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Performance Evaluation of Hybrid System (PV/ Wind/ Battery) Integrated with Smart Grids

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Keywords:

Photovoltaic; Wind turbine; Energy management; Battery; Smart grid; Renewable energy sources.

Highlights:

- *Integrating SG with Renewable Energy Sources: Utilizing digital and modern technologies to verify diverse energy distribution.*
- *Modeling Energy Storage System linked to Solar and Wind: Employing MATLAB/SIMULINK for electricity flow management and adaptable solutions for varying demand.*
- *Enhancing Maximum Power Point Tracking for Solar and Wind: Implementing PSO and P&O techniques to optimize energy production efficiency.*
- *Control Strategies for Smart Microgrid Efficiency Improvement: Efficient energy routing through Battery Energy Storage System (BESS) and dynamic AC/DC demands management.*

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Abstract: A smart grid (SG) is an interconnected system of electrical outlets that monitors and controls the energy flow from various sources to satisfy different consumers' loads. The smart grid achieves this goal by utilizing digital and other cutting-edge technology. To increase the diversity of energy delivered, SGs can be used with renewable power sources (RES) like solar and wind. Modern technologies in computer, telecommunication, supervisors, networking, and sensor measurement are used by SGs to increase the dependability and effectiveness of the entire system. Whenever businesses are producing, customers may direct the SG to switch on their home equipment at the lowest possible cost of power. Throughout peak periods, consumers can reduce demand by shutting down certain unnecessary electrical devices. This paper provides a model of an energy storage system (ESS) linked to a photovoltaic, a wind turbine, and the SG. To fulfill the load in a range of operating situations, the SG approach is demonstrated, and the electricity flow across the RES, ESS, and network is managed using MATLAB/SIMULINK software. This study proposes an energy management system to supply the energy required to meet the loads under various operating situations, including fluctuating wind velocity and sunlight. Regarding the solar energy system, a pair of separate approaches to maximum power point tracking techniques are suggested. Although the Perturb and Observe method is suggested for wind turbines and photovoltaic systems to generate maximum power output, the Particle Swarm Optimization strategy may generate powerful efficiencies, as explained in this study.

تقييم أداء النظام الهجين (الطاقة الشمسية/ طاقة الرياح/ البطارية) المتكامل مع الشبكات الذكية

احمد يحيى ياسين
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الخلاصة
الشبكة الذكية أو ما تُعرف بالاختصار SG ، هي نظام شبكة الكهرباء المرتبط بشكل كبير يعتمد على الشبكة الكهربائية الفعلية. يمكن دمج الشبكات الذكية مع مصادر الكهرباء المتجددة مثل الطاقة الشمسية والرياح لزيادة تنوع الطاقة المزودة. تستخدم الشبكات الذكية تقنيات حديثة مثل الحواسيب، وتكنولوجيا الاتصالات، وتكنولوجيا الإدارة، وتكنولوجيا الشبكات، وأجهزة القياس بالاستشعار لتحسين موثوقية النظام وكفاءته. عندما تكون تكاليف الكهرباء في أدنى مستوياتها، يمكن للمستهلكين توجيه الشبكة الذكية لتشغيل أجهزة منازلهم في حين تقوم الشركات بزيادة الإنتاج. يمكن للمستخدمين تقليل الاستهلاك خلال ساعات الذروة عن طريق إيقاف بعض الأجهزة الكهربائية الغير ضرورية. يقوم هذا البحث بتطوير نموذج فريد لنظام هجين يشمل الطاقة الشمسية ومحطة طاقة الرياح ونظام تخزين الطاقة المتصل بالشبكة الذكية. تم استخدام بيئة MATLAB/SIMULINK لعرض منهجية الشبكة الذكية وإدارة تدفق الطاقة بين مصادر الكهرباء المتجددة ونظام التخزين والشبكة لتوفير الطاقة للأحمال تحت مجموعة متنوعة من الظروف التشغيلية. يقدم هذا العمل نظام إدارة الطاقة لتوفير الطاقة الضرورية لتلبية الاحتياجات.

الكلمات الدالة: شبكة ذكية، مصدر طاقة متجددة، نظام الطاقة الشمسية، نظام طاقة الرياح، تتبع أقصى نقطة للقدرة، إدارة الطاقة، نظام تخزين الطاقة.

1.INTRODUCTION

Implementing SGs is necessary to maximize using dispersed electrical resources. Possibilities for RES for electricity generation seem to be developing because fossil fuels are expensive, have major environmental consequences, and require more use to be rationalized. The developed and developing nations are using RES more [1,2]. Nevertheless, successful Energy Management System (EMS) techniques are created before the SG technology can be sold and extensively used. Recently, the idea of an SG has been successfully applied to the network that supplies electrical power. The SG elements, which include the conventional energy sources integrated with the RES, are depicted in Fig.1. The major problem with renewable energy sources (RES) is their availability and continuity; solar, wind, and hydroelectricity are not always available whenever and wherever they are required [3]. Unlike typical power production sources, these RES are not "dispatchable," and their electricity output is uncontrollable due to discontinuous generation caused by daily and seasonal impacts and inadequate energy generation predictions. SGs are anticipated to offer further benefits in addition to their potential to facilitate the inclusion of RES [4]. Information and communication technologies are employed by SGs to facilitate data flow between control centers and other power system facilities. To enhance the economics, long-term viability, and consistency of energy generation and distribution, data regarding consumer and supplier activities is automatically gathered [5]. Due to its unpredictable nature and unpredictability, increasing RES output necessitates creative solutions to maintain grid stability and dependability. Localized SG adoption can contribute to improved network reliability and uniformity. To provide the loads at any particular time or to provide the loads with energy, energy storage systems (ESS) are required, and the SG can employ several strategies to meet the loads [6]. The SGs utilizing RES may avoid costly cable construction and transmission expenses, as well as monitor the system and provide viable alternatives for areas wishing to create green power off the grid [7]. Thanks to developments in powerful controllers and power electronic converters, the SG [8] can now accommodate many RES kinds. Many converter topologies and management strategies have been developed to combine RES, like wind and photovoltaic power [9]. Operators may utilize the Internet of Things (IoT) to collect SG data and conduct continuous self-assessments to resolve any difficulties promptly. For the SG and RES to communicate, data collection is essential. Following that, these data are quickly sent to the grid to alert the grid operator to any problems, enhancing service security and dependability [10]. There are significant doubts about the conventional fossil fuel-based power system's capacity to provide fairly clean, reliable, and affordable energy solutions for consumers and companies [11]. When combined with SGs, the conventional electrical system undergoes major modifications. Previously, electricity was generated and used instantly at network limits; in contrast, energy produced by SGs can be stored and used as needed, and electricity costs are rapidly declining [12]. This work's proposed hybrid smart grid system consists of a PV system, a wind turbine, and an energy storage system connected to the grid with variable load. This study proposes an energy management system to supply the energy required to meet the loads under various operating situations, including fluctuating wind speed and irradiation. The load-shedding procedure can be applied to balance the load with the available generations in case of a shortage on the generation side during grid operation. For the photovoltaic system, two distinct approaches to maximum power point tracking algorithms are suggested: the Perturb and Observe (P&O) and Particle Swarm Optimization (PSO) methods. While the Perturb & Observe method is suggested for wind turbines to generate maximum power output, the PSO strategy can produce high power efficiency compared to the P&O strategy during variable irradiation. The proposed system was simulated by employing the MATLAB program.

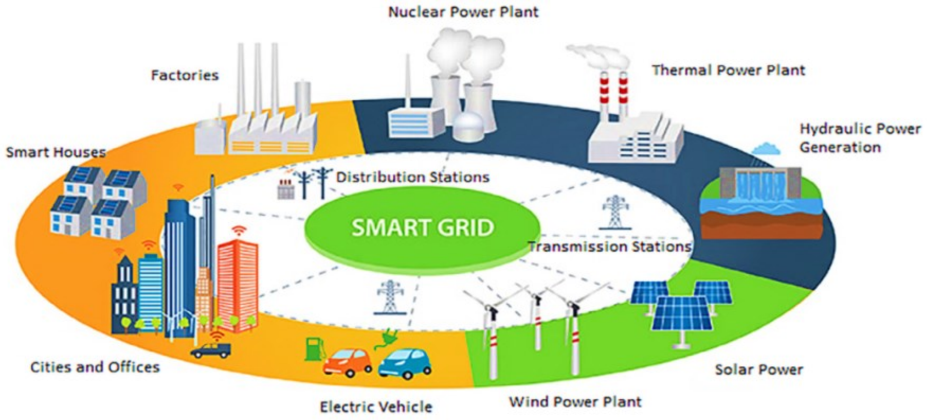

Fig. 1 Components of Smart Grid.

2.RES IMPLEMENTATION IN SMART GRIDS

Changing how power is produced has been proposed to prevent global warming and increase the amount of electricity available worldwide. As a result, RES and distributed energy generation are receiving more assistance and account for a larger share of total power output. The most difficult task for people who create and apply SG technologies is determining how to incorporate growing RES into a rigid system. The main factor propelling the development of distributed systems has been integrating distributed production with the power distribution infrastructure. However, scattered generation seldom gets feedback from the market or is involved in energy system management because of two things [13]. Firstly, with set feed-in tariffs, RES are given preference and are free from market rates as they are a shared source of distributed energy. Secondly, distribution networks' production often lacks the size and features to balance the market. Another concern is that distribution networks may be preserved by the growing usage of RES. Other possible problems include the sporadic nature of RES generation and the incapacity to dispatch. An SG employs digital technology to improve the distribution system, automate control, and continually monitor it to reduce energy consumption, raise dependability, and cut consumer costs. When working together, SG techniques can provide the adaptability needed to include variable generation, a component of RES, such as solar or wind power.

3.ADVANTAGES OF SG IN POWER SYSTEMS

Whenever the SG is employed in the electricity system, several advantages may be realized; the following list highlights the primary advantages [14]. Compared to traditional power sources, the cost of producing energy from RES is lower. Since SG technologies make it easier for RES to expand throughout electrical networks, they are credited with developing technology and bringing down energy prices over time [15]. Professional and novice workers will find work possibilities in the SG's development, maintenance, operation, and upkeep [16]. Furthermore, it will facilitate the expansion of electrical companies and offer state-of-the-art technological solutions. Client fulfillment has increased due to increased dependability and reduced expenses [17]. The SG lowers power outages while increasing energy efficiency. The SG benefits the climate as it promotes the utilization of electric cars (EVs) that lower carbon dioxide emissions, and alternative energy sources (RESs) [18]. Additionally, due to the fast electricity production, it requires less oil. SGs improve the present electric infrastructure's capabilities. They also have the capacity for self-healing and preventative upkeep. To increase system stability and efficiency, the Internet of Things (IoT) may be linked with the SG. Essentially, several IoT topologies exist, from conceptual to technical. This IoT paradigm's base layer relies on data flow and comprises devices like sensors and controllers. According to this idea, a sensor is only a place where data is produced, which means that the sensor might be a small device or a large current flow measuring system. These gadgets generate data and send it over the internet to reach the edge gateway. Edge gateways are utilized to sort, standardize, and evaluate data before sending it out. Following preparation, the information is maintained in a database open to the public and available to all stakeholders. Programs benefit from the data to offer services, like demand response, user notifications, and automatic device control. Thus, choices combined with processed data stored in databases enable human decision-making. Human decision-making is supported by illustrations that benefit from historical or present facts, system constraints, and rules and regulations. The Internet of Things focuses on collecting vast amounts of discrete sensor data and transforming it into information and visualizations that decision-makers can utilize. Each layer will be looked at more closely [19].

4.ENERGY STORAGE SYSTEM IN SG

Because electrical energy cannot be stored (for AC energy), the conventional electrical power industry functions based on instantaneous supply and demand. To prevent the overestimation effect on capital generation costs, generation and load must be balanced. The SG seamlessly integrates RES, including solar and wind power, to address the energy crisis and the issue of climate change. However, solar and wind power's inherent qualities and stochastic nature make running a safe power system difficult. The electrical network's installation of an ESS from the generator to the consumer offers an opportunity to go beyond the traditional electricity regulating paradigm by preserving energy at off-peak times and releasing it in case if required [20]. Moreover, ESS can improve resource utilization and grid reliability. ESS capabilities reduce traffic and limitations. They provide load balancing and peak shaving, facilitate easy RES linking, and allow islanding. Furthermore, EVs are charged and discharged following SG regulations; at times of high tariff and maximum load, EVS cannot be charged. When peak load requirements are met, EVs can help the power system by providing the necessary electricity at vehicle-to-grid stations (V2G) [21].

5.PROPOSED SYSTEM

To control energy and improve efficiency, this study established a control strategy for a smart microgrid system including PV, wind turbines, and ESS as well as AC and DC dynamic demands. The Battery Energy Storage System (BESS) control approach uses procedures for charging and discharging to keep a steady DC bus voltage. To maximize the PV system's output power, the two methods of MPPT utilized in this study are PSO and P&O. To determine the maximum power point (MPP) or limit the amount of power that the photovoltaic panel may provide to the load, a unidirectional boost converter is employed. To get the maximum power from the wind turbine, the wind turbine is designed as a Permanent Magnet Synchronous Generator (PMSG) that uses the (P&O) MPPT technique. Batteries are charged and discharged by the BESS via a bidirectional conversion.

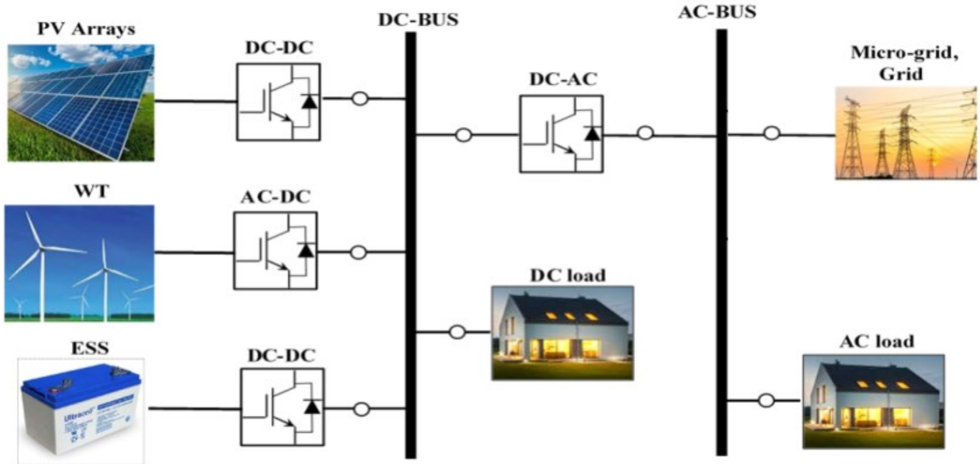

Fig. 2 The Proposed Smart Microgrid System.

The modeling outcomes in this study were evaluated using the MATLAB SIMULINK program. A three-phase voltage source inverter (VSI) using droop control is used to improve the output waveforms and stabilize the frequency. The smart hybrid grid requires an EMS strategy to supply the best possible power to meet the demands. Improving the functioning of the smart hybrid grid is the main goal of the power management strategy. Maintaining a supply-and-demand balance is the main objective of a power management plan. The suggested smart hybrid system is depicted in Fig.2. The results achieved in this work showed that the efficiency of the PV system could be improved when the PSO MPPT was used. On the other hand, wind turbine efficiency was maximized when the P&O MPPT was used between the PMSG and boost converter. The present work examines the reliability of supplying the variable load with the required power. The EMS between the different RES and the load used in this work increased the reliability and sustainability of the system.

5.1.PV System

In PV systems, sunshine is converted into direct current (DC) power by utilizing the phenomenon known as the photovoltaic effect

[22]. P and N semiconductors are combined to form PV cells. A photovoltaic cell can be conceptualized as a diode. If the connection absorbs light, the photovoltaic phenomenon might produce currents. A PV module requires many solar cells connected in parallel or series to provide enough voltage and power for various applications. A group of PV modules linked in series on a horizontal surface to provide a load with enough power is called an array [23]. The PV-cell circuit design with a single diode is displayed in Fig.3. The PV panels rotate in two distinct orientations orthogonal to the daylight path from the sun to generate the maximum amount of feasible power [24].

5.2. Wind Turbine

Wind turbines are expected to be among the most significant new RES, as they have been employed for thousands of years for different purposes, such as grinding grains, pushing water, and producing electricity when required. Various wind turbines had an output of 28% between 2000 and 2010, which accounts for up to 20% of Europe's energy generation [25]. A wind turbine converts a multi-bladed rotor's motion into electric power. In this procedure, wind energy may be used to propel a windmill, igniting a generator to generate power. In this case, the windmill is commonly called a wind turbine. This turbine converts wind energy from mechanical to electrical with the aid of a generator [26, 27]. Depending on the position of the shaft, turbines may be divided into two main categories: vertical and horizontal. Three-phase PMSGs with variable-pitch wind are the strongest among wind energy producers. These generators are well-known for their exceptional robustness and effectiveness. The produced AC power is converted into DC electricity using a three-phase uncontrolled rectifier. Figure 3 shows the basic parts of the PMSG with an MPPT-based wind turbine system; however, to raise the voltage and obtain the necessary DC bus, a step-up converter must also be used [26]. The wind turbine and PMSG forms utilized in the present study must boost the DC voltage to match the system's DC bus voltage using a three-phase unregulated rectifier to transform the three-phase output voltage to DC voltage. This process is depicted in Fig.3. Equations (1) and (2) provide the power coefficient (CP) and tip speed ratio (λ) of the suggested PMSG. For MPPT purposes, the (CP) and (λ) ought to function at (0.47 and 8.1); accordingly, Fig.4 [28]:

$$Cp(\lambda,\beta) = 0.5\frac{116}{\lambda - 0.4\beta - 5}e^{\frac{21}{\lambda}} \quad (1)$$

$$\frac{1}{\lambda i} = \frac{1}{(\lambda + 0.08\beta)} - \frac{0.035}{(1+\beta^3)} \quad (2)$$

where "β" represents the pitch angle, and "λ" represents the tip speed ratio through the MPPT method.

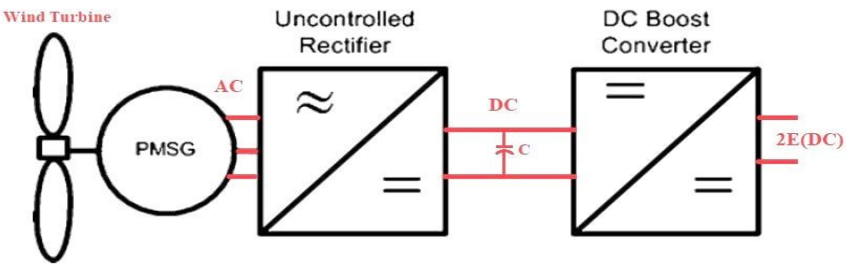

Fig. 3 PMSG Wind Turbine Configuration.

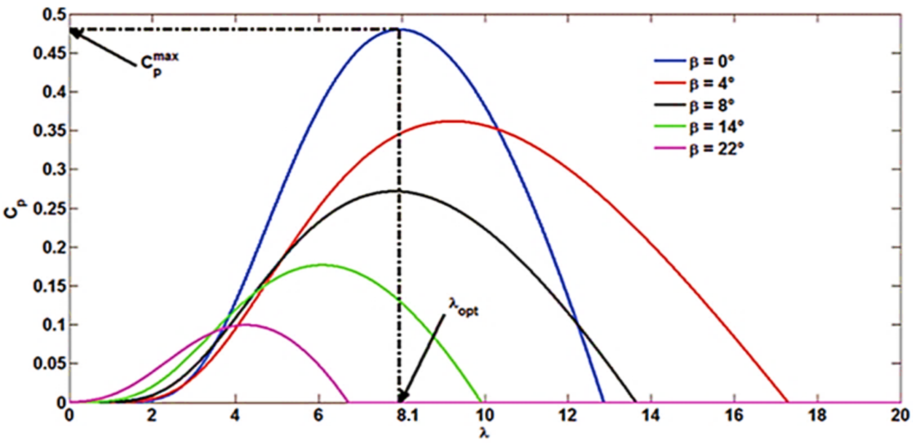

Fig. 4 (λ) Vs. (Cp) at Various Pitch Angles.

5.3. MPPT of the PV-Wind Turbine Systems

To control the amount of power gathered from the source and adjust the average DC voltage generated, an MPPT regulator is required. Every PV array has its own PV curve standard, which is the maximum quantity of power that a source may produce without resulting in damage or disturbance [29]. When wind speed fluctuates, or solar irradiation drops, MPPT methods are utilized to collect the most power. Many MPPTs are used to track the maximum power point of wind turbines and solar panels. They all aimed to get more power but performed it differently. Although it has issues with steady-state oscillation, the P&O technique is the most widely used technique for determining the MPPT for PV and wind turbine systems [30]. Additional approaches, like Particle Swarm Optimization (PSO) and algorithms for MPPT that utilize artificial intelligence, provide high-accuracy results under variable irradiation input. In this research, PSO and P&O are employed in PV systems, while P&O will be utilized for wind turbine systems. The basic workings of the P&O approach to extract the MPP from the electrical features curve for wind turbine and photovoltaic systems are depicted in Fig.5 (a) and (b). The boost conversions' duty cycles (D) are adjusted in accordance with the trajectory of the Pulse Width Modulation (PWM) signal, applied using the MPPT technique. Combining PV and wind turbines with boost converters is shown in Fig.6.

5.4.Battery Storage and EMS Controls

The battery storage system was utilized to compensate for power loss after monitoring and regulating the frequency for stability [31]. The electrochemical process of oxidation and decrease is used by BESS to transform chemical energy into electrical energy and electrical energy into chemical energy. Both directions of power transformation employ bidirectional control. It is a well-known fact of bidirectional converters that as the path of the power passing through an inverter changes, the orientation of the input voltage may also shift. Conversely, DC generally travels in the same direction. Since the suggested inverter utilizes a battery for electricity, changing the battery's polarity voltage would seriously disrupt the system's normal functioning. A DC/DC converter should be configured to regulate the power supply in each direction, regardless of the necessary polarity at the battery connections and the required DC arrangement at the inverter end [32]. Figure 7 (a) shows the bidirectional converter's main electrical circuit. Two switches will be utilized: switch (S2) for any occasion when power needs to be sent to the power system and switch (S1) for the step-down converter, which denotes that the power will be kept in the BESS. The inner current loop controls the battery current to track the supplied instruction, i_Bat*. Figure 7 (b) depicts the bidirectional converter's control circuit. The initial input for the inner loop (i_bat*) comes from the outside voltage loop, which also regulates the DC-link voltage. A PWM technique is used to apply a train of pulses to the switches; these switches function alternately [33]. The charging and discharging of the battery are controlled by the bidirectional DC/DC converter construction.

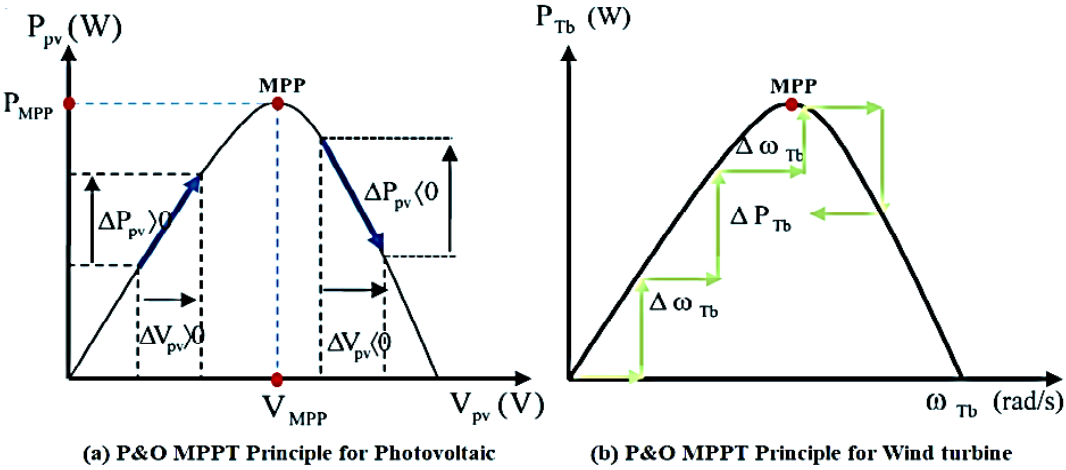

Fig. 5 (a and b) Fundamental Workings of the P&O Technique for Solar and Wind Power.

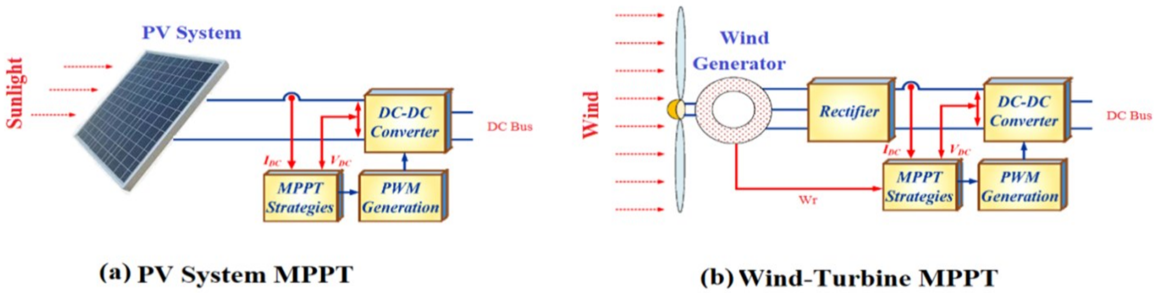

Fig. 6 (a and b) PV and Wind-Turbine Connections.

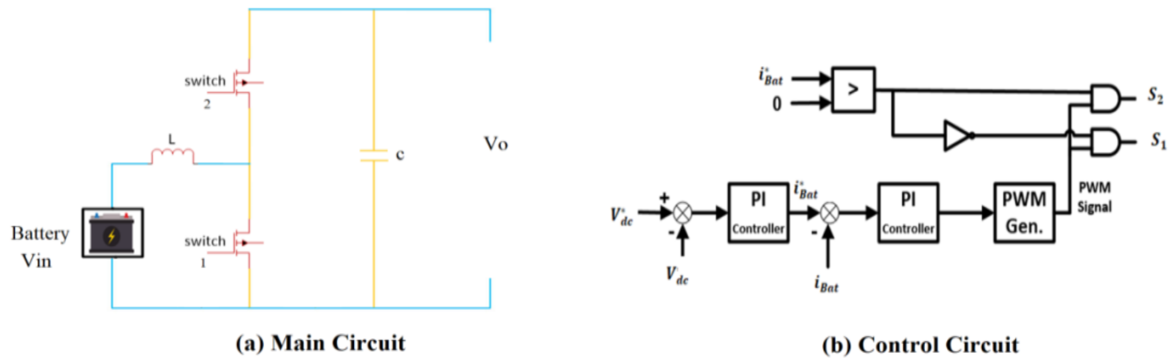

Fig. 7 Main and Control Circuits of the Bidirectional Converter.

The energy system was constructed according to the charging and discharging technique outlined in this part. The SG requires an EMS approach to supply the proper power flow to satisfy the load demands. The primary objective of the EMS technique is to enhance the proposed system operation. Maintaining equilibrium among the generation and load is the major goal of a power management strategy. This project's energy management is predicated on the DC bus system's voltage regulation.

5.5.Inverter Control

The basis for the inverter controller suggested in the present study is laid by two significant correlations observed in Virtual Synchronous Generators (VSG): one relates to power and frequency, and the second is between voltage and reactive power. Figure 8 shows the droop strategy for control. While the power input to the prime mover controls frequency, the excitation system's reactive power controls the voltage of the VSG. Reference values must be used to modify the active and reactive power to manage the voltage and frequency of the inverter [34]. Although synchronous generators and inverters have different topologies, they operate according to the same basic ideas.

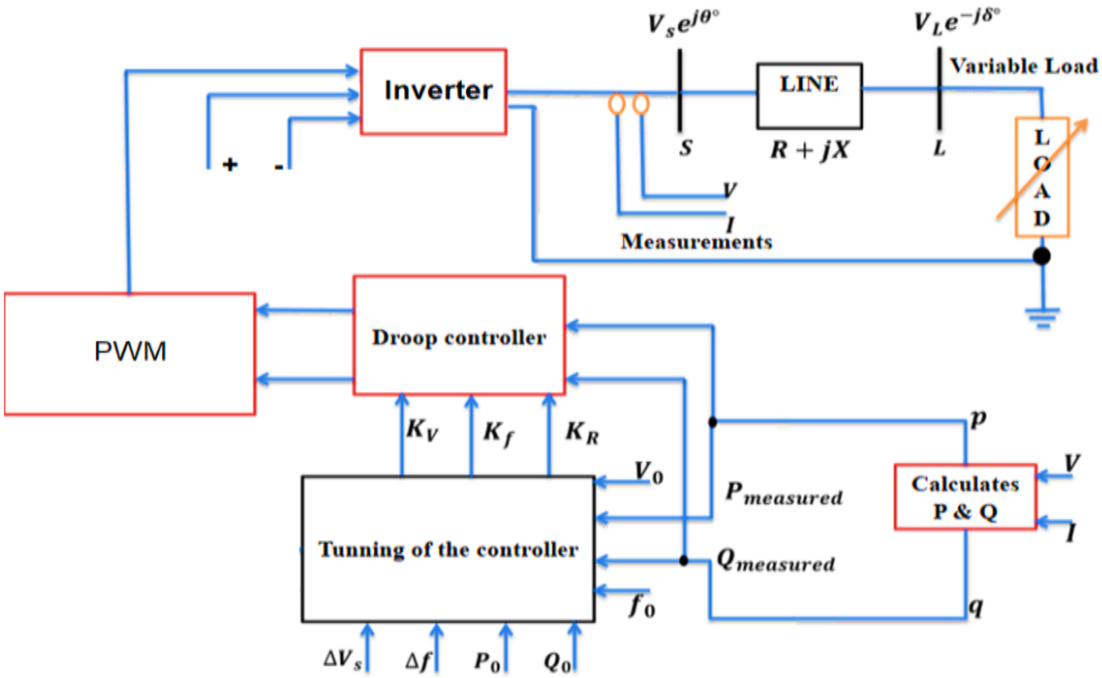

Fig. 8 A Schematic Representation of the Three-Phase Inverter's Voltage Regulation System Utilizing Droop Control.

Monitoring the constituents of grid voltages and currents computes the active and reactive powers. The difference between the observed and specified quantities for voltage, frequency, active, and reactive components is determined. Similar to how the frequency may be changed based on the active power variation and the characteristic of the P-F curve (Kf) in the droop control, the voltage may be regulated based on the reactive power variation and the droop parameter in the Q-V curve (Kv).

6.SIMULATION AND RESULTS

The proposed SG was created with MATLAB/Simulink, as shown in Fig.9. A PMSG wind turbine yields 27 kW at 11 m/s wind speed. In comparison, a photovoltaic array configuration with 12×13 "Tainergy-Tech TKSG-30001" panels generates around 47 kW at 1000 A/m². A DC-DC step-up converter connects the PV systems to the DC bus and boosts the voltage to 800 at the DC bus voltage. A rectifier and a DC-DC step-up converter connect the wind turbine to the PV system. Whenever the demand exceeds the amount of electricity produced by the RES or exceeds the power provided by the RES, the BESS is utilized for storing energy in an emergency. Table 1 summarizes the technical parameters of the recommended PV, wind turbine, and battery systems. The predicted input irradiation dropped from 1000 to 800 W/m² at t=7 sec of the simulation, while the temperature was predicted to remain fixed at 25 °C. The photovoltaic system voltage and current of the suggested network utilizing the P&O MPPT approach are shown in Fig.10 (a), and the output power is shown in Fig.10 (b). The equation below provides the PV method's efficiency whenever the MPPT technique is applied:

$$\eta(pso) = \frac{Maximum\ Measured\ Power}{Calculated\ Power} * 100\% \quad (3)$$

η(pso) = (46.5Kw)/(46.88 Kw) *100% = 99.19%
Using P&O MPPT, the efficiency is about:
η(pso) = (46.1Kw)/(46.88 Kw) *100% = 98.33%. Figure 11 depicts the modeling of the suggested PMSG wind turbine based on Eqs. (1) and (2) of the proposed wind turbine. The power factor (Cp) of the proposed PMSG averaged 0.48, and its tip speed ratio (λ) was roughly (8.1), as illustrated in Fig.4. The present study considers that the maximum power could be produced whenever the blade angle of the pitch angle is equal to zero (β=0). The MATLAB program's estimation of the tip speed ratio and power coefficient of the suggested PMSG wind turbine are displayed in Fig.12 (a) and (b), respectively. The wind turbine's MPPT was attained anytime the wind velocity reached 11 m/s (before t=10.5 sec), as shown in Fig.13. The wind turbine's input/output characteristics are displayed in Fig. 13, along with the three-phase voltage, wind speed, torque, pitch angle, power, and turbine speed in rad/sec. The suggested EMS utilized in the present investigation can be summed up as outlined below: In the case of a lack in the production sector, the necessary power can be brought in via the ESS; the electrical grid may be on backup for ecological and financial reasons, and electricity produced from RES can satisfy the load. The BESS will be charged whenever the load is less than the total energy produced by the wind turbines and photovoltaic cells. The IoT can be utilized to add reserve margin to boost generation capacity or regulate loads for load-shedding reasons. The present study suggests using on-grid functioning for the EMS.

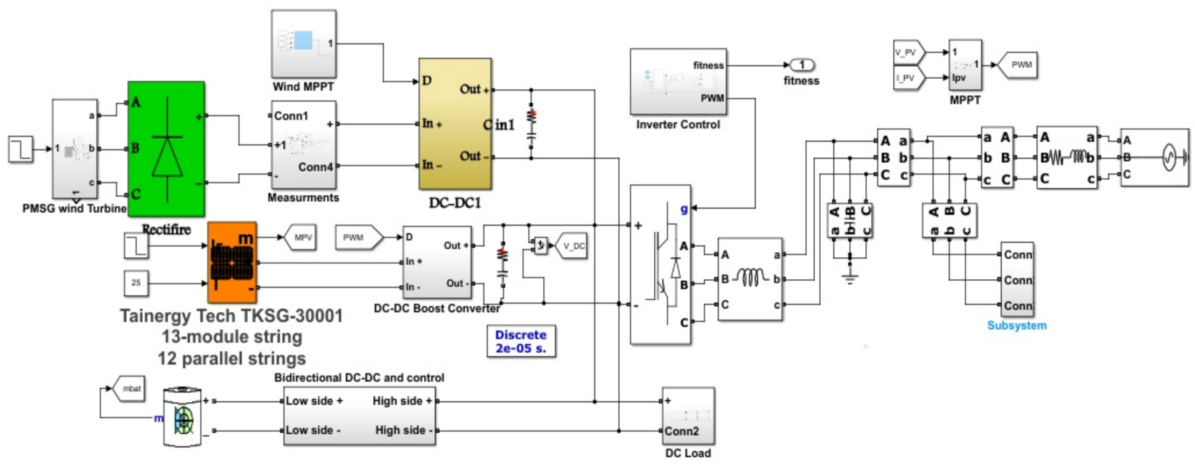

Fig. 9 The Suggested System's Execution Utilizing the MATLAB/Simulink Software.

Table 1 The Parameters of the Proposed System.

Wind Turbine		Photovoltaic system		BESS parameters	
Name	**Value**	**Name**	**Value**	**Name**	**Value**
Output power (W)	27500	Output power (W)	46880	Output Voltage (V)	400
Wind Speed (m/s)	11	Power for every panel (W)	300.5	Output Current (Ah)	1000
Radius of wings(m)	4.75	Panels in series	13	BESS Capacity (Wh)	400000
Poles	16	Panels in parallel	12	Percentage of Charging (%)	70
Resistance of the stator coil (Ω)	0.5251	Voltage for every panel (V)	36.742	Kind of BESS	Lithium-Ion
Inductance in the Stator coil(H)	0.00711	Current for every panel (A)	8.181	Cut-off voltage (V)	301
Output voltage (V)	324	System Voltage (V)	478	The internal resistance of the BESS (Ω)	0.041
Flux generated (Φ)	2.41	System current (A)	98.16	Discharge current (A)	434.6

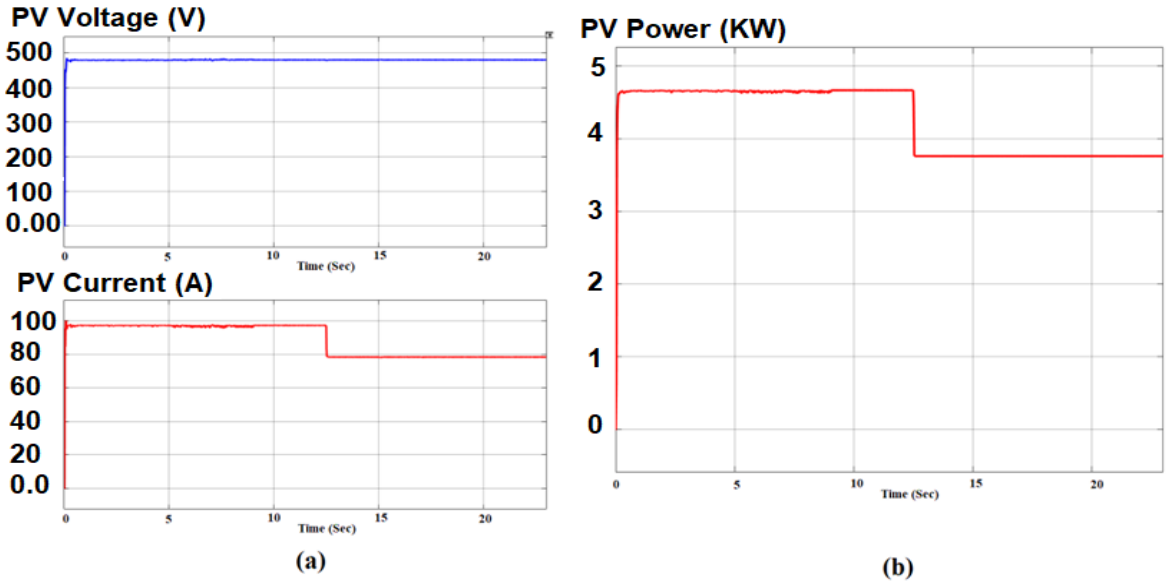

Fig. 10 (a) The Measured PV Voltage and Current, (b) The Measured Power.

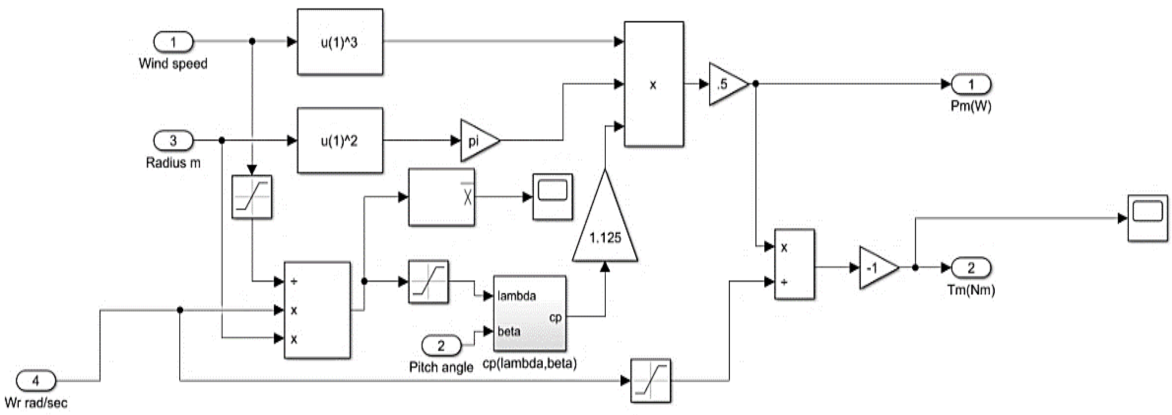

Fig. 11 Design of the Suggested Wind Turbine Developed with the MATLAB Software.

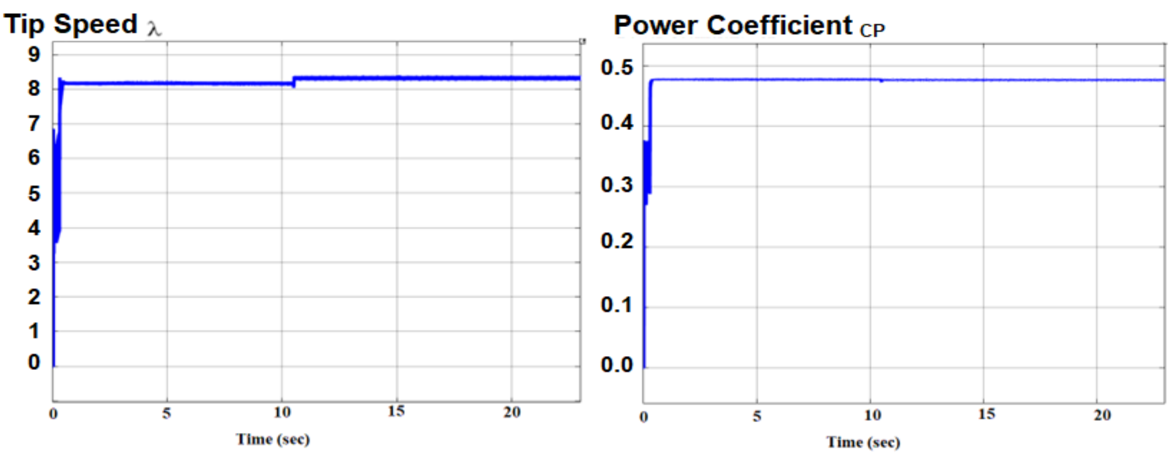

Fig. 12 Tip Speed Ratio (a) and Power Coefficient and (b) Utilizing the MATLAB Software.

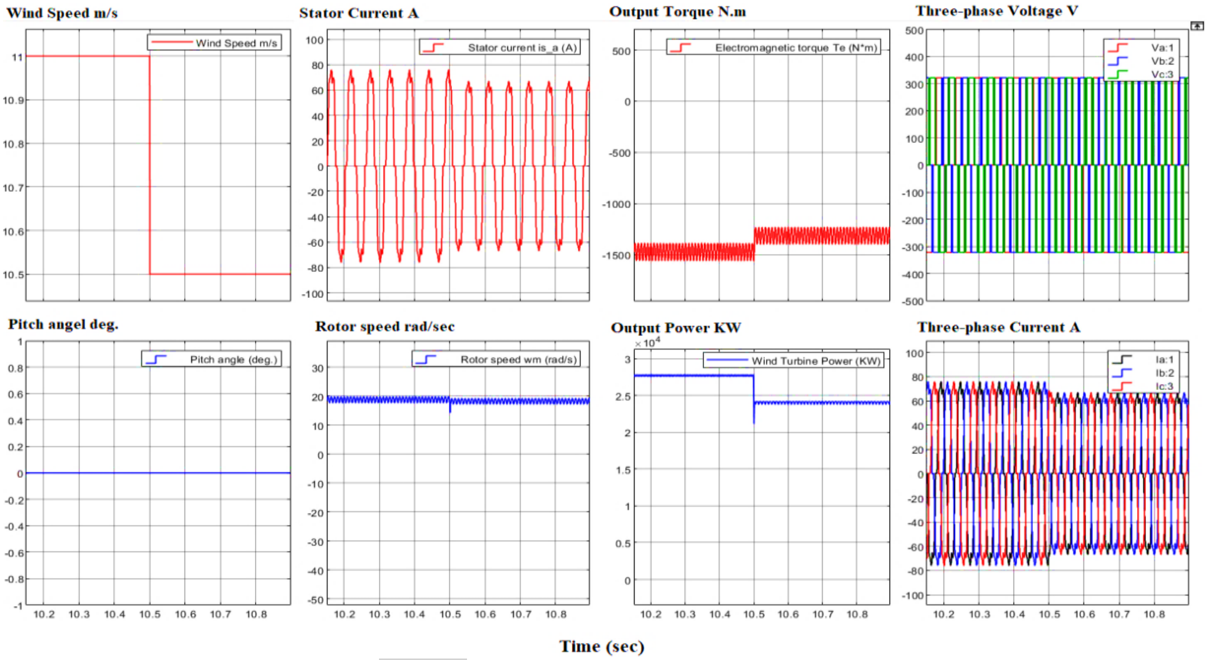

Fig. 13 PMSG Wind Turbine Outputs.

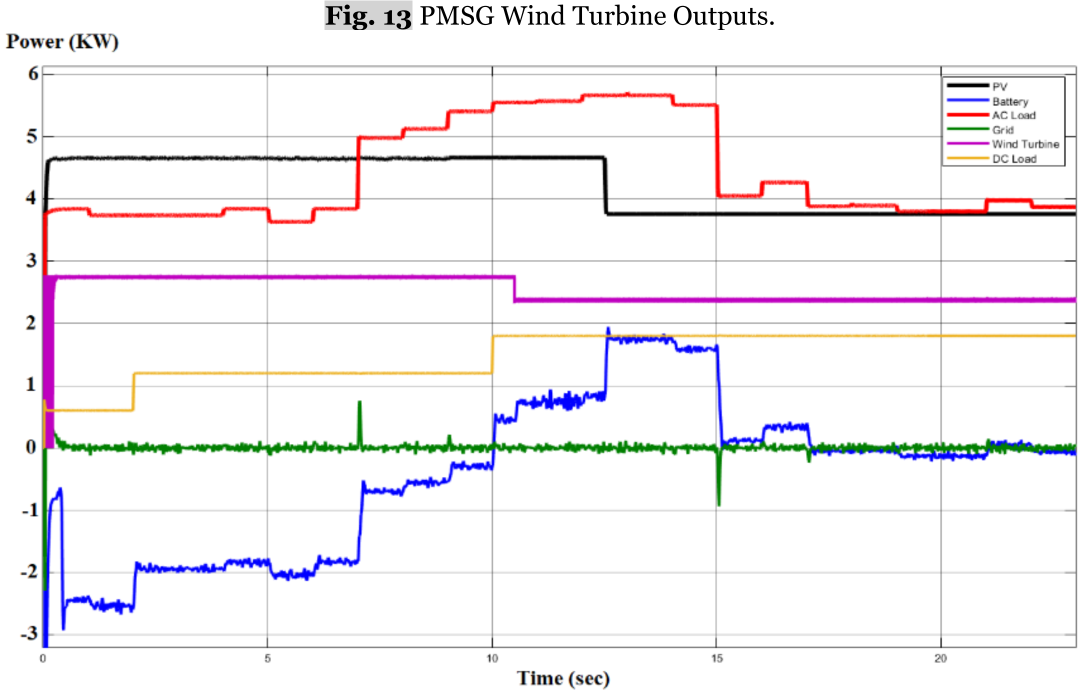

Fig. 14 Energy Management System Operation.

7.CONCLUSION

The Smart Grid (SG) revolutionizes the power infrastructure by introducing an interconnected system that capitalizes on modern technological advancements. The present study highlighted integrating a hybrid solar, wind turbine, and energy storage system (ESS) with the SG, demonstrated using the MATLAB/SIMULINK environment. A significant finding was the superior efficiency of the PSO MPPT over the P&O MPPT, offering potential optimization avenues for smart grids. Introducing IoT for scheduling loads and generations further accentuates the reliability and adaptability of the system. With global standardization initiatives and technological advancements, SGs not only reshape energy consumption patterns but also pave the way for a more sustainable and efficient power infrastructure. According to the results achieved in this work, PV and wind turbines work with high efficiency when the MPPT algorithms are used. The PV efficiency with PSO was about 99.19%, while the efficiency of the wind turbine works with the maximum allowed power for ideal values of the CP and lambda to achieve the MPPT. The sustainability and reliability of the proposed system were considered by applying an EMS that allows using the power generated by the RES, makes the grid standby for emergency operation conditions, and reduces CO2 emissions.

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NOMENCLATURE

SG	Smart grid
CP	Power coefficient
P-F	Power factor
RES	Renewable Power Sources
ESS	Energy storage system
EMS	Energy Management System
IoT	Internet of Things
PSO	Particle Swarm Optimization
EVs	Electric cars
BESS	Battery Energy Storage System
MPP	Maximum power point
PMSG	Permanent Magnet Synchronous Generators
VSI	voltage source inverter
DC	Direct current
D	Duty cycles
PWM	Pulse Width Modulation
Greek symbols	
Λ	Tip speed ratio
β	Represent the pitch angle

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