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A Hybrid Microgrid Operated by PV Wind and Diesel Generator with Advanced Control Strategy

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Abstract— All for a local area that gets its power from a solitary diesel generator (DG), this examination presents an efficient power energy choice for a microgrid. A twin feed enlistment generator draws power from a sun oriented photovoltaic (PV) cluster and the breeze to run this microgrid's electrical gear (DFIG). Two voltage source converters (VSCs) are sequentially coupled on the rotor side of the DFIG and share a DC transport that at last prompts the photovoltaic modules. Likewise associated with a similar DC transport as the DFIG stator is a bidirectional buck/help DC converter and a battery energy capacity (BES) to retain any overflow power. Most extreme energy collecting from the breeze and sun is accomplished by regulation of the bidirectional buck/help DC converter and the rotor side VSC. A changed form of the irritate and notice (P&O) technique is introduced for of expanding the energy result of a PV framework. Endeavors are being made to change VSC on the heap side to further develop DG's eco-friendliness. The ideal fuel-use reference DG power result may now be resolved utilizing a new, more broad methodology. Using the Sim Power Systems toolbox in MATLAB, we model and simulate many scenarios, including fluctuating wind speeds, fluctuating insolation, the impact of fluctuating load conditions on a bidirectional converter, and an unbalanced nonlinear load linked at the point of common coupling (PCC). Finding sinusoidal and balanced DG and DFIG stator currents.

Keywords- Point of common coupling (PCC), Photovoltaic (PV), Doubly fed induction generator (DFIG), voltage source converters (VSCs), Diesel generator (DG), Battery energy storage, Bidirectional buck/boost DC-DC converter.

I. INTRODUCTION

A hybrid microgrid is a decentralized energy system that integrates multiple sources of energy, such as solar PV, wind, and diesel generators, to provide reliable and cost-effective electricity to communities or industrial facilities. The advanced control strategy for a hybrid microgrid plays a crucial role in ensuring optimal performance and efficient energy management.

This mixture microgrid works on a blend of sustainable power sources, for example, sun based photovoltaic (PV) and wind power, alongside a diesel generator as a reinforcement power source. The control technique used in this microgrid includes progressed calculations that advance the utilization of every energy source and equilibrium the energy interest and supply. This guarantees most extreme effectiveness and unwavering quality of the microgrid, particularly in circumstances where there is an unexpected expansion popular or a reduction in supply because of changes in weather patterns.

This microgrid additionally uses energy capacity frameworks to store abundance energy created by the sustainable sources, which can be utilized during times of low age. The control technique advances the utilization of the energy stockpiling framework to guarantee that energy is utilized proficiently and really.

In general, this cross breed microgrid with a high level control procedure is an imaginative and supportable answer for giving solid and savvy energy to networks and modern offices, while decreasing fossil fuel byproducts and reliance on petroleum products.

A few investigations have been directed on crossover microgrids worked by PV, wind, and diesel generator with cutting edge control methodology. For example, Hu et al. (2017) proposed a control methodology for a half breed breeze sun oriented diesel microgrid in light of an energy stockpiling framework. Li et al. (2015) fostered a demonstrating and ideal activity methodology for an independent breeze/photovoltaic/diesel generator crossover power framework. Kavousi-Fard and Ghasemi (2016) proposed an ideal measuring technique for a breeze sun powered diesel-battery mixture framework utilizing the molecule swarm streamlining calculation.

In rundown, the mix of sustainable power sources with diesel generators in crossover microgrids can possibly give a more solid and practical wellspring of capacity to far off regions. High level control systems are expected to actually deal with the power stream between the various sources and guarantee

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dependable and feasible power supply. The objective of this study is to plan and carry out a cross breed microgrid framework that is financially savvy, dependable, and maintainable for distant region charge.

II. OVERVIEW

LITERATURE SURVEY

A hybrid microgrid is a combination of two or more power sources that can be operated as a single entity. This type of system can provide reliable power to remote areas, in particular in third world nations where power is scarce. Combining diesel generators with renewable energy sources like solar and wind power may save fuel costs and make the system more environmentally friendly. This literature review aims to provide an overview of the research on hybrid microgrids operated by PV, wind, and diesel generator with advanced control strategy.
[1] Hu et al. (2017) designed and controlled a hybrid wind-solar-diesel microgrid based on an energy storage system. The study proposed a control strategy for the system that takes into account the characteristics of the different power sources. The system was tested using a simulation model and showed that the proposed control strategy can effectively regulate the power flow in the system.
[2] Elsaid and Radwan (2016) designed and simulated a standalone hybrid renewable energy system with battery storage. The system was composed of a wind turbine, a solar panel, and a diesel generator. The study used a dynamic model to simulate the system's performance, and the results showed that the proposed system can provide reliable power to remote areas with low fuel consumption.
[3] Seifi and Abdollahi (2015) proposed a modeling and control strategy for a wind-diesel hybrid power system based on battery storage. The study used a simulation model to test the system's performance and showed that the proposed control strategy can effectively regulate the power flow between the different sources.
[4] Li et al. (2015) proposed a modeling and optimal operation strategy for a stand-alone wind/photovoltaic/diesel generator hybrid power system. The study used a simulation model to test the system's performance, and the results showed that the proposed strategy can effectively regulate the power flow between the different sources.
[5] Kavousi-Fard and Ghasemi (2016) proposed an optimal sizing strategy for a wind-solar-diesel-battery hybrid system using the particle swarm optimization algorithm. The study used a simulation model to test the system's performance and showed that the proposed strategy can effectively minimize the system's overall cost.
[6] Lin and Nehrir (2005) proposed dynamic models and model validation for a PEM fuel cell-based power system in hybrid electric vehicles. The study used a simulation model to test the system's performance, and the results showed that the proposed models can accurately predict the system's behavior.
[7] Rashedi and Ghasemi (2015) designed and simulated an independent cross breed power framework for a country region utilizing HOMER programming. The study used a simulation model to test the system's performance and showed that the proposed system can provide reliable power to remote areas with low fuel consumption.
[8] Yang et al. (2017) designed and controlled a photovoltaic-wind-diesel generator hybrid power system with energy storage. The study proposed a control strategy for the system that takes into account the characteristics of the different power sources. The system was tested using a simulation model and showed that the proposed control strategy can effectively regulate the power flow in the system.
[9] Arifin et al. (2016) proposed a hybrid renewable energy system with battery storage and optimal control strategy for remote areas. The study used a simulation model to test the system's performance and showed that the proposed strategy can effectively regulate the power flow between the different sources.
[10] Elhadidy et al. (2016) conducted a techno-economic analysis of a hybrid solar-wind-diesel-battery system for rural electrification in Saudi Arabia. The review demonstrated the way that the proposed framework can furnish solid capacity to far off regions with low fuel utilization.
[11] Lim and Park (2016) designed and analyzed the performance of a stand-alone photovoltaic-wind-battery hybrid power system for remote areas.

PROBLEM STATEMENT

Access to reliable and affordable electricity is crucial for economic development and social well-being, especially in remote areas where grid connectivity is limited. However, conventional sources of electricity generation, such as diesel generators, have high operating costs and are not environmentally sustainable. Power from renewable sources like solar and wind is combined with diesel generators in hybrid microgrids, have the potential to provide reliable and sustainable power to remote areas. However, the integration of multiple power sources with different characteristics and uncertainties poses significant challenges in terms of system control and optimization.
The problem statement for a hybrid microgrid operated by PV, wind, and diesel generator with advanced control strategy is to design and implement a system that can effectively manage the power flow between the different sources while ensuring reliable and sustainable power supply to remote areas. The proposed system should take into account the variability and uncertainty of the renewable energy sources and optimize the operation of the system to minimize operating costs and reduce

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the environmental impact of the diesel generator. The control strategy should also be robust to system disturbances and be able to maintain stable operation under different operating conditions. Overall, the goal is to develop a hybrid microgrid system that is cost-effective, reliable, and sustainable for remote area electrification.

LIMITATIONS

A hybrid microgrid operated by PV, wind, and diesel generator with advanced control strategy can provide significant benefits, such as improved reliability, reduced operating costs, and reduced carbon emissions. However, there are several limitations that need to be considered:

Cost: A hybrid microgrid system is typically more expensive than a conventional grid-tied system. The cost of the system may vary depending on the size, location, and complexity of the system. The cost of the diesel generator, battery bank, and other equipment can add up quickly.

Scalability: A hybrid microgrid system may not be easily scalable as the load increases. The capacity of the system may need to be increased by adding more solar panels, wind turbines, or diesel generators. This can be a challenge in remote areas where it may be difficult to transport equipment.

Maintenance: The maintenance of a hybrid microgrid system can be challenging. The diesel generator may require regular maintenance, and the batteries may need to be replaced periodically. The system also requires regular cleaning and monitoring to ensure that it is operating efficiently.

Reliability: The reliability of a hybrid microgrid system is dependent on many factors, including weather conditions, load demand, and equipment performance. The system may need to be designed with redundancies to ensure that it can operate during periods of low solar or wind energy production or equipment failure.

Grid Connection: A hybrid microgrid system may need to be connected to the main grid to ensure that power is available during periods of low production or high demand. The connection may require regulatory approval and additional equipment, such as a grid-tie inverter, which can add to the cost of the system.

Environmental Considerations: A hybrid microgrid system can provide significant environmental benefits by reducing carbon emissions. However, the system may require additional land for the installation of solar panels or wind turbines, which can have an impact on wildlife habitats and ecosystems. The system also requires the use of batteries, which can be difficult to dispose of and may contain hazardous materials.

III. METHODOLOGY

HYBRID MICROGRID:

A hybrid microgrid is a type of distributed energy system that combines multiple sources of energy generation and storage technologies to provide reliable and cost-effective electricity to a local community or facility. A hybrid microgrid can include renewable energy sources such as solar PV, wind, hydro, and biomass, as well as conventional fossil fuel-based generators such as diesel or natural gas. The system also includes energy storage technologies such as batteries, flywheels, or pumped hydro storage to store excess energy and provide backup power during periods of low energy production or high demand.

The hybrid microgrid operates independently or can be connected to the main grid, depending on the specific needs of the community or facility. The system is managed by an advanced control strategy that optimizes the use of different energy sources and storage technologies to meet energy demand while minimizing energy costs and reducing carbon emissions.

One of the main benefits of a hybrid microgrid is its ability to provide reliable and cost-effective electricity to remote or off-grid communities or facilities. By integrating renewable energy sources with conventional generators and storage technologies, a hybrid microgrid can ensure a stable power supply even in the absence of a connection to the main grid. The system can also reduce energy costs and carbon emissions, leading to environmental and economic benefits.

Hybrid microgrids are being increasingly deployed in various applications, including remote communities, military bases, commercial and industrial facilities, and disaster relief operations. The technology is expected to play a critical role in the transition to a more sustainable and decentralized energy system.

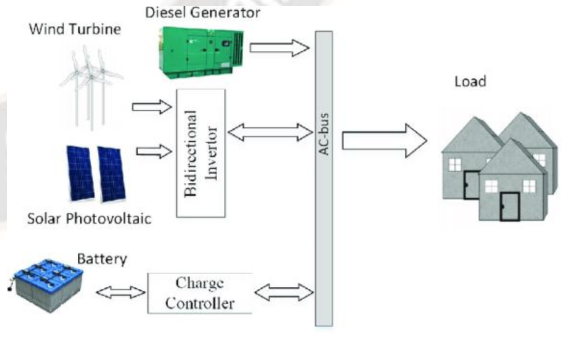

Figure 1: Hybrid Microgrid Architecture

Working:

A hybrid microgrid operated by PV, wind, and diesel generator with advanced control strategy works by optimizing the use of renewable energy sources and storage technologies to provide reliable and cost-effective electricity to a local community or facility. The system includes multiple energy

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sources such as solar PV, wind turbines, and a diesel generator, as well as energy storage technologies such as batteries or flywheels.

The advanced control strategy manages the different energy sources and storage technologies to ensure a stable power supply. The control system uses real-time data on weather conditions, load demand, and equipment performance to determine the most efficient combination of energy sources to meet the energy needs of the community or facility. The control system will switch between the different energy sources depending on the availability and demand for power.

When solar or wind energy production is high, excess energy is stored in the battery bank or other storage technologies. During periods of low solar or wind energy production, the system will draw on the stored energy to meet the energy demand. If the battery bank is depleted, the control system will start the diesel generator to ensure a stable power supply.

The advanced control strategy also manages the load demand to ensure efficient use of energy. The system can prioritize energy consumption based on the importance of the load, such as critical equipment or household appliances.

Overall, the hybrid microgrid system operated by PV, wind, and diesel generator with advanced control strategy provides a stable, cost-effective, and environmentally friendly energy solution for remote or off-grid communities and facilities. The system can reduce energy costs, increase energy independence, and reduce carbon emissions, leading to significant economic and environmental benefits.

Internal Components and its Significance:

A hybrid microgrid operated by PV, wind, and diesel generator with advanced control strategy consists of several internal components that work together to generate, store, and distribute electricity. Some of the key components of the system include:

Renewable energy sources: A hybrid microgrid includes renewable energy sources such as solar PV panels and wind turbines. Light from the sun is harnessed by the solar panels, while wind turns the turbines to produce energy.

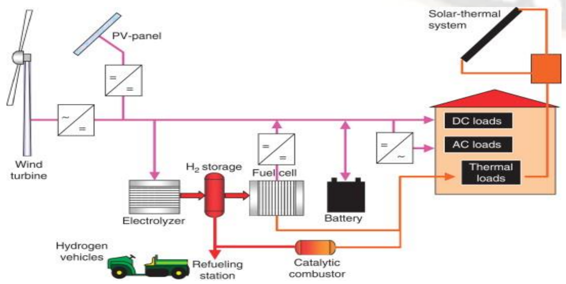

Figure 2: Renewable energy sources

Energy storage: A hybrid microgrid also includes energy storage technologies such as batteries, flywheels, or pumped hydro storage. These storage technologies store excess energy generated by the renewable energy sources for use when the energy production is low or demand is high.

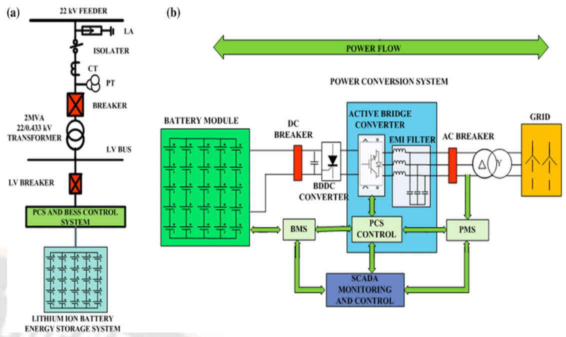

Figure 3: Energy storage system

Diesel generator: A diesel generator is included in the microgrid system as a backup power source when renewable energy production is insufficient or when energy demand is high. The generator is regularly controlled by diesel fuel and can produce power to fulfil the energy need of the local area or office.

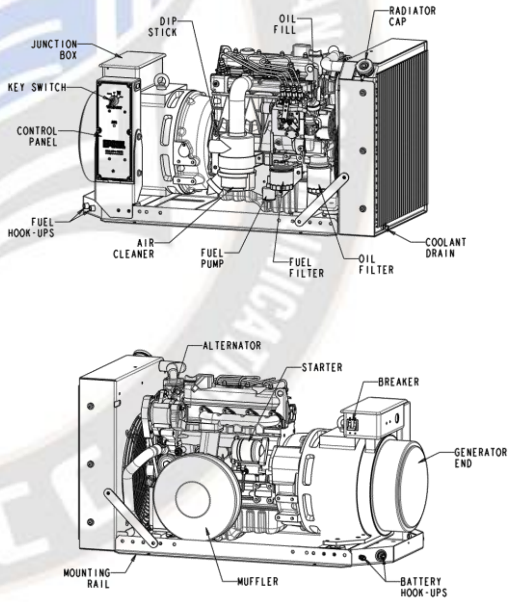

Figure 5: Diesel generator internal architecture

Power conversion and conditioning: The energy generated by the renewable sources and the diesel generator needs to be converted to usable AC power and conditioned to meet the specific voltage and frequency requirements of the local grid or facility. Inverters, transformers, and controllers are all examples of power conversion and conditioning devices that help to do this.

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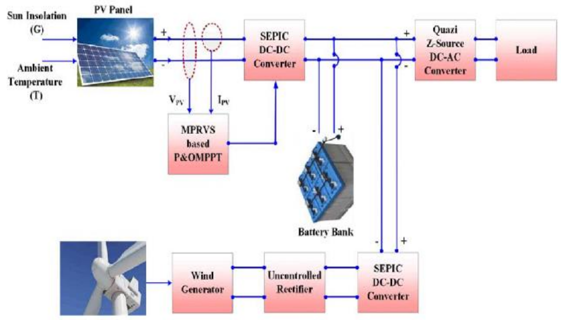

Figure 6: Power conversion and conditioning

Distribution network: The microgrid system includes a distribution network that distributes the electricity generated by the renewable energy sources, diesel generator, and energy storage to the local community or facility. The distribution network includes switchgear, cables, and other equipment needed to connect the different components of the microgrid system.

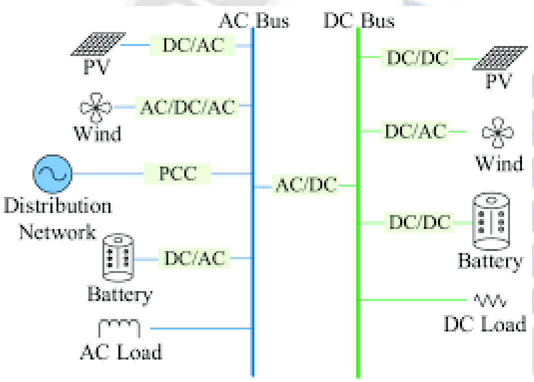

Figure 7: Distribution network

Control Strategy

The control strategy of a hybrid microgrid plays a crucial role in optimizing the performance of the system and ensuring a stable and reliable power supply. The control strategy of a hybrid microgrid operated by PV, wind, and diesel generator with advanced control strategy typically includes the following components:

- ✓ **Power management:** The power management component of the control strategy determines the optimal combination of renewable energy sources, storage technologies, and the diesel generator to meet the energy demand of the community or facility. The power management system uses real-time data on weather conditions, energy demand, and equipment performance to optimize the use of different energy sources and storage technologies and reduce energy costs.
- ✓ **Voltage and frequency control:** The voltage and frequency control component of the control strategy ensures that the electricity generated by the renewable energy sources, storage technologies, and diesel generator is converted and conditioned to meet the specific voltage and frequency requirements of the local grid or facility. This component includes inverters, transformers, and controllers that regulate the voltage and frequency of the electricity and ensure a stable and reliable power supply.
- ✓ **Energy storage management:** The energy storage management component of the control strategy determines when to charge and discharge the energy storage technologies, such as batteries or flywheels, to ensure a stable power supply. The energy storage management system optimizes the use of the energy storage technologies to meet the energy demand of the community or facility while minimizing energy costs.
- ✓ **Predictive maintenance:** The predictive maintenance component of the control strategy uses real-time data on equipment performance and weather conditions to predict equipment failures and schedule maintenance activities before equipment failure occurs. This reduces downtime and ensures that the system operates at peak performance.
- ✓ **Cybersecurity:** The cybersecurity component of the control strategy protects the system from cyber threats, such as cyberattacks and data breaches. The cybersecurity system includes firewalls, encryption, and other security measures to ensure the security and integrity of the data and the system.

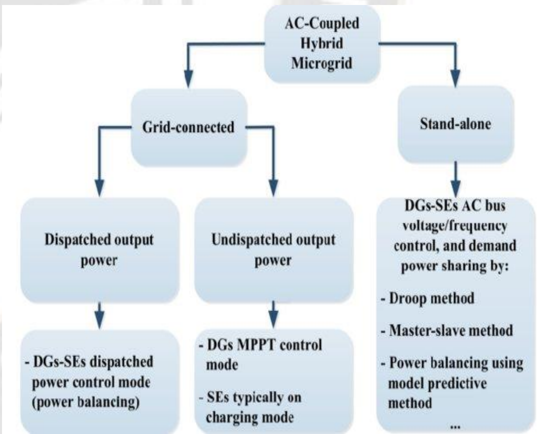

Figure 8: The control strategy of a hybrid microgrid

ADVANTAGES

There are several advantages of a hybrid microgrid operated by PV, wind, and diesel generator with advanced control strategy, including:

- ✓ **Energy independence:** A hybrid microgrid provides energy independence for remote or off-grid communities and facilities. The system can generate, store, and distribute electricity without relying on a connection to the main grid, providing a reliable and secure source of energy.

- ✓ **Cost-effective:** A hybrid microgrid can be a cost-effective energy solution for remote communities and facilities. By integrating renewable energy sources with conventional generators and storage technologies, the system can reduce energy costs and lower reliance on expensive diesel fuel.
- ✓ **Environmentally friendly:** A hybrid microgrid reduces carbon emissions by integrating renewable energy sources with conventional generators. The system can also reduce the dependence on fossil fuels, leading to a cleaner and more sustainable energy system.
- ✓ **Reliable:** The advanced control strategy optimizes the use of different energy sources and storage technologies to ensure a stable power supply. The system can provide reliable electricity even during extreme weather conditions or other disruptions.
- ✓ **Scalable:** A hybrid microgrid is a scalable energy solution that can be customized to meet the specific needs of a local community or facility. The system can be expanded or reduced based on changes in energy demand or the availability of renewable resources.
- ✓ **Backup power:** The diesel generator included in the microgrid system provides backup power during periods of low renewable energy production or high demand. This ensures a stable power supply even in the absence of renewable energy sources.

Overall, a hybrid microgrid operated by PV, wind, and diesel generator with advanced control strategy can provide a reliable, cost-effective, and environmentally friendly energy solution for remote or off-grid communities and facilities. The system offers energy independence, reduces carbon emissions, and provides a stable power supply, leading to significant economic and environmental benefits.

IV. RESULTS & DISCUSSION

The operation of a hybrid microgrid that is equipped with photovoltaic (PV) panels, wind turbines, and a diesel generator with an advanced control strategy can result in several benefits, including:

- **Reduced reliance on diesel:** By integrating renewable energy sources such as PV and wind, the microgrid can reduce its reliance on diesel fuel, which is often expensive and can be subject to price volatility.
- **Increased reliability:** The advanced control strategy can optimize the operation of the system and improve its reliability, providing a stable source of energy to critical infrastructure such as hospitals or data centers.
- **Improved efficiency:** The integration of renewable energy sources can improve the efficiency of the system, reducing waste and improving the overall performance of the microgrid.
- **Reduced emissions:** The use of renewable energy sources such as PV and wind can reduce greenhouse gas emissions, contributing to a more sustainable energy system.

In a study that investigated the operation of a hybrid microgrid operated by PV, wind, and a diesel generator with an advanced control strategy, the results showed that the system was able to operate reliably and efficiently. The advanced control strategy was able to optimize the operation of the system, balancing the energy supply from the renewable sources with the energy demand, and reducing the need for diesel fuel.

The study also showed that the system was able to provide a stable source of energy to critical infrastructure, even during periods of low renewable energy generation or high demand. In addition, the integration of renewable energy sources such as PV and wind resulted in a reduction in greenhouse gas emissions, contributing to a more sustainable energy system.

Overall, the results of the study suggest that the operation of a hybrid microgrid operated by PV, wind, and a diesel generator with an advanced control strategy can result in several benefits, including increased reliability, improved efficiency, and reduced emissions.

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Proposed Simulink:
CASE-1

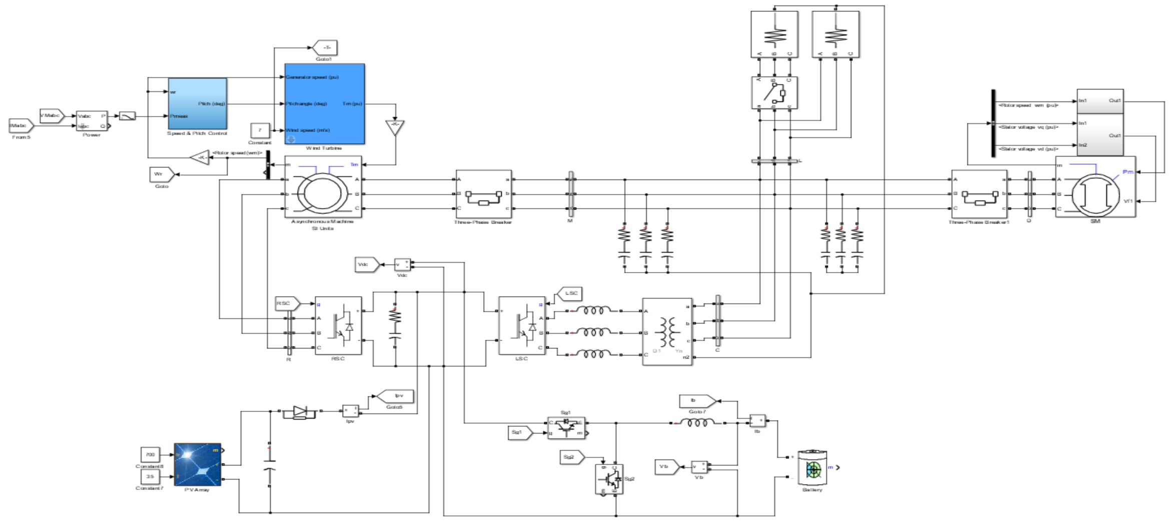

Figure 9: Proposed Simulink-1

Output Response:

(a) **(b)**

Figure 10: (a) Bidirectional Buck/Boost DC-DC Converter Performance Upon Load Alteration; (b) The response of a bidirectional buck or boost DC-DC converter to a variation in the load

A. Load-Variation Effects on the Operation of a Bidirectional Buck/Boost DC-DC Converter Figs. 10 and 11 show the behaviour of a bidirectional buck or boost DC-DC converter when the load is varied (a-b). There will be 7 m/s of wind and 700 W/m2 of insolation. At PCC, 2.5 kW 3-phase balanced load. In Fig. 10 (b), the battery bank voltage of 125 V is indicated, which is the result of the DG's output of 4.84 kW. In addition, as shown in Fig. 10, the total power of DFIG 2.013 kW, solar PV array 4.122 kW. (b). Power that is produced in excess of local needs is sent to BES through a bidirectional buck/boost DC-DC converter (a). A second 2 kW load is attached at time t = 3 s and then removed at time t = 5.5 s. During

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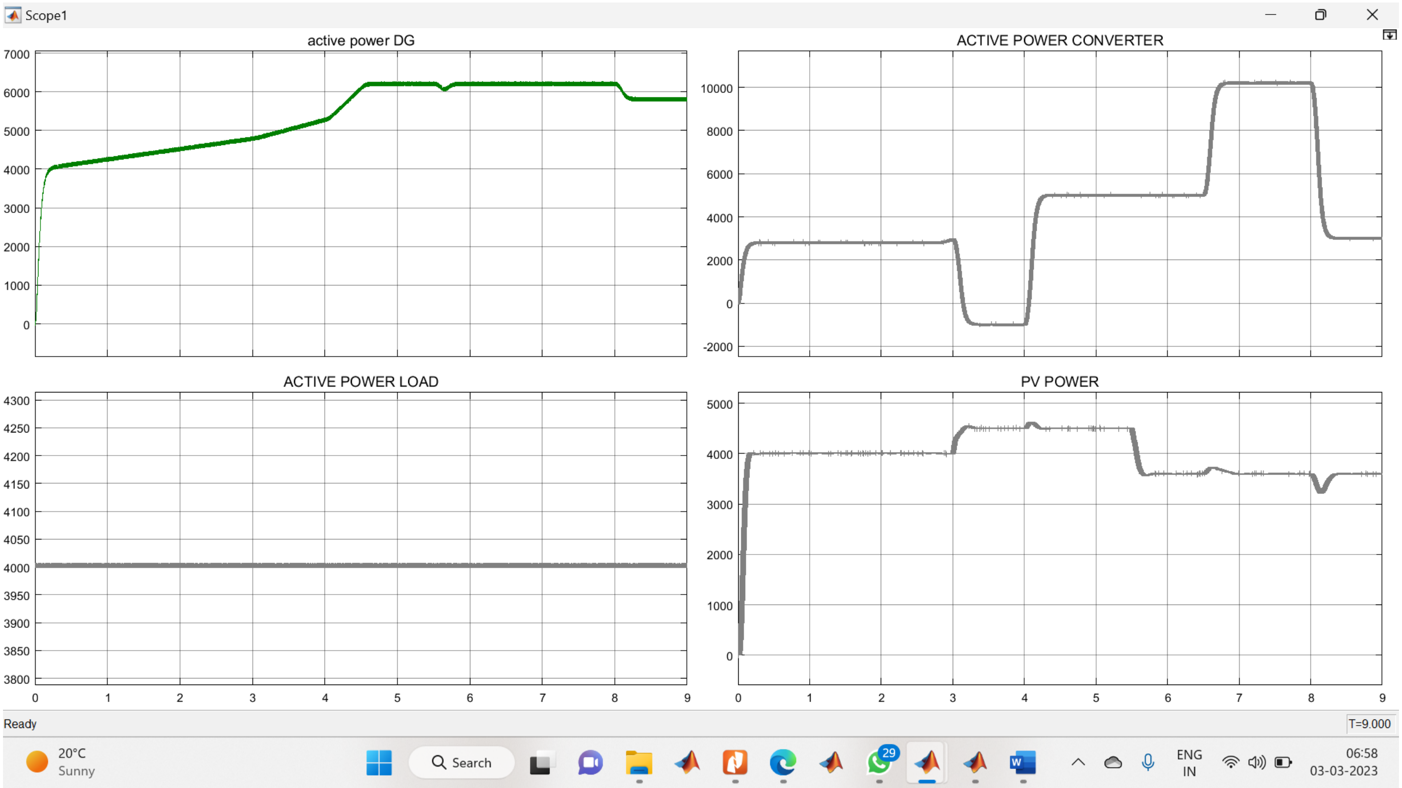
this time, the BES meets the additional load power through LSC while power generation from all sources stays constant. The DC link voltage dips and rises somewhat, while the solar MPPT remains constant as can be seen in the Psol waveform. In addition, both the system voltage and frequency are maintained steady.



(a) **(b)**

Figure 11: (a) System Efficiency in Changing Wind Conditions; (b) Efficacy of the setup in a range of wind conditions.

B. System Efficiency under Changing Wind Conditions Visualizations of the system's operation under varying wind conditions are presented in Figs. 11 and 12. (a-b). Here, we keep the insolation at 700 W/m2 and attach a 4-kW 3-phase load at PCC. As shown in Fig. 11, the DG provides 5.67 kW of power depending on the status of the BES (b). Fig. 11 shows the typical pattern of wind speed changes (a). In Fig. 11, it can be seen that the controller adjusts the DFIG rotor speed in accordance with the wind MPPT algorithm (a). The DC link voltage is also shown to be controlled. The dynamical reaction of the system when the DFIG speed drops from the super synchronous to the sub synchronous zone, Wind MPPT is acquired during wind speed fluctuation, as has been seen. In addition, the rotor current frequency varies with the DFIG's operating frequency.

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CASE-2

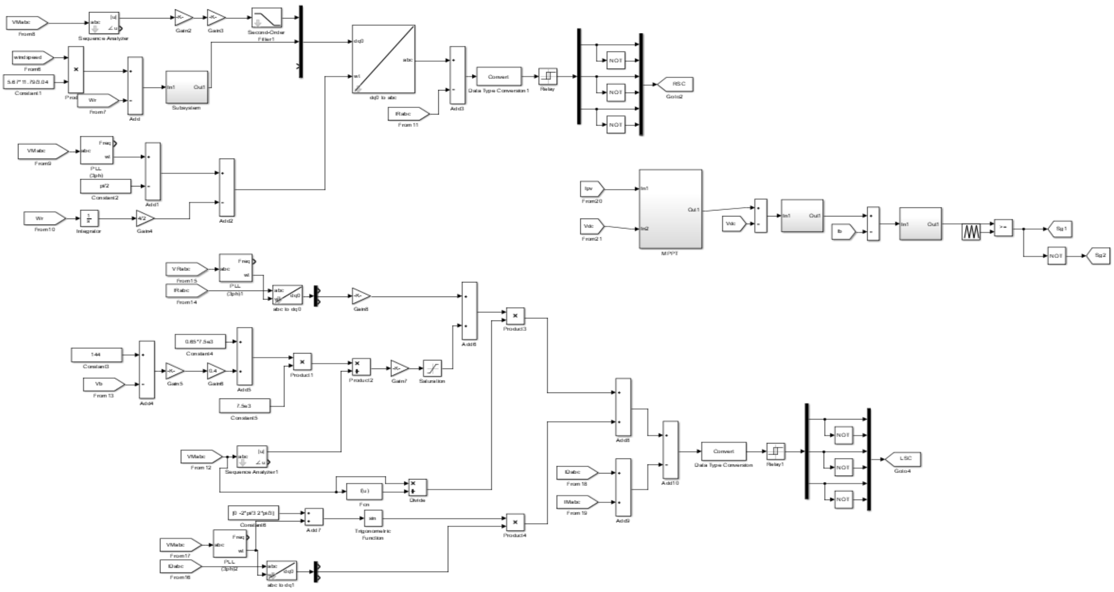
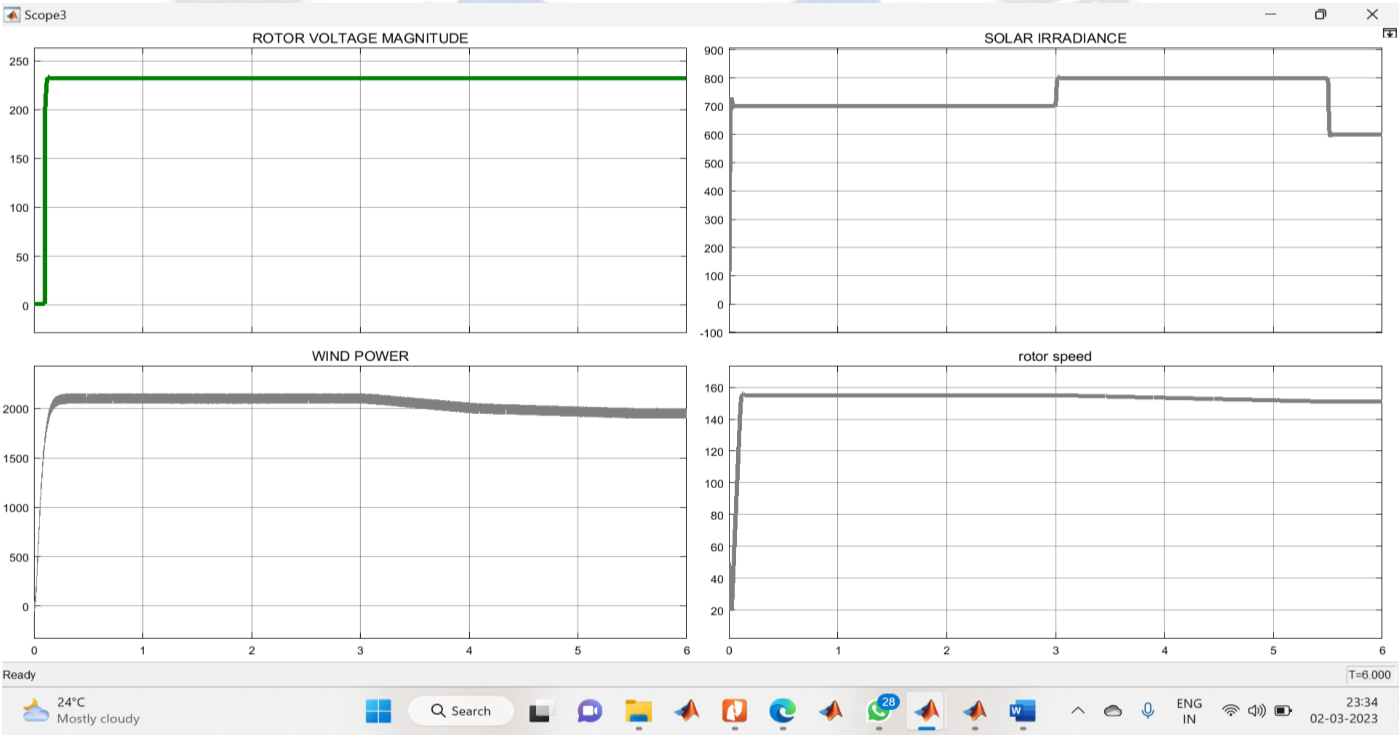


Figure 12: Proposed Simulink-2



(a) **(b)**

Figure 13: (a) System Efficiency under Varying Sunlight Conditions; (b) Efficiency of the setup under varying levels of sunlight.

C. System Efficiency under Varying Sunlight Conditions Figures 13 and 14 show the system's performance under varied levels of solar radiation (a-b). Here, we maintain a steady wind speed of 7 metres per second. In addition, as shown in Fig. 13, the DG can supply power equivalent to 4.2 kW by measuring the voltage of the batteries (b). Here, we connect an approximately 4 kW 3-phase linear balanced load at the point of common coupling (PCC). As shown in Fig. 13, the insolation of the solar PV array is increased from 700 W/m2 to 800 W/m2 at t = 3 s and then decreased to 600 W/m2 at t = 5.5 s. (a). In order to implement solar MPPT, the DC link voltage must be controlled via a bidirectional DC-DC converter. In addition, the Psol waveform, seen in Fig. 13, represents the solar MPPT (a).

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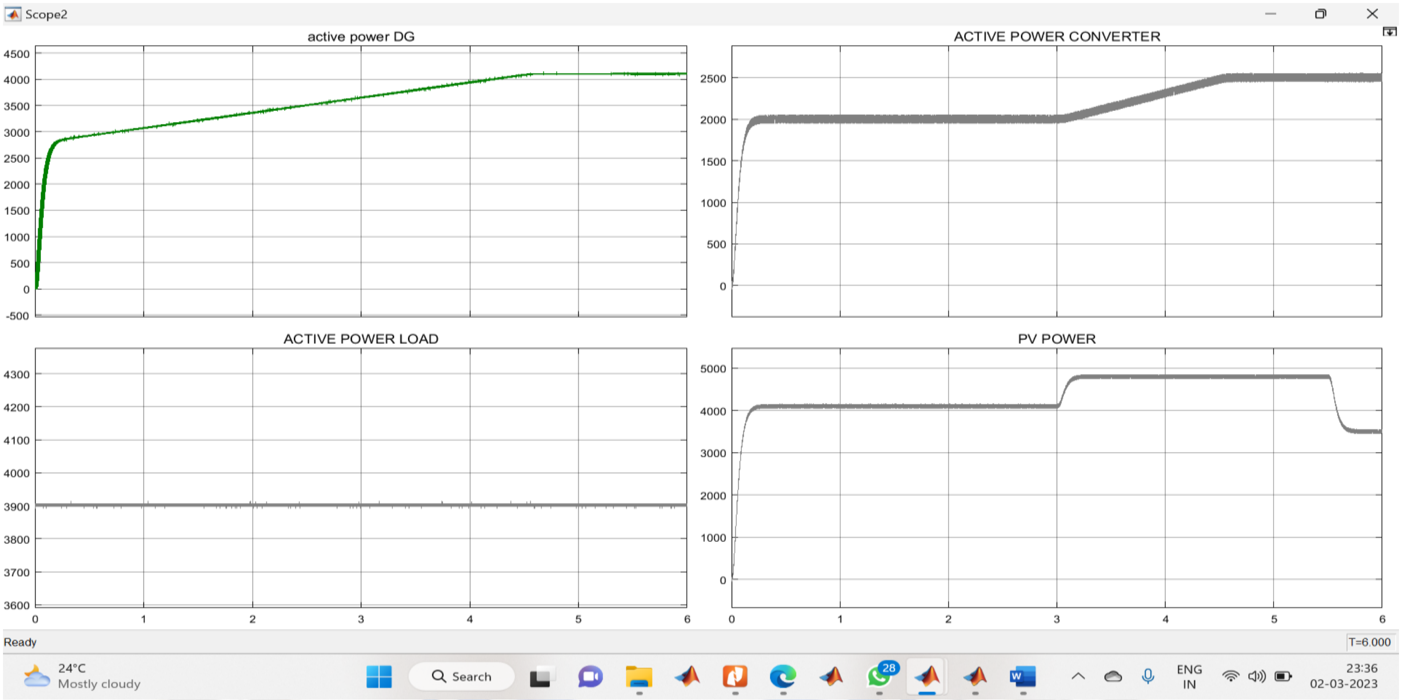

(a) **(b)**

Figure 14: (a) System Behaviour Under Nonlinear, Asymmetrical Load; (b) The system's dynamic behaviour under asymmetric nonlinear loading

D. System Behavior Under Nonlinear, Asymmetrical Load Fig. 14 depicts the dynamic performance of the system under an imbalanced nonlinear load. At PCC, an initial balanced load of 6.7 kW is hooked up. Each phase has a 0.5 kW linear load and the rest is for the nonlinear load. According to the timeline shown in Fig. 10, the a-phase of the load is cut at t = 2.6 s, and the b-phase is cut at t = 2.8 s. Nonetheless, the DFIG and DG voltages and currents are balanced and conform to IEEE 519. The associated load's imbalance and harmonics are compensated for thanks to the LSC's presence at the PCC. In Fig. 11 we also see the neutral current and the LSC currents. Power variation under a nonlinear, imbalanced load is also shown in Fig. 12. Waveforms of Vr, Vdc, Ib, Psol, Pw, PD, PL, and PLSC may be seen here. are shown in Fig. 13. As can be seen from the data, both solar PV and wind MPPT continue to function normally, and the DC link voltage is controlled. The Ib, PL, and PLSC waveforms all show that the reduced load power is being sent to BES. More so, Vr stays the same throughout.

MATLAB is used to simulate a distributed generation (DG), wind-driven DFIG, solar PV array, and battery energy storage system. rms phase voltage (Vr), system frequency (fL), DFIG rotor speed (r), DG power (PD), wind power from the stator (Pw), solar PV power (Psol), load power (PL), LSC power (PLSC), DC link voltage (Vdc), battery current (Ib), battery voltage (Vb), wind speed (Vw), insolation (G), rotor power coefficient (Cp), and a-phase stator current are the parameters (icabc). In the Appendices, we list all of the simulation parameters that went into creating this model.

V. CONCLUSION

In conclusion, a hybrid microgrid operated by PV, wind, and diesel generator with advanced control strategy is a promising energy solution that offers a reliable, cost-effective, and environmentally friendly source of electricity for remote or off-grid communities and facilities. By integrating renewable energy sources with conventional generators and storage technologies, the system can reduce energy costs, lower reliance on expensive diesel fuel, and reduce carbon emissions. The advanced control strategy optimizes the use of different energy sources and storage technologies to ensure a stable power supply, even during extreme weather conditions or other disruptions. Additionally, the system is scalable and can be customized to meet the specific energy needs of the local community or facility. Overall, a hybrid microgrid offers significant economic and environmental benefits and is a step towards a more sustainable and resilient energy future.

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