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Optimal Control Strategy for Power Management Control of an Independent Photovoltaic, Wind Turbine, Battery System with Diesel Generator

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ABSTRACT- The need for a greater supply of energy from sustainable sources is growing because of increasing energy prices, concerns about nuclear power, climate change, and power grid disruptions. This research offers a method for the balance of power management of a combination of multi-source DC and AC supplier systems that enables sources of clean energy based on an independent grid to function economically and with the highest levels of system predictability and stability possible. The DC microgrid's hybrid generation source consists of a diesel power source, wind, photovoltaic (PV) power, and a battery bank. The energy system can fulfill the load demand for electricity at any moment by connecting various renewable sources. It can function both off and on the grid. The microgrid may occasionally not be able to provide sufficient electricity, while every green energy source's electricity contribution is based on how its supply varies and how much power is needed to meet demand. As a result, a diesel generator is required as additional backup power, particularly while operating off-grid. This paper designs and implements an MPPT technique for a PV system based on the GWO algorithm. By creating PWM pulses in response to variations in the PV panel voltage, this method modifies the converter's duty cycle, while wind turbines using MPPT based on P&O, to get the most out of hybrid energy sources that are renewable while simultaneously enhancing the quality of power. The priority sources of electricity for the grid are photovoltaics and wind power. Based on the results of simulations and experiments, the proposed control method for DC, which uses the MPPT approach, can dynamically switch between all of the system's various modes of operation, independent of the battery's condition or environment, ensuring safe operation and constant bus voltage. An analysis was conducted on the suggested system's performance. It has been noted that compared to the conventional approaches, the suggested GWO-based MPPT methodology is quicker and produces fewer MPP oscillations. It offers a more effective reaction to quickly shifting atmospheric conditions. Results of simulation for the recommended control scheme with MATLAB/Simulink.

Keywords: Grey wolf optimization, P&O Optimization, MPPT, PV module Wind Turbine, DG, energy management.

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1. INTRODUCTION

The world population is growing, technology is developing, and industry is advancing, which means that countries' energy needs are always rising. The need for electrical energy has grown significantly in importance in recent years due to environmental issues. Insufficient traditional energy sources, and diminished usage [1][2]. During the manufacturing of electrical energy, many kinds of pollution are produced. The combustion of fossil fuels releases emissions into the atmosphere, which are attributed to thermal power plants that use coal or oil. However, the growth of nuclear power plants, which accelerated during the oil crisis, did have a detrimental effect on air quality [3][4]. Conversely, they also produce radioactive waste, which poses significant challenges for processing, transportation, and storage. The dread of depending entirely on one energy source and all of its hazards, the emergence of the market for energy production, and the opening of the market for the generation of electricity are all factors that contribute to the availability of renewable energy these days [5][6].

As a result, there is a requirement to control energy flow on these combining sources of clean energy to ensure reliability and accessibility of electricity. Nevertheless, controlling these hybrid systems for renewable energy is typically a tough undertaking. One extremely difficult challenge is maintaining the voltage in a microgrid with hybrid distributed energy sources (DERs) Considering a range of ±5% of the DC bus power [7][8]. According to research on energy released by the

European Commission, by 2050, around 50% of the world's energy output will come from hydropower, offshore wind turbines, photovoltaic (PV) plants, and onshore wind turbines. The amount of power consumed will rise by 140% compared to present levels, and as other resources become more expensive, Energy from the sun and wind will dominate the sources of renewable energy, as shown in *figure (1)*. Moreover, because of the enormous need for energy, energy from the sun and wind will continue to develop and grow. For example, the overall capacity of energy from renewable sources has expanded by 11% and is expected to reach over 3146 GW by the end of 2021 [9]. Approximately 90% of every source of renewable energy is composed of solar and wind power combined. As seen in *figure (2)*, This number refers to the world's energy use over the past 10 years. [10].

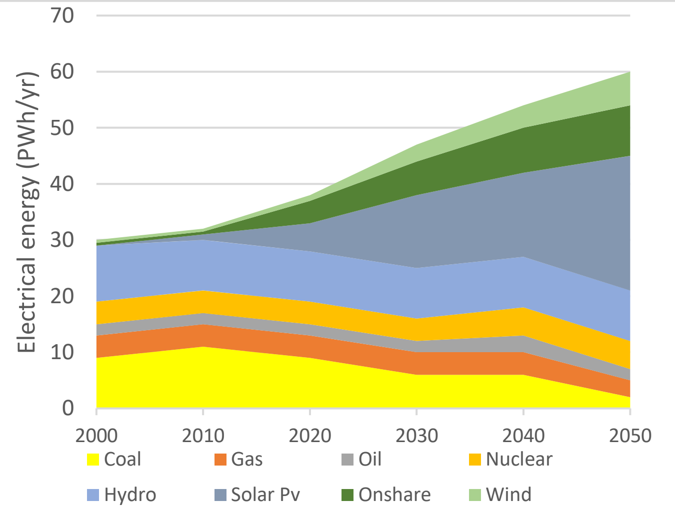

Figure 1. World electricity generation by source [11]

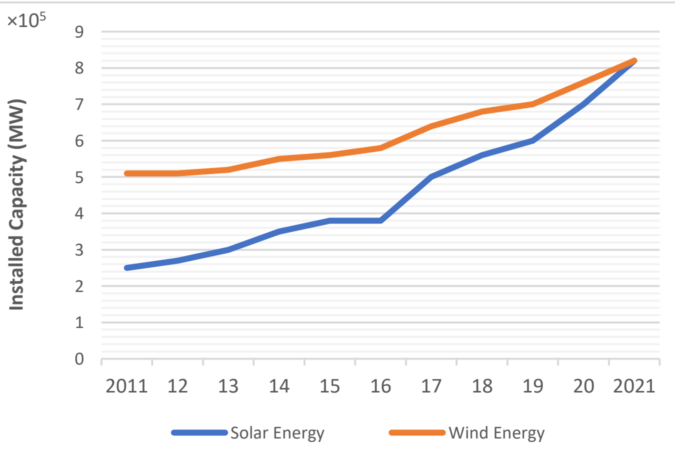

Figure 2. Changes in established wind and solar power systems' capacities [10].

2. RELATED WORK

The most recent advancements in power electronics allow the autonomous DC microgrid to operate at peak efficiency. Nevertheless, supplemental management of energy units is required for the efficient use of energy and uninterrupted power transmission to the loads due to the unpredictable nature of environmentally friendly power sources. When building efficient microgrids, site-specific features and electrical system circumstances should be taken into account, according to a recent instance analysis. It is essential to have the required electrical and management infrastructure and equipment set up to optimize the microgrid's functionality. Electronic converters for electricity are used by the majority of dispersed producing sources for connecting to the energy grid. guaranteeing the efficient maintenance of these converters' financial performance. To satisfy the load requirement as economically as possible, a hybrid power plant comprising wind turbines, solar power panels, battery packs, as well as diesel was built and optimized.

R. E. H. In this study, Bouchekara and others presented an ideal design for a small-scale PV/wind/diesel Hybrid Microgrid System (HMS) for Yanbu, Saudi Arabia, considering the uncertainties associated with renewable energy supplies and battery deterioration. Superior outcomes compared to the traditional MOEA/D technique are obtained by skillfully combining several decomposition strategies in this method. Based on various circumstances and housing counts (5 and 10 dwellings), 12 case studies were examined. Each time, the recommended method generated a collection of answers that were assembled into a Pareto front (PF). The designer can choose the best solution from the PF by considering several characteristics[12].

The scientific community has published several control solutions to deal with voltage issues associated with DC-link problems. The latest advancements and developments regarding hybrid microgrid configuration with renewable energy management and planning are reviewed in[13]. To manage the DC voltage, a fuzzy controller and voltage control are coupled in [14]. A fuzzy logic control approach using fewer rules is examined in [15]. M. Kumar, and e.t [16] uses an additional proportional-integral controller. The previously discussed control methods, however, are linear and capable of controlling the DC link within a brief working window. Therefore, nonlinear controllers have been studied by researchers to get around this constraint. The wind turbine (WT-PMSG), a batteries energy storage system, and a photovoltaic (PV) system were all utilized by Mwaka I. Jumaand e.t [17]. Maximum power point tracking-based proportional-integral (PI) controllers are in charge of the DERs. The MPPT tracks the maximum power point of the DERs using the perturb and observe (P&O) technique. The study presented here helps bring electricity to remote islanded locations that are far away from the electrical grid. Two situations were simulated: one with a constant DC load and the other with step variations in the DC demand. Moreover, there were variations in wind velocity and irradiance. The generated power of the DC microgrid follows the reference value quite well, according to the simulation findings.

To ascertain the necessary power and BESS capacity for optimal shaving achievement, [18] carried out the research. Assume that the grid operators apply the peak energy management strategies from this study. In such a scenario, it

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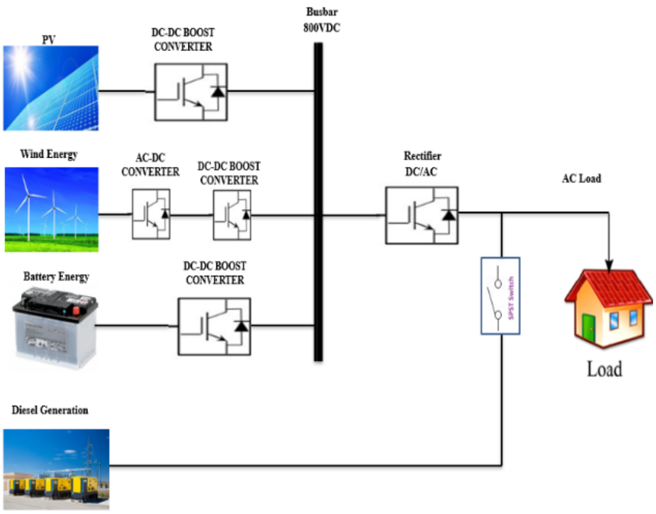
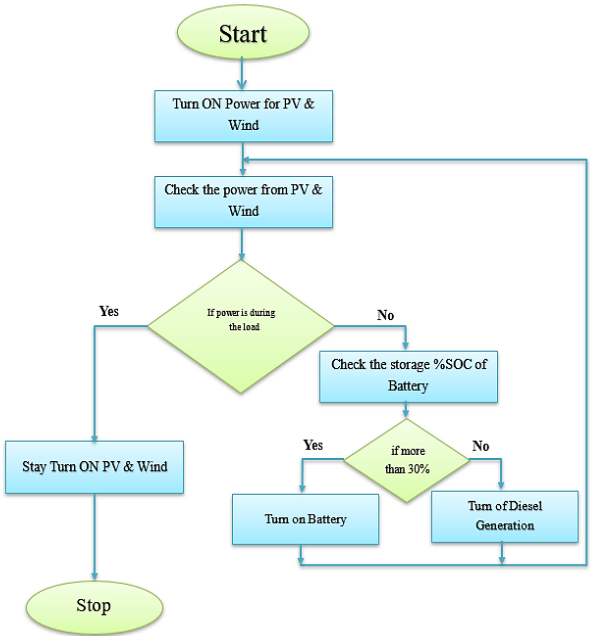
may make it possible for them to provide flexibility in grid services, such as response to demand as well as voltage and frequency management. Using BESS software, these capabilities may allow business owners to use peak-shaving tactics and increase income. An optimization method was used in[19] , and [20] to find the optimal capacity of a hybrid PV/Wind/PHS energy system for people living in cities. Through the help of sources of clean energy, primarily wind and solar power, the system provides 85% of the load's energy demands; the PHS provides the other fifteen percent. An optimum planning technique for microgrids with battery energy storage systems is developed to handle the random unit commitments difficulty, taking into account the disparities of solar power, turbines for wind power, and load fluctuations [21]. The goal of this strategy was to lower the overall operating costs of the microgrid by lowering BESS life degradation and emphasizing operation scheduling.

3. DESIGN AND SYSTEM DESCRIPTION

In this study, we investigated the optimum control of a hybrid system that combines solar, wind, battery, and diesel generation. The combination of PV and wind renewable energy, battery, and diesel generator systems is more efficient in terms of energy output than a single source. However, for a standalone microgrid to function properly, In the event of bad conditions, The PV power and wind energy generator necessitate a power battery backup. This affects the hybrid system's cost, efficiency, dependability, and environmental emissions[22]. Furthermore, each element's behavior affects how the PV–wind hybrid system operates. For a microgrid to operate as efficiently as possible, each renewable power source's performance must be corrected. In this section, every part of the entire system is modeled and explained. Figure 3 shows the suggested hybrid energy system that is being employed in this investigation. The hybrid energy system flowchart is displayed in *figure 4*.



Figures 3. The suggested hybrid energy system used in this work



Figures 4. Shows the flowchart of the hybrid energy system

3.1 Photovoltaic array

Photovoltaic (PV) energy, commonly referred to as solar energy, is gaining traction as a major source of renewable energy. It is considered one of the primary sources of renewable energy due to its abundance, lack of pollution, and recyclable nature. The quantity of PV power generated depends on several factors, including solar irradiation, PV cell temperature, array voltage, and PV array current. To maximize the PV energy produced, an MPPT technique is needed to establish and maintain peak power. On the other hand, limited PV power production algorithms have to be employed to control PV generation because of the overcharging and recharging power limitations of batteries [23].

3.2 Wind energy

wind power is now one of the most abundant, cleanest, and fastest-growing energy sources [24]. Furthermore, over the previous 10 years, investments in high-power wind energy projects have generated a great deal of interest in the energy strategy for this type of energy in the future[25]. Devices that transform the aerodynamic energy of wind into mechanical energy are called wind turbines (WTs) and are crucial for energy conversion. Using a generator and the necessary power converter topologies, the captured mechanical energy is converted into electrical energy in accordance with customer demands. Wind Energy Conversion System (WECS) is the standard term used to describe wind energy. WECS structures can be used in various configurations, from simple designs to intricate Wind Firms. Under both constant and variable wind speed conditions, WECS structures may be operated with the appropriate configurations. Variable Speed WECSs (VS-WECS) can produce electricity in all wind speed ranges by regulating shaft speed in response to wind speed, thanks to MPPT algorithms and controllers [26].

3.3 GWO Algorithm

GWO Method to improve the MPPT, the grey wolf optimization technique is used being. In 2014, Mirjalili make the initial proposal for the gray Wolf algorithm in 2014, Mirjalili made the initial proposal for the gray Wolf algorithm [27]. This mathematical model mimics the social dynamics of a pack of gray wolves as they pursue their prey. The pack's wolves are sorted into various groups according to their strength and level of fitness. Similar to a wolf pack chasing prey and surrounding the answer. And ultimately reaching the intended solution, the model classifies the possible solutions for a given issue according to how close they are to the required output while simultaneously moving the responses toward the intended values. To arrive at the ideal answer, the mathematical model uses the solution that falls within alpha (α). The following is the equation that the GWO used to do this: To maximize the power from the PV array, the suggested GWO-optimized method in this work shortens the (MPPT) and produces an output voltage that is almost constant. The duty cycle of the switching pulse may be adjusted ideally. To obtain MPP, the appropriate computations are carried out by the GWO. To offer load electricity to a manufacturing facility or dwellings, the MPPT algorithm assessed solar irradiance and wind speeds in addition to a selected load profile.

This paper designs and implements an MPPT technique for a PV system based on the GWO algorithm. By creating PWM pulses in response to variations in the PV panel voltage, this method modifies the converter's duty cycle. An analysis was conducted on the suggested system's performance. It has been noted that compared to the conventional approaches, the suggested GWO-based MPPT methodology is quicker and produces less MPP oscillations. It offers a more effective reaction to quickly shifting atmospheric conditions.

3.4 P&O algorithm-based MPPT method

A vector-based control technique is used to regulate PMSG. The machine side speed, generator, current controllers, and three-phase power converter are all part of the overall PMSG drive system. Using a current regulator, the vector controller produces PWM signals. The two current regulators in this optimum control are used to manage the element currents id and iq that correspond to the required torque Tref. Thus, the evaluated value of the flux is retained. The wind turbine's operational point changes to MPP when a disturbance increases power, and the voltage disturbance proceeds in the same manner. After reaching its peak power, the disturbance reverses and the power instantly drops [8]. To preserve the power variation, the perturbation size is kept to a minimum. An additional proportional integrated control was used to measure the duty cycle ratio in the MPPT-based conversion to set the reference perturbation voltage. While many highly effective Approaches like fuzzy logic and neural networks are costly as well as complex, two of the most widely used techniques at the moment are incremental conductance and perturb and observe (P&O), as they are straightforward approaches that can function in any weather[28]. The hybrid maximum power point tracking (MPPT) technique, which is the foundation of the suggested optimization plan, is linked to the P&O strategy and offers benefits. Many benefits come with the hybrid MPPT approach, such as decreased battery stress due to increased power, efficiency, and reaction time. *Equations (1) and (2)* are used to simulate the velocity of the controller, whereas *equations (3) and (4)* describe the current regulator

$$w_{error} = w_{ref} - w_w \quad (1)$$

$$T_{ref} = k_p w_{error} + k_i \int w_{error}\,(t)dt \quad (2)$$

$$i_q = \frac{2T_{ref}}{3p\gamma m} \quad (3)$$

$$= 0 \quad (4)$$

3.5 DC/DC Boost Converter

To obtain a greater DC voltage on the DC bus, the uncontrolled DC voltage that comes from either the photovoltaic (PV) system or the PMSG converter must be adjusted. This is made possible by the DC/DC boost converter, which operates in the constant-state continuous conduction mode with current, as shown by *equations (5) and (6)* [29]. Vin/Iin represents the boost converter's unregulated input voltage/current, while VDC/IDC represents the regulated output voltage/current. Thus, using the work of *equations (7) and (8)*, respectively, the inductance L and capacitance C of the boost converter are calculated. With a permitted voltage ripple of ΔVDC, A particular frequency is used by the boost converter to switch, while resistor R represents the DC load.

$$V_{DC} = \frac{V_{in}}{1-D} \quad (5)$$

$$I_{DC} = I_{in}(1-D) \quad (6)$$

$$L \geq \frac{D(1-D)^2 R}{2fs} \quad (7)$$

$$C \geq \frac{D}{\Delta V_{DC} f_s R} \quad (8)$$

3.6 Battery Energy Storage System (BSS)

As an energy buffer, a battery bank is necessary in PV systems for power balance. The battery unit comprises a battery, a filter, a DC/AC inverter, a bidirectional DC/DC converter, and associated control circuits that enable the battery to supply energy in both directions. Among them, the bidirectional DC/DC converter control uses a double closed-loop control method. The inner loop, which may absorb or deliver the corresponding power by the system demand instruction, is the inductor current, and the outside loop is the DC bus voltage [30]. The following is a summary of the parameters of the element components used in this study. A summary of the parameters of the element components used in this study is given in *table 1*.

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Table 1. Summary of the parameters of the element components used in this study

Parameters	Value/Unit	Parameters	Value/Unit
Solar Energy		Battery parameters	
Rating of the power	(**400**) W	The type of battery	Lithium -Ion
Maximum - Peak-voltage	(47.9) V	Rated voltage	400 v
Open-circuit voltage	(**55.2**) V	Rated Capacity	1000 Ah
Maximum Peak current	(8.36) A	Initial state of charge	70%
Short circuit current	(9.5) A	Battery-response-time	30 s
Current-temperature-coefficient	(0.041) %/◦C	Cut-off-voltage	300 V
Voltage-temperature-coefficient	(-0.236) %/◦C	Fully-charge-voltage	465.5 V
Temperature-range	(−40 ◦C to +80 ◦C)	Normal-discharge-current	434.78 A
Wind factors		DG parameters	
Rating of the power	(28 KW/m2)	Normal power	10 KW–12.5 KVA
Rating of the voltage	(320) V	Rated voltage	400 V
Start-up-wind-speed	(2.5 m/s)	Frequency	50 Hz
Rating of wind speed	(10.5 m/s)		
Maximum-wind-speed	(35 m/s)		
Rating of rotation speed	(800 r/m)		
Rotor blade diameter	(**1.2**m)		

4. RESULTS

This study presents an integrated hybrid power plant that may be divided into four primary components: diesel generation, BSS, wind power, solar power, and hybrid energy sources that are linked to DC and AC connections via appropriate conversions. The simulation result of the proposed system is the parameter formed and used in MATLAB/Simulink. DERs for a standalone solar PV plant rated at 41.6 kW. The solar PV plant produces electricity intermittently at a DC voltage of around 600 V. Then, the DC-DC boost converter raises that voltage and sends it to the DC line to provide a constant supply of 800 V. A 28 kW permanent synchronous generator (WT-PMSG) is installed on the WT. generators to a DC bus, while a bidirectional buck-boost converter connects the power plants to the batteries. Figure 5 displays the EMS design. WT-PMSG is a highly productive and dependable option for a variety of applications, particularly renewable energy systems. Its architectural advantages and recent advances make it an attractive option for industrial power generation requirements. Thanks to its efficiency and dependability, it is also a viable solution for big power generation systems.

The findings show that the solar power system generates electricity between 30,000 and 40,000 W. It's also evident that a winds turbine generates approximately 28,000 and 30,000 watts of electricity. The BSS power varies arbitrarily between 9000 and -9000 W. The BSS works wonderfully in both charging and discharging modes. Shows how the planned electrical consumption control would deliver a constant 55,000 W of electrical power to the load. As seen in *figure (6).*

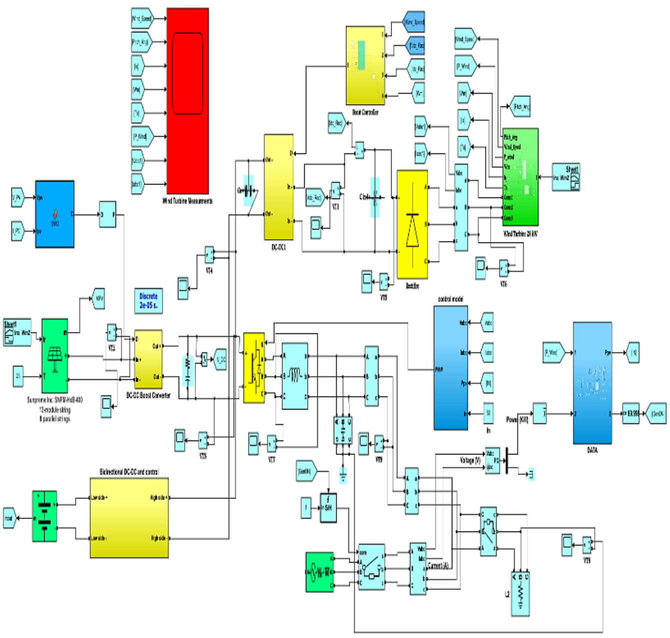

Figure 5. Simulation diagram of the energy management system for this proposed system

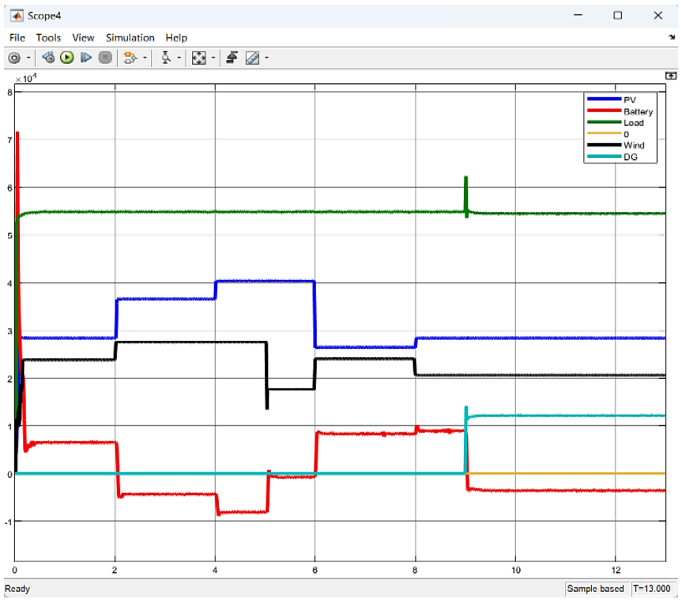

Figure 6. shows the result of the energy management system for this proposed system.

Energy Management Systems (EMS) are devices that can used to track, measure, analyze, and manage energy consumption. These systems may include Building Automation Systems (BAS) for HVAC and lighting management, Energy Information Systems (EIS) for gathering and analyzing information, and Industrial Energy Management Systems (IEMS) for manufacturing facilities.
Employ Energy Storage Systems (ESS) can store electricity during non-peak times and release it throughout peak demand periods, so minimizing the need for additional power production and optimizing energy use. Involvement in Demand Response Systems (DRS) might help the load on the electricity grid and may result in advantages for transferring energy usage to off-peak hours.

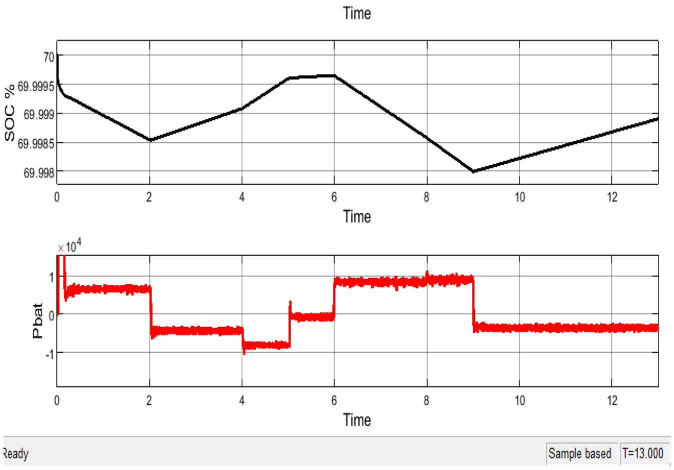

Figure 7. shows the battery power and its SOC

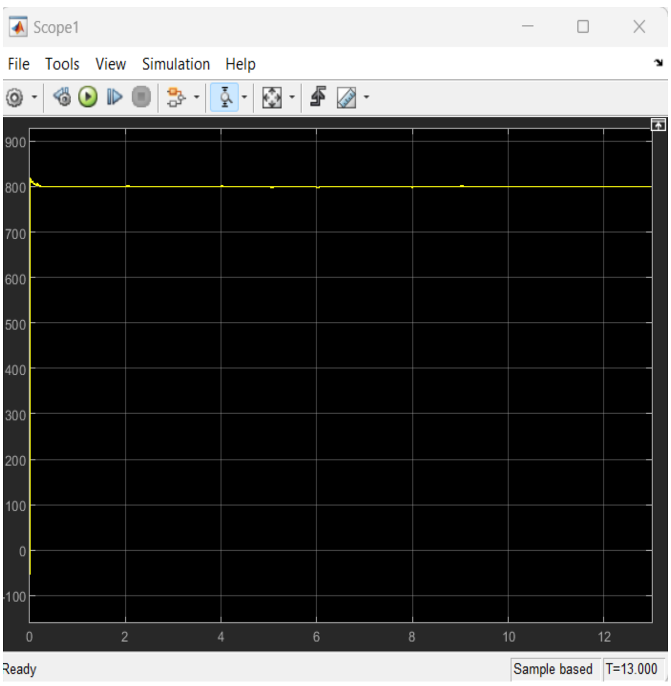

Figure 8(A). Output voltage of boost converter for various sources at 800 VD.

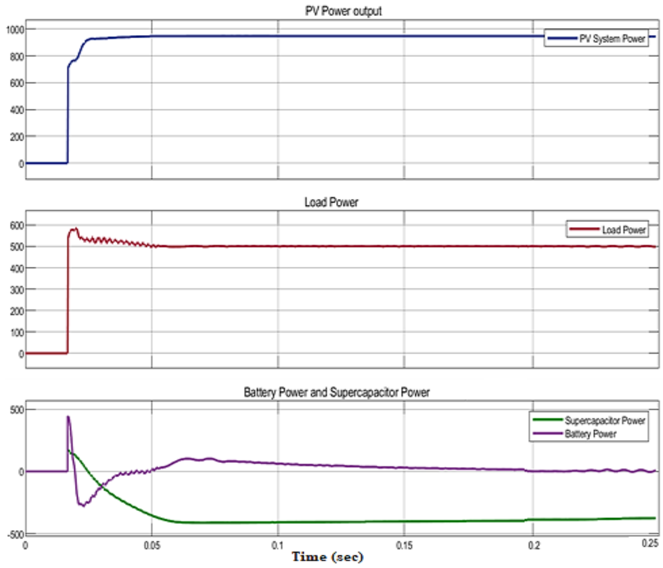

Figure 8 (B). Overall output control system for power management system

Figure 7 displays the battery power and state of charge. According to the data shown, when SOC > 30%, the pack of batteries provides the required power with approximately 9000 W during the duration intervals 0–2 s; however, during the periods 2–5 s, the produced P exceeds the power needed by the load. As a result, the battery receives around 5500 W of power from various sources.

Figure 8 (A, B) shows the voltages generated from various sources of solar cells, wind energy, and batteries stabilized using a converter. The voltage that needs to be maintained is then raised to 800 volts DC using a boost converter. Subsequently, the 800-volt voltage is transformed from DC to AC via an inverter and applied to the power source, as shown below.

Figure 8 (A) shows the amount of voltage output for photovoltaic energy after using the boost Converter via the GWO algorithm. The results show that the external voltage is 800 volts DC and that the GWO for the boost converter works well with a fast response time. In addition, shows the amount of voltage produced for the total energy after combining it from the three sources, which are solar energy, wind energy, and batteries, after combining and converting it from direct current to alternating current using a boost converter. The results show that the external voltage is 800 V AC, and the boost converter algorithm works well with a fast response time.

Figure 8 (B) depicts the total output control mechanism for a PMS, which is intended to assure the secure and effective functioning of the electrical infrastructure. This system combines several components to control and monitor power generators, switchboards, and huge consumers.

The PMS controls and monitors these electrical components, assuring their efficiency and safety. This involves controlling the transformation of low-energy input into useful electrical power, which is crucial to the system's efficiency in general.

The PMS is frequently included as part of an Integrative Automation System (IAS), allowing for more extensive control of the electrical infrastructure. This integration aids in controlling and administrating electrical generators, however, switchboards, and huge shoppers, to guarantee the entire electrical infrastructure runs smoothly.

The method for optimizing for energy from renewable source-based technologies was provided by the researchers in[31]. The energy management system, which is coupled to a shared DC bus, was not discussed by the authors though. The researchers in [32] suggest an independent system for domestic use that is based on a hybrid renewable energy source. These solutions, however, are appropriate for small communities and take into account all sources in one place. In [33][34], independent solutions based on diesel generators are suggested. The restricted use of these systems and the lack of knowledge on the applicability of having sources in diverse places are the only drawbacks. Furthermore, the writers omitted any mention of FC and electrolyzer. In[35], the frequency control of independent microgrids powered by renewable energy sources is demonstrated. Nevertheless, the materials are all in one place, and the writers didn't include the energy management system or the uses for electrolyzers (FC). In [36], the MPPT component of a freestanding microgrid powered by hybrid renewable energy sources is covered; however, the energy management system and FC applications.

In conclusion, the proposed control system excelled at the other approaches, successfully controlled the hybrid power, and satisfied the goals of the current study. The benefits of the suggested P&O and GWO according to MPPT are highlighted in the current section through the application of artificial intelligence for managing energy. The given reaction demonstrates that the suggested method successfully controls the DC voltage at its point of reference.

5. CONCLUSIONS

Two optimization-based MPPT algorithms were created and presented in this study for the power management of hybrid sources of electricity. The system was simulated in a PV system using the MATLAB/Simulink program to determine the effectiveness of each technique under various atmospheric conditions. To reliably fulfill the load's power requirement and stabilize the voltage on the DC bus, this study suggests an approach for power balancing management of a combination of multi-source DC and AC source systems. Solar power (PV), wind turbines, battery banks, and diesel production comprise the combined hybrid power sources. The algorithms used in MPPT were created and put into use to guarantee the highest possible power production from solar PV and WT-PMSG. In this paper, P&O regulators were added to the algorithms used in MPPT to manage the direct current (DC) microgrid voltage. The designed GWO algorithm for PV and P&O in wind turbines. In the present study, the combined RES could accomplish three goals: maximum power tracking, voltage output correction of errors via feedback management, and enhanced power delivery. In this study, wind and photovoltaic (PV) energy sources are usually favored to reduce grid charges. The proposed controller provides consistent power generation and continuous service. It is evident that compared with the suggested control techniques, the suggested strategy performs better and creates more power. Nevertheless, more investigations are needed to fully understand the AC/DC microgrid's reliability. The findings of Simulations and experiments demonstrate that the suggested DC control approach, which depends on the MPPT approach, can switch between the entire system's various operation methods with flexibility, regardless of the status of the battery or outside conditions, guaranteeing both safe working and steady bus voltage. Simulation outcomes using MATLAB/Simulink with the suggested control architecture. The findings from this study are helpful for electrifying island communities that are disconnected from the electrical system. Experimental validation of the suggested control on an actual test bench will be the focus of future research. Conflicts of Interest: No conflicts related to interests are disclosed by the authors.

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