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Modelling and Control of a Stand-Alone Hybrid PV-Wind Micro-Grid System

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Abstract: ***Microgrids are quickly becoming a necessity for the future of electricity. The use of renewable energy sources provides a viable alternative to traditional methods of producing electricity. Generation of electricity via traditional energy sources has severe consequences for the natural world and for human well-being. Renewably sourced energy is widely available across the cosmos. Renewable energy is dependable, efficient, sustainable, and clean. Wind and solar power are becoming increasingly important in today's society. This paper details the design and control of a stand-alone micro-grid that utilises a Permanent Magnet Synchronous Generator (PMSG) powered by photovoltaic cells and a wind energy conversion device. In order to ensure efficient functioning of a microgrid system despite non-linear parameter fluctuations, a novel intelligent control approach based on ANFIS control has been presented. The designed system was constructed in MATLAB/Simulink and simulated under constant load and step load variations. The BESS was able to charge thanks to the controllers, despite fluctuations in the load and other external parameters like irradiance and wind speed.***

Keywords: PV, Wind Energy, Microgrid, Fuzzy Logic, ANFIS.

1. INTRODUCTION

Unsustainability of fossil fuel resources is a problem in today's globe because of rising energy needs brought on by industrialization and the urbanisation of human existence. Rising global temperatures can be directly attributed to the massive increase in GHG emissions that was triggered by these record-breaking consumption rates. Droughts, harsh weather, food shortages, and other negative consequences of global warming are more apparent now than at any time in the past. Furthermore, oil and natural gas reserves are being drained at an alarming rate. The widespread problem of reliance on fossil fuels now demands immediate action at all levels of society. Smaller buildings can be designed using wind and PV-based

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imperativeness systems that incorporate energy storage and intelligent control. The reliance on the grid control, which is predominately fossil power, may be lowered by employing such a small size cross section in a reasonable region. The components of a small-scale network that generates its own electricity from renewable, environmentally friendly, and economically viable sources (REGS) are listed. In their vehicles, the designers have offered a unified control structure for the equitable distribution of economic resources on a microscale. The metrics of structure execution, such as control quality, structure efficiency, etc., under the exceptional working conditions, have not been included. There are many forms of energy, however solar and wind power generation systems for a relative power age require greater space on the earth. Microgrids are comprised of a wide array of parts. Figure 1 depicts the microgrid components.

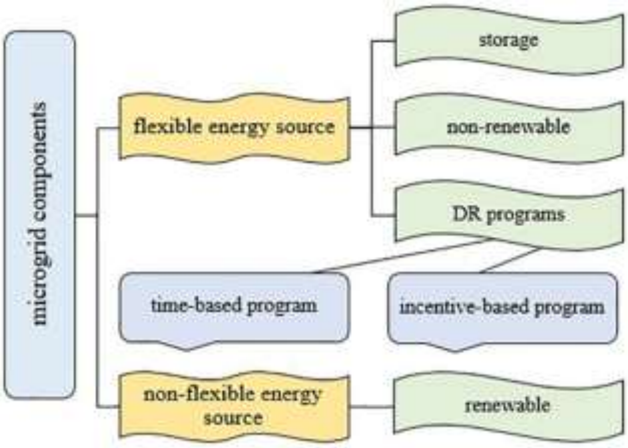

Fig.1: Microgrid view of different energy sources.

Different types of microgrids are depicted in Figure 2. To be considered flexible, a microgrid must be able to import and export energy to and from the grid while also controlling the active and reactive-power flows.

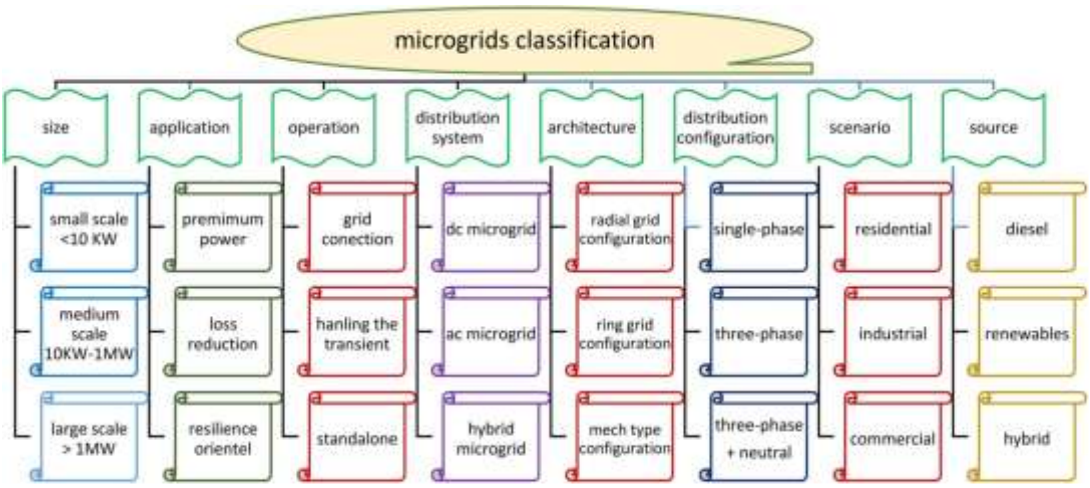

Fig.2: Microgrid classifications.

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In order to control the flow of energy in a particular hybrid energy system (HES) that makes use of wind, PV, fuel cell, micro turbine, diesel, and energy storage, a mixed integer linear programming formulation of microgrid energy management (MGEM) is developed. HESs that run on antiquated fuels like diesel produce more greenhouse gases and have a negative impact on the system's ability to keep the environment clean. Smart and intelligent controllers' effects on HRES power management are rarely described or discussed in the literature. Microgrids that are connected together in a hybrid configuration are the subject of this research. Droop and power flow control are at the centre of power management in the hybrid AC/DC Microgrid. DC and AC sub-grids can both benefit from droop control. If the latter method is adopted, individual source fluctuations are kept to a minimum by an interlinking between the two sub-grids, which is primarily utilised to manage the scenario where any sub-grid breakdown occurs due to overstress.

This work aims to address this need by developing a sophisticated controller for a targeted Hybrid renewable energy micro-grid system. The most important results of this study are: This publication presents research on a hybrid wind and PV system that may be used in places far from the power grid. To get the desired results from an off-microgrid setup, a smart controller is employed. When the energy produced by the PV panel is more than the energy consumed by the load, the surplus energy is utilised to charge the batteries, which is the anticipated behaviour of the control system. The batteries are discharged to supply additional power when the electricity supplied by the PV panel is inadequate to fulfil the load's demands. In addition, the smart controller is used to safeguard the battery banks in typical, overcharging, and over discharging circumstances. The controller should act suitably in all cases. In typical use, where the battery's level of charge is between 20% and 80%, the controller operates as intended. When the state-of-charge (SOC) hits 80%, a specific instruction is given to shut down the PV panels and the wind turbine. Before the SOC reaches a safe threshold, set at 75% in this controller, the PV panel and wind turbine cannot be connected. Below 20% SOC, other orders are sent out to power down the inverter and disconnect the loads. Until the batteries reach 75% of their capacity, the inverter will not supply power.

System Modelling

When deployed, the benefits and drawbacks of each kind of microgrid power systemalternating current (AC), direct current (DC), and hybrid become clear. There have been various analyses of the benefits and drawbacks of both AC and DC microgrids. DC microgrids can function either in conjunction with the mains power supply or independently. Schematic representation of a typical AC microgrid structure.

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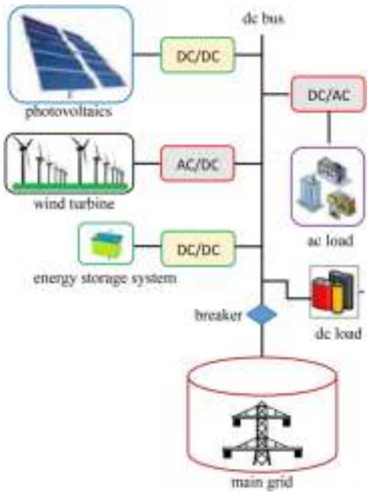

Fig.3: DC microgrid.

A DC microgrid's distribution system can be either monopolar, bipolar, or homopolar. All the renewable energy sources and the loads in an AC microgrid are linked to a central AC bus. The complexity of controlling and operating AC microgrids is their primary drawback. Figure 4 depicts a typical AC microgrid layout. Based on the wiring in place, microgrid ac may be broken down into three distinct categories: single-phase, three-phase without neutral-point lines, and three-phase with neutral-point lines.

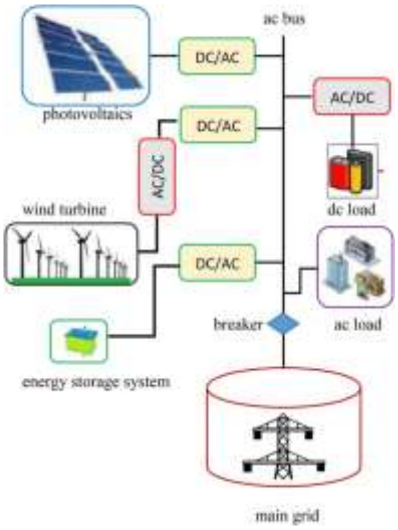

Fig.4: AC microgrid.

The micro-grid system under investigation is made up of three primary components: a photovoltaic (PV) array, a permanent magnet synchronous generator (PMSG) powered by wind energy and power electronics connecting the AC and DC sides of the grid. Each power electrical equipment often needs many controllers. The recommended microgrid's system setup and design are depicted in Figure 5. In the following paragraphs, we'll examine the various configurations in further depth.

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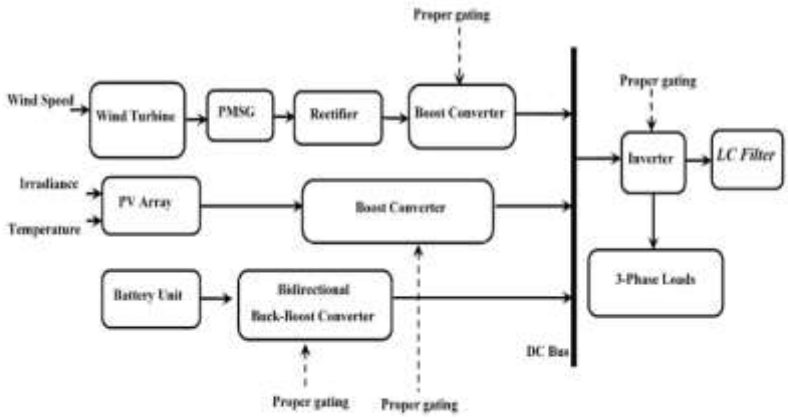

Fig.5: System configuration of the suggested microgrid.

Matlab's toolbox was used to create this application because the NN structure can be quickly generated using the gensim command in the mfile and Simulink's user-friendliness makes it simple to create and test simulations of complex systems. There are three distinct levels to this network: Input Layer Subtle Second Layer Exiting at Layer 3. The hidden layer's job is to connect the visible layers (the input and the output). There are as many neurons in the input and output layers as there are signals. Though the neurons in the input layer lack transfer function, they do have a scale factor built into each input to help equalise the signals coming in. Those calculated signals are sent from the input layer to the hidden layer, which in turn sends them to the output layer. Following computation, the hidden layer sends weights to the output layer. When the output is not what was expected, the error is sent back to the input layer through a process called back propagation (feedback). As a result of training and learning, the neural network's weights are optimised to reduce error. If the results aren't satisfactory after some amount of time, the process restarts. Presently, the most often used network architecture is the back propagation network. The weights and biases of a neural network can be set using any number of techniques. The LM method is employed since it is the quickest of these algorithms when it comes to NN training. It's four times as quick as comparable systems. For this network to function, it must be trained using an input data set, after which simulations must be done to yield results.

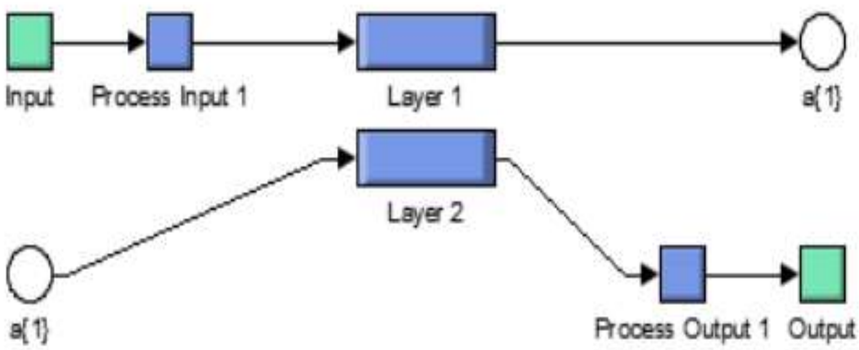

Fig.6: Neural Network Architecture.

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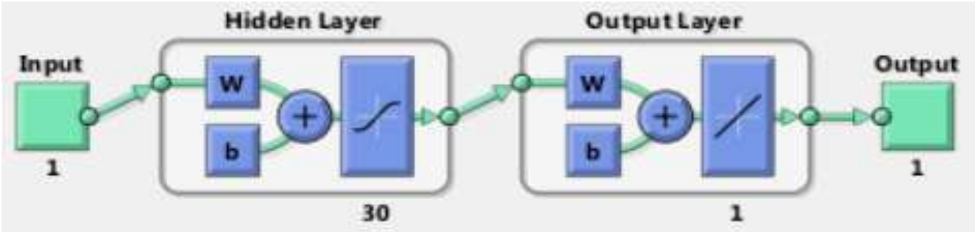

Fig.7: Custom Neural Network

Simulation Results
Case-1-- Normal Condition:-

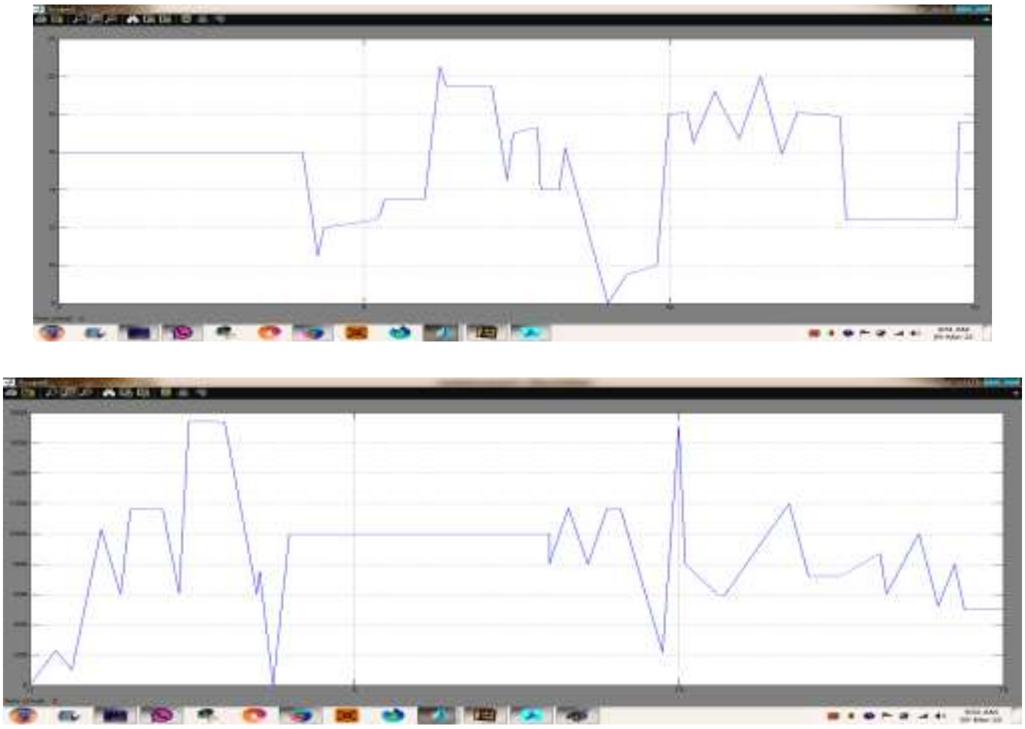

Fig: 8- Irradiance (W/m2), wind speed (m/s).

Figure 8 is a simulation showing system performance in three different cases. The impact of the PV system is analysed in the range of t = 0 to 4 s, with irradiance and wind speed held constant. With the wind speed held constant at 14 m/s, the irradiance is varied between zero and twelve hundred W/m2. Between t = 0 and t = 60, (2) the impact of the wind system is analysed with varying wind speeds and constant irradiance (4 s to 8 s). Since we know that 1000 W/m2 of irradiance will always be there, we can easily examine the influence of the wind controller. The system is studied in detail for (t > 8 s) under varying irradiance and wind speeds throughout the remaining simulation time. For the first scenario of the simulation, t = (0-4) s, the irradiance is meant to mimic a clear day irradiance as the sun shines with minimal values of irradiance, then grows to its peak for that day, and then

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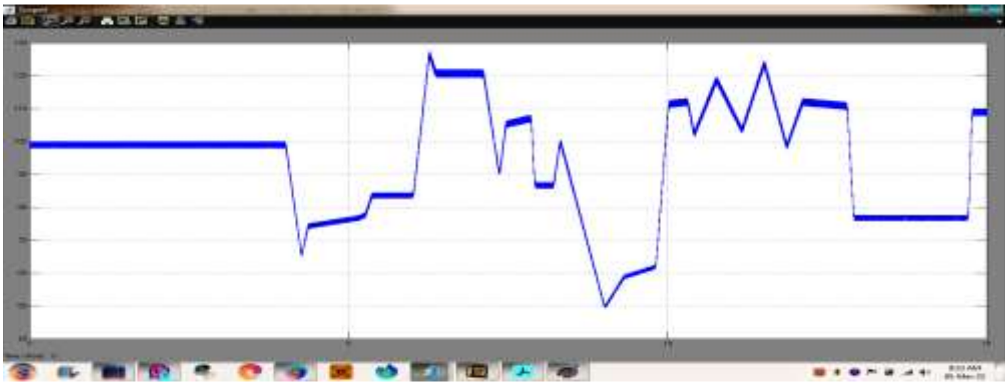
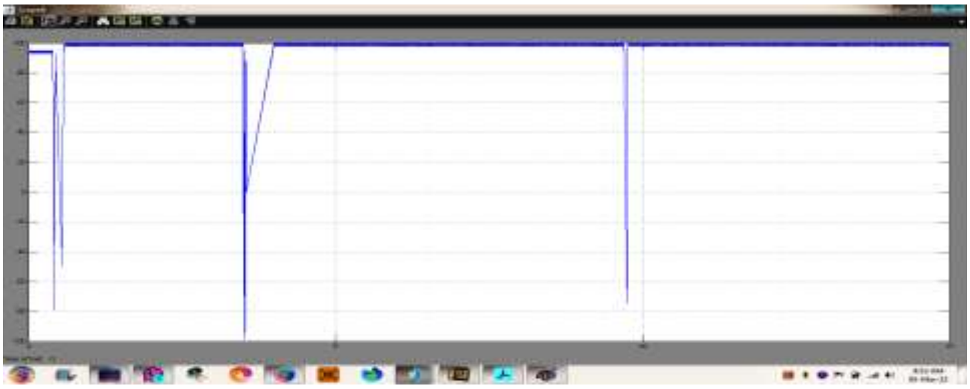
decreases again with some clouds randomly passing by. To account for the possibility that clouds in a simulated environment would obscure some or all of the sun's rays, the irradiance has been set to gradually increase from zero to one thousand two hundred watts per square metre (W/m2) before decreasing to zero once more. As this scenario is meant to test and evaluate the solar energy element alone, the wind speed is held constant at 14 m/s during this time period. The second scenario, with time constant t = (4 s to 8), is designed such that the impact of the wind turbine controller may be readily seen in the virtual environment. Constant irradiance and wind speeds (8-25 m/s) are used to achieve such observability. In the third case, t > 8 s, we simulate varying and unpredictable irradiance and wind speed to test the responsiveness of the control method.





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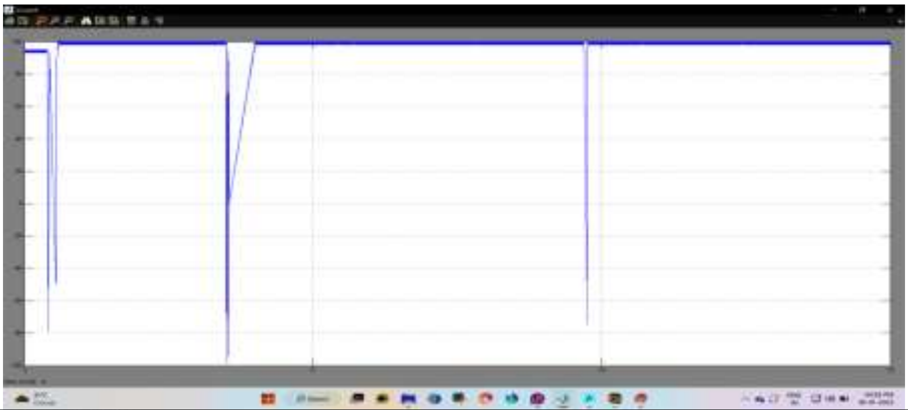
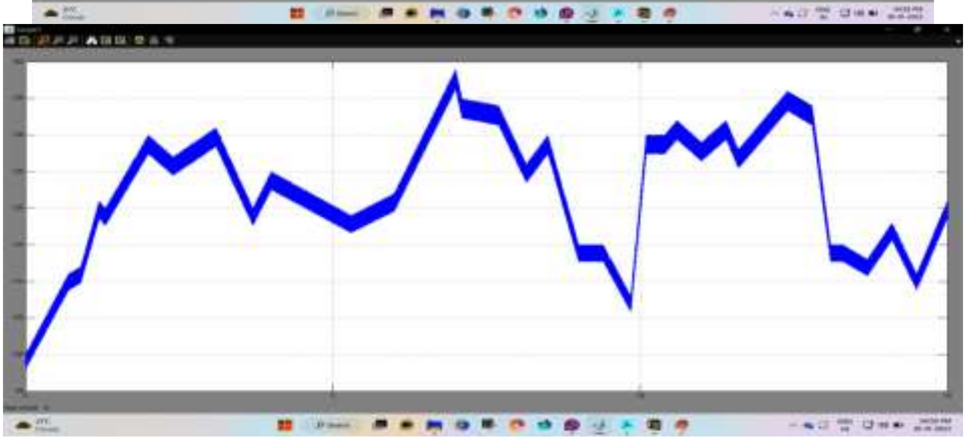
Existing waveforms
PMSG rectified voltage, PV voltage, and battery voltage, respectively.





Proposed waveforms
Fig 9. Proposed waveforms of PMSG rectified voltage, PV voltage, and battery voltage, respectively.

PMSG rectified voltage, PV voltage, and battery voltage are displayed in Figure 9. Here we can see that the MPPT is doing its job correctly because the PV voltage is always at Vmax when the irradiation is greater than zero.

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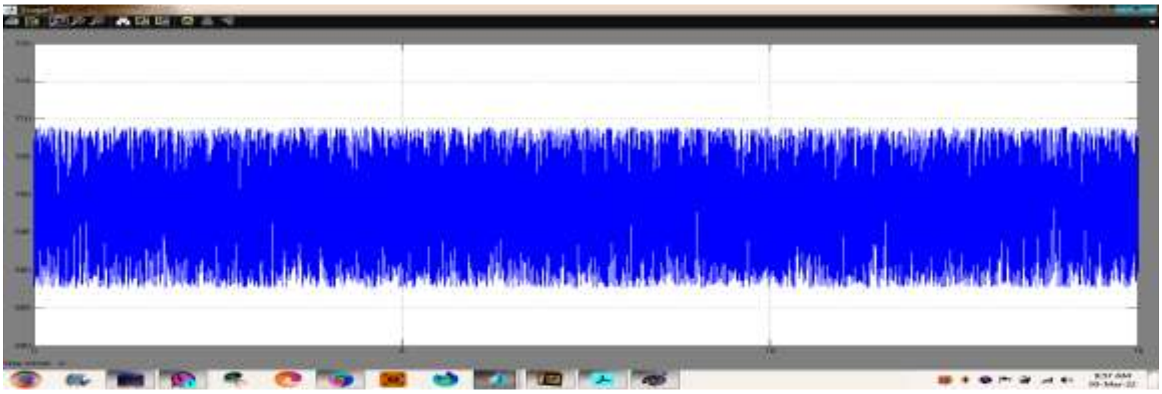
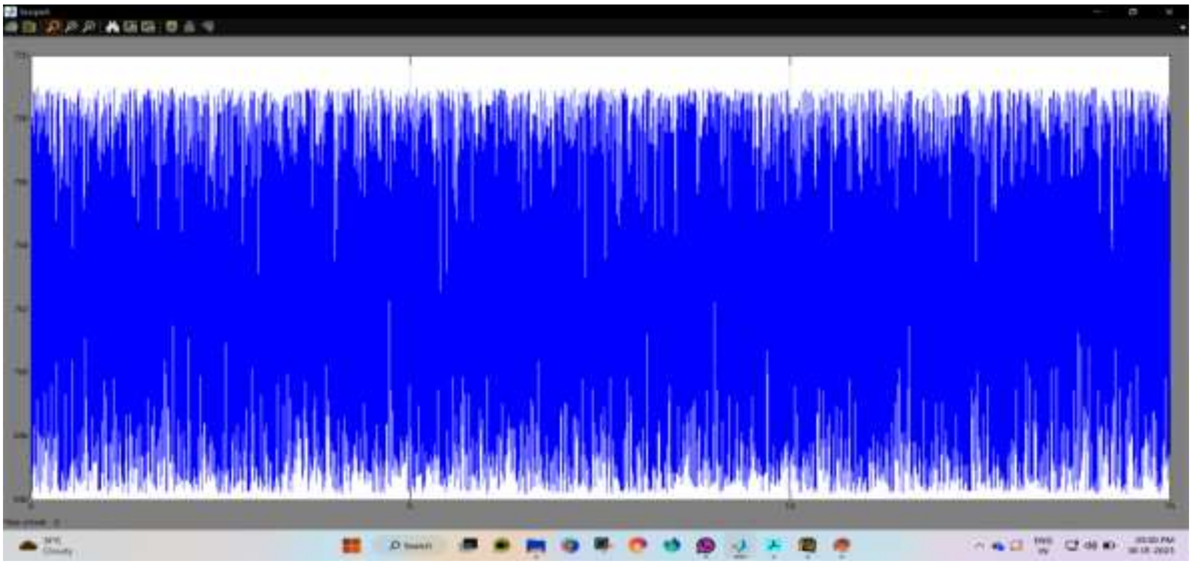
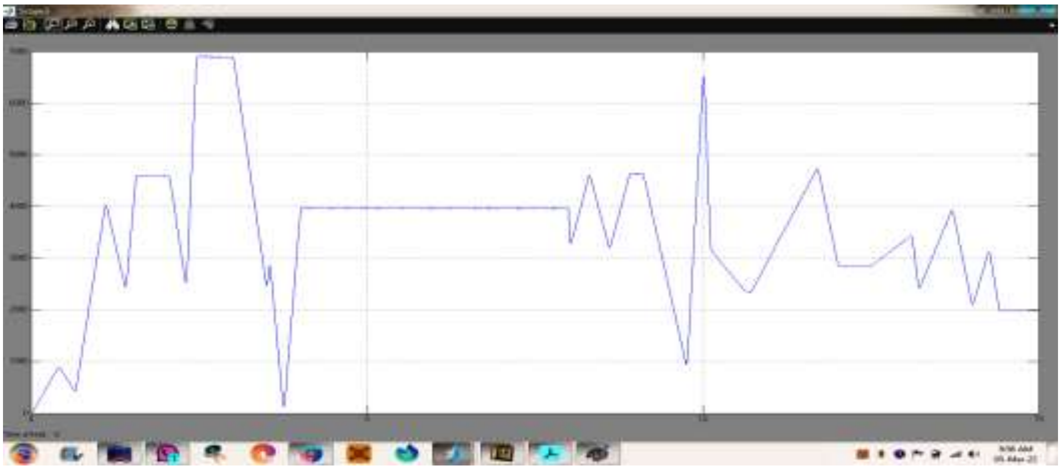


Existing waveform



Proposed system

Fig. 10 DC output voltage



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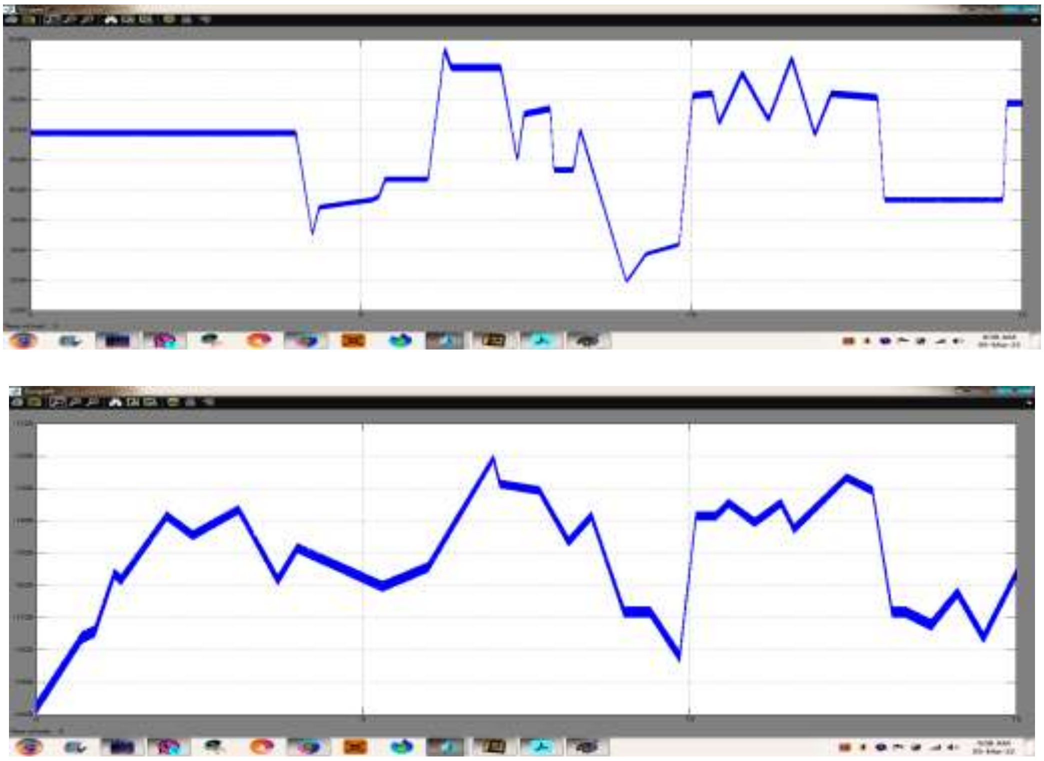

Existing waveforms

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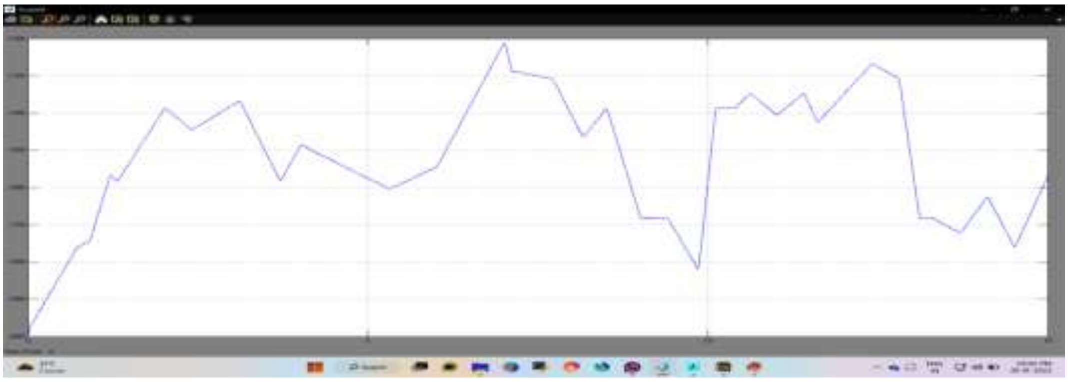
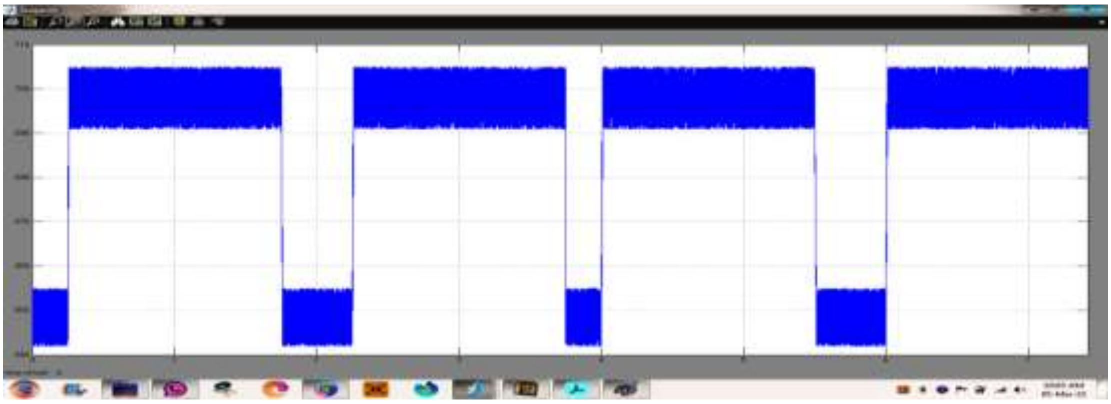


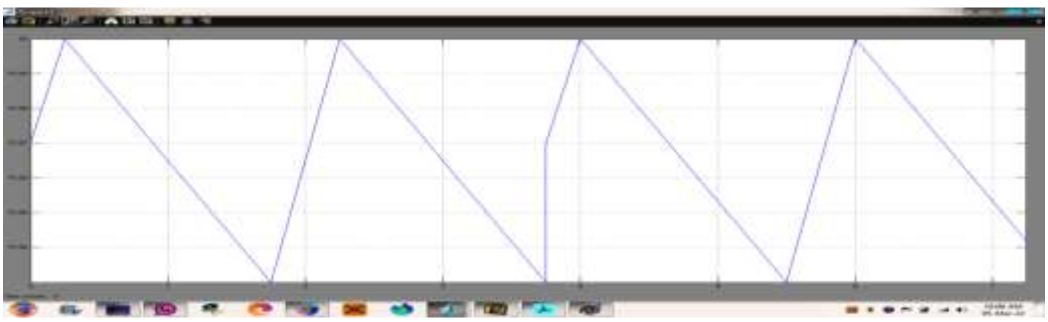
Proposed waveforms

Fig.11 Power Flow in the system at a load power of 2k: (1) power output of the PV panel, (2) wind power, (3) power storage in the batteries unit.

In Figure 10, we can see the DC bus voltage fluctuating somewhat due to changes in both the irradiance and the wind speed. This diagram displays the inverter-driven three-phase voltages and currents. Transient Voltage and Current Distortion are 3% and 5%, respectively. In Figure 11, we can see how the system's power is distributed, with a steady supply of about 2080W going to the inverter. Only 2 kW are being used by the load, with the rest being lost in the LC filter and other power electronics.

Casae-2 -- Overcharging Condition:-





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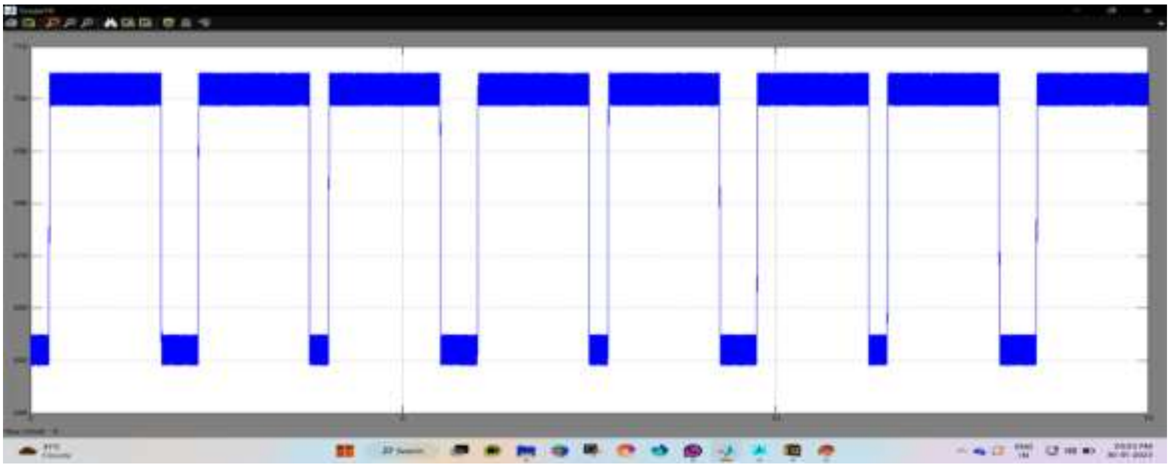

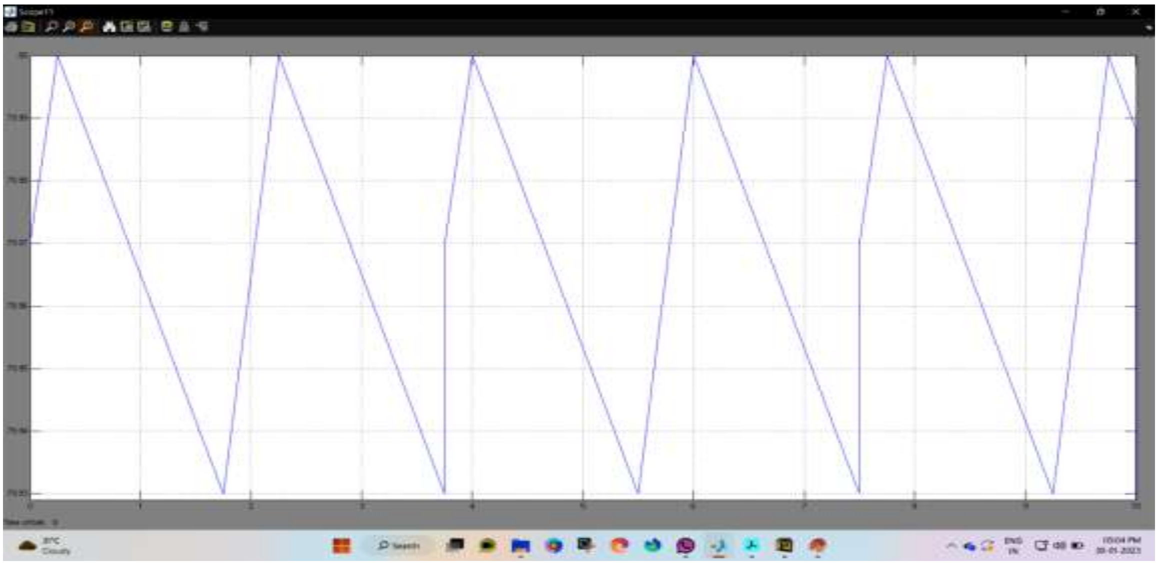

Proposed waveforms

Fig.12 PMSG rotational speed in rpm and Batteries SOC in % for the overcharging condition.

The load requires 2 kilowatts of power, while solar and wind generate 4.8 and 4.9 kilowatts, respectively. In addition, 2 kW is used for feeding the load, and the remaining 7.7 kW is being sent to the batteries. This will continue until the maximum SOC is achieved (currently set at 80%). There are now no solar or wind power sources since two breakers have been turned off. Since their combined output is zero, the load must be supplied entirely by the charged batteries, resulting in a decline in SOC. The state of charge (SOC) of the batteries continues to drop until it reaches a user-defined SOC limit, in our case 75%. In Fig. 12, we see the controller's actions when overcharging. When the power from the sources is reduced, SOC decreases as well (from 80% to 79.93% to 80% to 79.93%).

Case-3 -Overdischarging Condition:-

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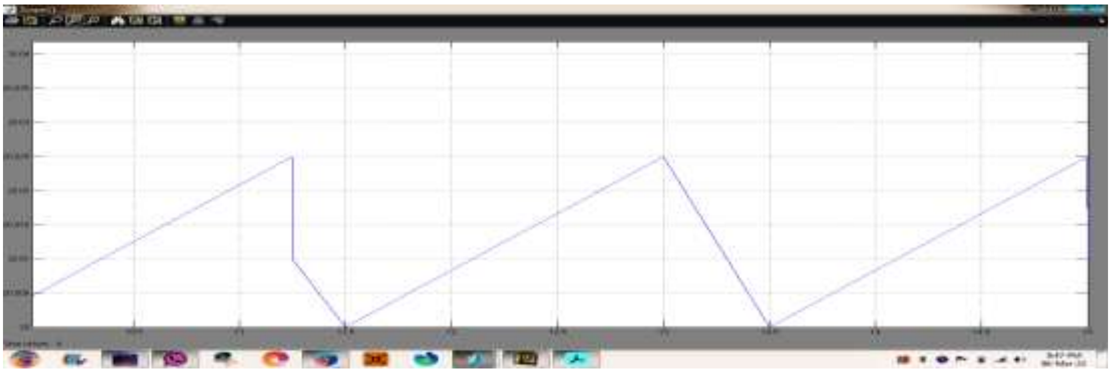
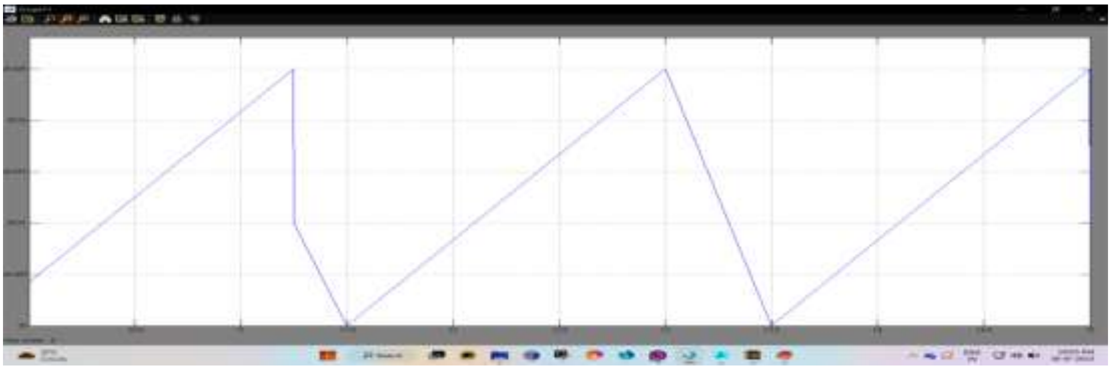


Existing waveform



Proposed waveform

Fig:13 Batteries SOC in % for the over discharging condition.

When the state of charge (SOC) of the batteries drops below 20%, the load is turned off to prevent further discharge and potential damage. They are turned off and remain that way until a secure SOC margin is reached. The value of 20.025% is used as the secure upper bound in this study. In Figure 13, we can see that the PV system and WECS are providing insufficient power, which is causing the batteries to drain. If the batteries' state of charge drops below 20%, the power is cut off. The batteries are fed and charged using the electricity from the PV system and WECS. When the SOC level reaches the predetermined safety threshold, the load circuit breaker is closed.

2. CONCLUSION

Design and control of a standalone micro-grid system with a PV system and WECS were suggested in this study. To regulate and collect the maximum power feasible from the PV system, fuzzy logic-based MPPT was employed for a boost converter. Two PI voltage and current control loops maintained a consistent DC bus voltage from the PV system to the battery storage system. The control system is meant to accomplish the load in all instances. Whenever the amount of energy produced by the PV panel is greater than the amount needed by the load, the surplus is used to charge the batteries. When the energy produced by the PV panels is insufficient, the batteries supply the difference. And under all conditions, from

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normal to overcharging to over discharging, the controller is used to safeguard the battery banks. The controller needs to make the right decisions in each scenario. Under typical circumstances (20% SOC 80%), the controller operates as designed regardless of the battery's level of charge. At 80% SOC, both the PV panels and the wind turbine are shut off and a predetermined order is sent out. Before the SOC reaches a safe 75% threshold, this controller disables the PV panel and wind turbine connections. Other commands are sent out to switch off the inverter and disconnect the loads when SOC falls below 20%. Turning off the inverter's power means waiting for the batteries to reach an adequate charge level before it can be turned back on. The difficulty of delivering electricity to outlying locations without access to the main grid was addressed by the development of a standalone microgrid system and the accompanying controllers.

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