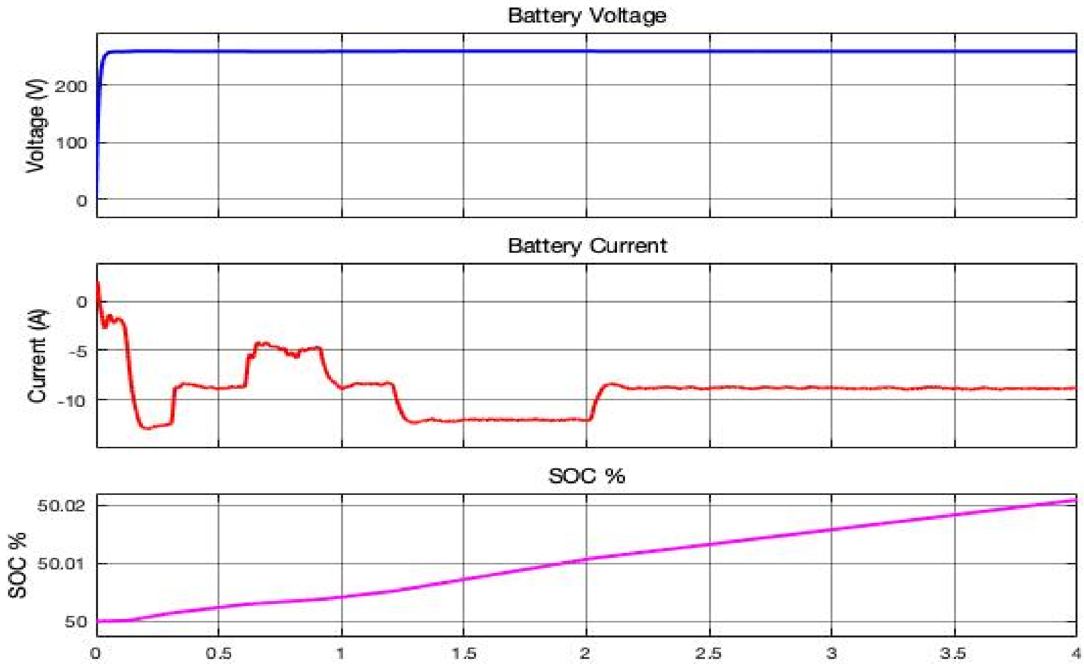

Figure 18: Battery power dynamics during Grid connected mode of operation

Grid connected mode of operation

The microgrid's power flow is bidirectional, but when it is connected to the external grid, it can switch power to maintain a steady supply for the nearby microgrid. There will be an agreement between the grid and the microgrid in grid connected mode to trade power. This agreement is based on two factors:

1. Magnitude of reference current (Iref)
2. The SOC of battery

The figure depicted below represent the agreement between Grid and Microgrid

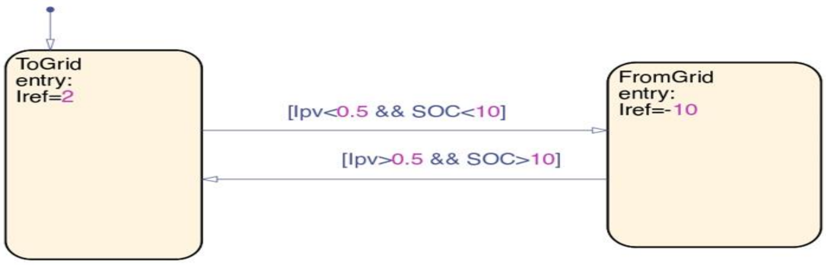

Figure 89: Agreement between Grid & Microgrid

Table depicted below shows the amount of power being exchange between grid and microgrid.

Table 4: Amount of Current & Power sent to grid

Current sent to grid	2A
Power sent to grid	326 W

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Table 5: Amount of Current & Power received from grid

Current received from grid	10A
Power received from grid	1.63 kw

The figure 22 shows exchange of power between grid and microgrid. Initially amount of power transferred from grid is 1KW, after 2 sec the speed of wind is reduced, and additional load has been added to the grid. Because of which the microgrid starts receiving power from grid.

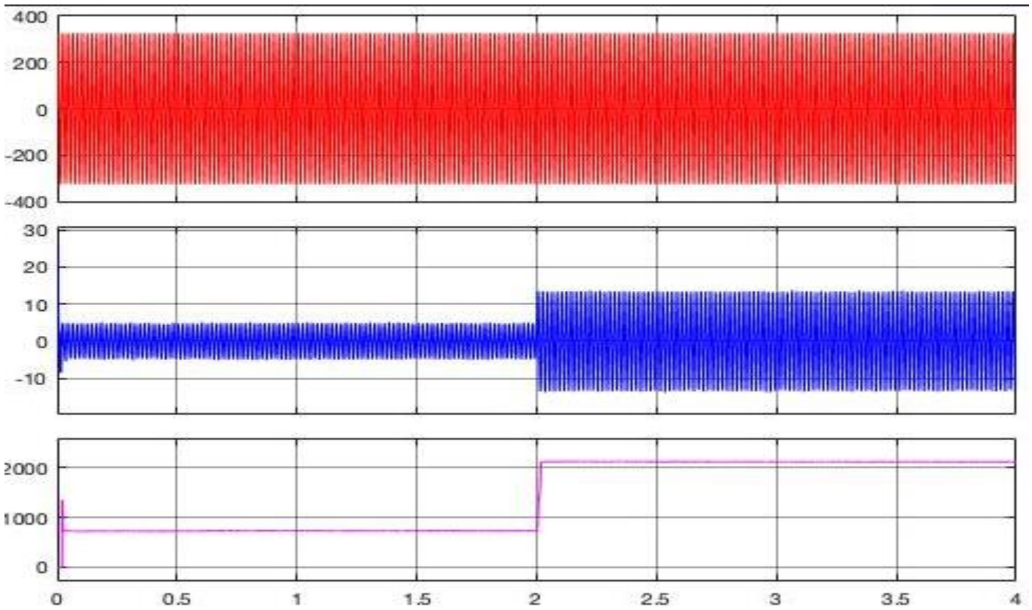

Figure 20: Power exchange between microgrid and Grid

Load power measurement in Islanded mode of operation

In the proposed model, resistive load has been taken. Two different type of load is taken for power calculation. A dc load of magnitude 1000 W is considered, which is connected directly to DC bus. The AC load is connected to the AC bus. Initially connected load is 1000 W, and after 2 sec additional load is introduced with magnitude of 1400 W. The figure 23 shown below shows load voltage, current and load power of designed system.

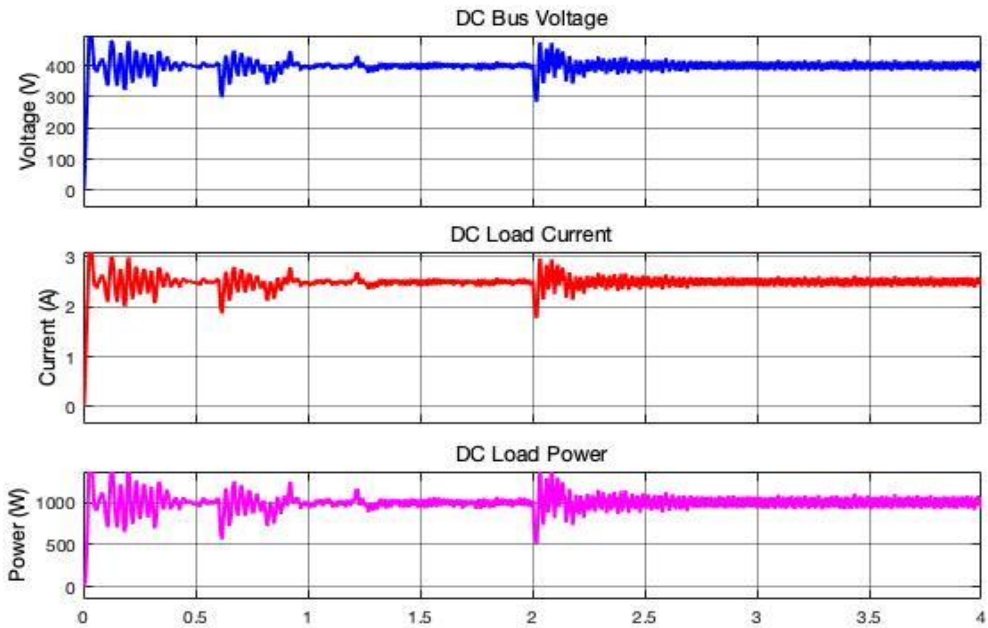

Figure 21: Power measurement of DC load in islanded mode of operation

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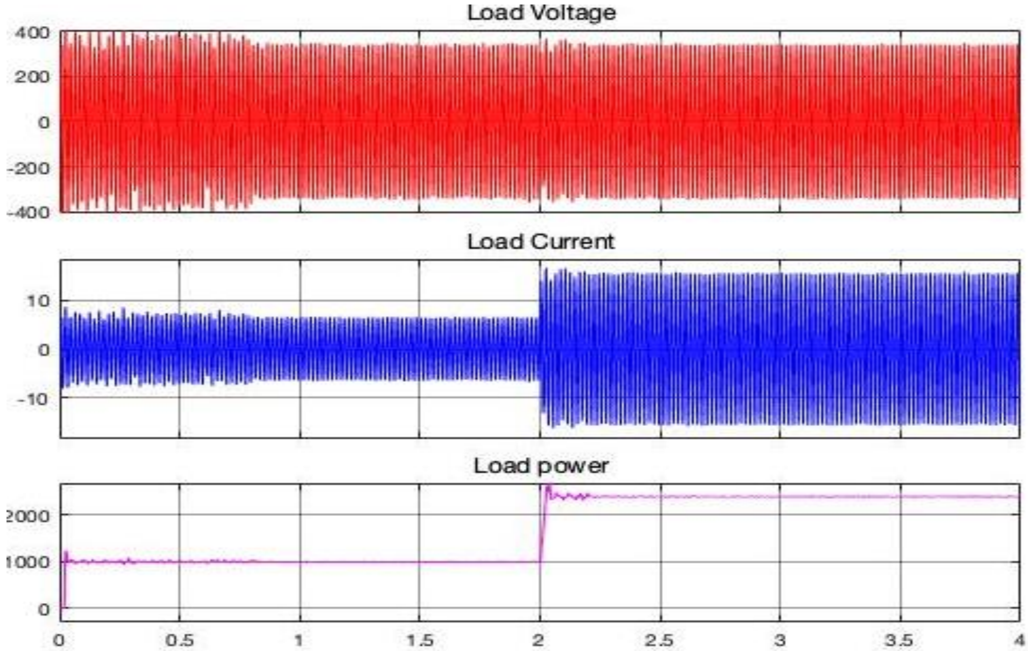

Figure 22: Power measurement of AC load in islanded mode of operation

Load power measurement in Grid mode of operation

In the grid connected mode, additional demanded power is supplied by grid. As we can observe in the figure 25, that initially 327W is being supplied by microgrid and the remaining power is supplied by grid. After 2 sec the magnitude of load connected to system is increased because of addition of 1400W resistive load to ac bus.

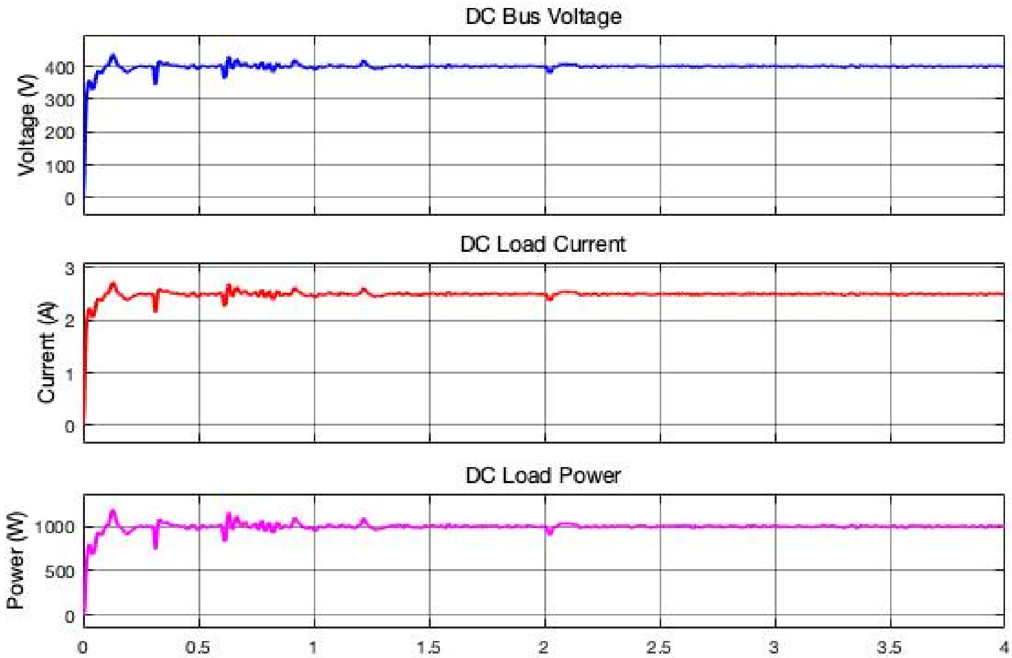

Figure 23: Power measurement of DC load in grid mode of operation

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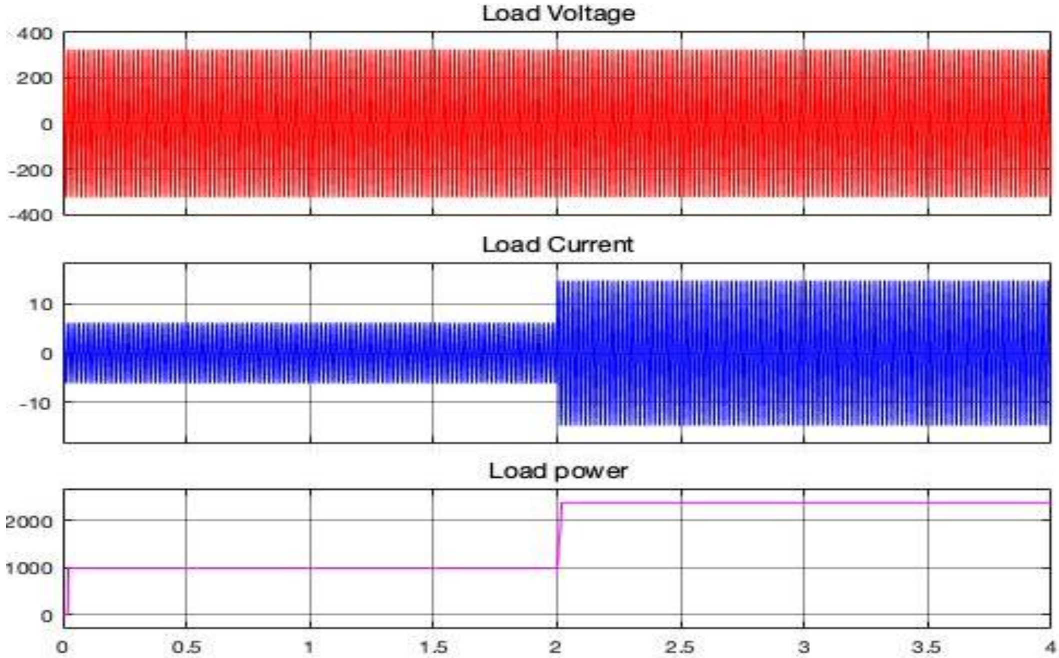

Figure 24: Power measurement of AC load in grid mode of operation

VIII. CONCLUSION

In this dissertation work, a method for designing microgrid systems is discussed. This paper's major contributions are an overview of microgrids and a flexible method for designing a Renewable energy-based hybrid microgrid using the MATLAB SIMULATION model. It is possible to develop and execute isolated hybrid microgrids using the analyses and methodology presented in this report. These hybrid microgrids will offer effective, affordable, and clean energy while boosting the microgrid's dependability and resilience in remote places. A single-phase inverter is used to intercouple microgrid with grid. The microgrid can run in an isolated or grid-tied mode. the two modes or alternate between them. The voltage, current and power characteristics of different components are considered for operation of microgrid. The voltage level has been maintained constant even though climatic condition fluctuates (with variable speed of wind and variable temperature and irradiance of PV module). To extract maximum power from wind turbine a P&O MPPT algorithm is used. for extracting maximum power from solar PV module INC MPPT algorithm is used. Solar PV generation and BESS are becoming more and more affordable, and they are quickly approaching cost parity with conventional electricity sources. Due to the widespread deployment of these technologies, energy presumption where end users import, and export electricity might soon become the rule rather than the exception.

IX. FUTURE SCOPE

Based on work done in this paper, researchers have future development from this work. Some of future development scopes are being mentioned below:

- The improvement in microgrid technology so that it may be used not only on isolated islands but also in places where a reliable supply of electricity is already available. To create a design model for of interconnected microgrids, research can also be expanded.
- To protect the microgrid during the faulty condition of microgrid we can implement different islanding detection techniques.

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