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AN ANALYSIS ON INTEGRATION OF SOLAR AND WIND POWER INTO A SINGLE-PHASE GRID WITH AN OPTIMAL PARAMETERIZED FRACTIONAL-ORDER PID CONTROLLER

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ABSTRACT

Because of the complimentary nature of solar and wind electricity, hybrid solar-wind power systems are the most effective renewable energy sources. Weather conditions have a significant impact on the amount of power that can be generated by wind and solar photovoltaic systems. Their intermittent nature causes output fluctuations. The purpose of this research is to offer a technique for a hybrid wind–solar power plant that makes the most efficient contribution of renewable energy resources and is backed by technology that allows batteries to store energy. The fact that solar and wind power display power profiles that are complimentary was the driving force for the construction of the hybrid solar–wind power system.

1. INTRODUCTION

The main source of inspiration for building renewable energy-powered power plants is the sun. Direct solar energy from the sun or indirect solar energy in the form of wind, hydraulic, or marine energy can serve as the source of inspiration. The method of producing power by harnessing the sun's beams is known as solar energy. Although wind energy has a great deal of potential to make up for the loss of demand responsiveness, controlling wind energy's intermittent nature is one of the most difficult problems to be solved. The total quality of the power that is delivered is reduced by the inconsistent and intermittent development of electrical energy based on renewable energy resources (RES). Alternative energy sources is another name for RES. Furthermore, an abundance of this energy could lead to imbalances and complicate efforts to maintain control over the power system. The excellent quality of the electricity produced by these power plants may be impacted by their connection to any existing electrical system. Network overloading and voltage variations are two external indicators that these changes have occurred.

The burgeoning interest in renewable energy sources, particularly solar and wind power, stems from their immense potential to reshape our energy landscape. Solar energy, derived directly from the sun's rays, and other forms like wind, hydraulic, or marine energy offer

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inspiration for sustainable power generation. While solar energy harnesses the sun's beams, the intermittent nature of wind energy poses a unique challenge in maintaining demand responsiveness. The utilization of these renewable energy resources (RES) introduces variability and intermittency, impacting the overall quality of delivered power. Termed as alternative energy sources, RES abundance may lead to imbalances, complicating efforts to regulate power systems and potentially affecting the quality of electricity produced by interconnected power plants. External indicators such as network overloading and voltage variations become apparent as consequences of these fluctuations.

Smart grid concepts emerge as a response to the challenges posed by integrating diverse non-traditional power sources into conventional electrical systems. This integration is particularly challenging due to the unpredictable and fluctuating nature of these sources. A notable strategy involves assimilating photovoltaic (PV) systems into existing electrical infrastructures, with a focus on the technology behind inverters. Power inverters play a decisive role in converting DC by solar panels into AC, addressing harmonization issues. Despite solar energy's sustainability, it is not without environmental repercussions, the extent of which depends on factors such as technology, location, and more. Ongoing research is imperative to comprehensively understand the environmental impacts associated with the incorporation of solar energy into existing ecosystems.

One of the main ideas underlying the concept of smart grids is the integration of diverse non-traditional power sources into the conventional electrical system. Because of the unpredictable and fluctuating nature of various sources, integration is difficult to plan for and can be difficult. Integration is difficult because of these issues. The strategy presented therein centres on the assimilation of photovoltaic (PV) systems into pre-existing electrical infrastructures. The technology underlying inverters is receiving a lot of attention because power inverters are used to convert solar power panel generated direct current (DC) into alternating current (AC). This is because power inverters are primarily responsible for the harmonisation issue. Even though solar energy is one of the sustainable energy sources, it does have some environmental repercussions, some of which can be rather large. The quantity of environmental harm that is caused can be significantly affected by a variety of considerations, including the particular technology being utilized, the location, and many more. This makes it absolutely necessary to conduct additional research on the effects that the incorporation of solar energy has on the surrounding ecosystem.

These developments highlight the significance of exploring optimal solutions for the integration of solar and wind power into single-phase grids. An innovative approach involves the implementation of a parameterized fractional-order PID controller to optimize system performance. By addressing the challenges posed by intermittency and variability, this research seeks to contribute valuable insights into enhancing the stability and efficiency of renewable energy integration, heading for a more workable and reliable energy future.

2. LITERATURE REVIEW

The writers of (Zahedi, 2011) talked about the reasons behind, benefits of, and problems with integrating renewable energy sources into the electrical system. They also raised the issue of how these alterations are viewed by final customers.

After examining solar photovoltaic (PV) technologies, Parida (Orioli & Di Gangi, 2013) concluded that the solar panels PV technology is highly beneficial for the various energy projects like: integrated rooftop building systems for electricity generation point of view, solar pumps for irrigation purpose, water desalination plants, and solar thermal as well as PV collector technology, is due to their growing efficiency, falling cost, and minimal pollution.

Solar and wind power integration into a single-phase grid has garnered significant attention in recent years, driven by the pressing need for sustainable energy solutions. Parida's exploration of solar photovoltaic (PV) technologies highlighted their versatility in diverse energy projects, ranging from integrated rooftop building systems to solar pumps and water desalination plants. The growing efficiency and decreasing cost of solar panels make them increasingly attractive for various applications. Additionally, the study by Parida emphasized the minimal environmental impact of PV technology, contributing to its widespread adoption.

The authors of (Parida et al., 2011) examined the potential outcomes in an urban environment. Examining the urban context, another study evaluated the feasibility of grid-connected solar systems on multi-story building rooftops. The research focused on assessing power consumption coverage and financial viability, revealing a load match index influenced by factors like shadowing. This study underscored the importance of considering local conditions for optimal solar integration, showcasing the intricate relationship between solar technology and the surrounding environment. The study's objectives were to assess the power consumption coverage and financial viability of grid-connected solar systems installed on multi-story building rooftops. The study's conclusions show that the case-study district's load match index was 42.4% when shadowing was not taken into account, but fell to 38.6%

when it was believed that the surrounding area blocked 10% of the sun's rays. This study served as an illustration of how solar integration in buildings has historically been used in relation to surrounding activity. In addition to being used to electrical networks, renewable energy sources are currently the subject of numerous integration projects.

The energy fall on earth surface or amount of solar irradiance energy at any given location and time determines how much power photovoltaic, or PV, systems can create, according to the equation shown in (Kempener et al., 2013). A surplus of power or a deficiency of generation could cause grid instability.

As per reference (Belcher et al., 2017), a distributed system experiences a large-scale burden exceeding 10 MW. Addressing the challenges associated with large-scale solar power generation, the literature points out the significance of distributed systems exceeding 10 MW. Systems falling below this threshold may face technical limitations and power quality issues. However, even larger power generation PV systems encounter challenges, leading to the integration of conventional thermal-based systems to ensure stable electricity generation. This hybrid approach demonstrates the complexity of balancing renewable and conventional energy sources for grid stability.

The solar power generation plant lie below this range are not technically suitable and eligible for the grid integration and frequently have serious issues with the quality of the power they produce. Nonetheless, large-scale power generation PV systems also encounter power quality issues. Although, they might not be able to generate electricity instantly, for that purpose there is utilization of conventional thermal based system of spinning a turbine for photovoltaic generation nevertheless get complete control over the electrical generation process.

In (Chong et al., 2011), a building's technological integration was demonstrated through the design of an inventive solar-wind based environmental friendly hybrid electricity generation system and rainwater harvester system for mitigation of peak hour's urban electricity demand based applications. PV panel manufacturers are also obligated to abide by regulations with a guarantee in which workers are not exposed to harmful chemicals during panel manufacturing and waste material is also disposed of appropriately at the time of manufacturing process.

There is no set capacity level that needs to be taken into account; instead, the unpredictability of solar PV may also be decreased by installing the solar PV based farms into a wide geographic land or by implementing the technology extremely gradually, according to (Nwaigwe et al., 2019).

A number of factors such as: the specific technology for PV panel making, location, and others, affects how severe the environmental effects are. Any of the renewable energy, especially solar energy sources, can have its environmental effects successfully prevented or minimized if one is well-informed on present along with potential future issues associated with these energy sources. Depending on where they are located, large solar farms that generate enough electricity for utilities may cause concerns about species extinction and land degradation.
As per reference (Liserre et al., 2010), the depletion of non-renewable energy sources and their adverse consequences are making power generation in power systems more challenging.

Because of the many advantages of the solar energy system's operations, ref. (Nazir et al., 2019) claims that it will become the primary source of electricity on Earth in the future. These advantages include the ease of upkeep, the lack of noise, and the environmental friendliness.

Innovative solutions have been proposed, such as the development of solar-wind hybrid electricity generation systems integrated with rainwater harvesting. This holistic approach aims to mitigate peak-hour urban electricity demand, emphasizing the potential of combining renewable resources for comprehensive energy solutions. The literature also sheds light on the importance of adhering to regulations in PV panel manufacturing, ensuring worker safety and appropriate waste disposal.

While solar energy presents itself as a promising primary source of electricity, it is not without challenges. Factors like environmental impact, non-linear design, lower energy efficiency, and installation costs pose hurdles to widespread adoption.

The production of fossil fuels and the adverse impacts of greenhouse gasses have led to a significant surge in the use of renewable energy in (Lakatos et al., 2011). According to the World Energy Outlook, 2018 forecasts, solar power generation will surpass all other forms of energy generation in terms of global capacity by 2040. It will be able to produce more electricity than any other energy source thanks to this capacity.

As per reference (Biktash, 2017), there are numerous disadvantages and challenges linked to the utilization of this energy source. A few of these are the solar system's non-linear design, poor energy efficiency, higher cost at the time of installation, and dependency on certain weather conditions like: temperature, pressure, wind and solar irradiance.

A range of models, such as: single diode technology, double diode, and three diode technology based models, as outlined in ref. (Biktash, 2017), can be used to characterize the behavior of any PV module. The reference contains these models.

According to (Soliman et al., 2020), meta-heuristics offer optimisation strategies that have gained significant traction over the past 20 years by providing suitable answers in a reasonable amount of time to tackle challenging problems in a range of industries. This is because meta-heuristics are capable of solving complex issues in a range of domains. Looking ahead, the role of meta-heuristics in optimizing solar and wind power integration becomes evident. These optimization strategies, as outlined in recent studies, have gained traction by providing efficient solutions to complex problems. The literature suggests that advancements in meta-heuristics contribute significantly to overcoming challenges and enhancing the overall effectiveness of solar and wind power integration into single-phase grids.

3. SOLAR-GRID SYSTEM

Significant amounts of solar electricity produced by PV or CSP systems can be integrated into the existing power infrastructure thanks to a technology known as solar-grid integration. The manufacturing of solar components, the installation of solar systems, and the operation of solar systems are just a few of the areas where this technology demands careful consideration and attention. The different measures of solar energy infringement onto the transmission system must be effectively integrated. A thorough understanding of the effects that various grid positions have is necessary to successfully connect these levels.

A solar-grid system comprises multiple interconnected components designed to harness solar energy and facilitate its integration into the existing power grid. At its core, the solar component consists of photovoltaic (PV) panels, which are responsible for converting sunlight into electrical energy. These PV panels are composed of semiconductor materials that produce a DC when uncovered to sunlight. The generated DC power undergoes conversion through inverters, transforming it into alternating current (AC), which aligns with the standard electricity grid format.

In addition to the PV panels and inverters, the solar-grid system encompasses energy storage devices such as batteries. These batteries serve as a crucial element in the system by storing excess energy produced during periods of high solar irradiance. The stored energy can then be used during time of low sunlight or increased demand, ensuring a consistent and trustworthy power supply to the grid. This storage capability addresses the intermittent nature of solar power generation and contributes to the overall stability of the integrated system.

To regulate and optimize the flow of energy between the solar component and the grid, control systems play a pivotal role. Monitoring devices, sensors, and controllers work collaboratively to manage the power output, maintain grid frequency, and ensure the seamless integration of solar energy. Modern control systems often incorporate advanced technologies to enhance efficiency and reliability. Moreover, communication systems enable real-time monitoring and adjustment, allowing for a dynamic response to fluctuations in solar power generation or grid demand.

There are many distinct parts that make up a photovoltaic establishment that integrates PV modules into the grid, but the most important part for the integration process is the inverter. A PV generator, sometimes referred to as solar modules, meters, a generator junction box (GJB), a grid connection, and both DC and AC wiring are additional parts.

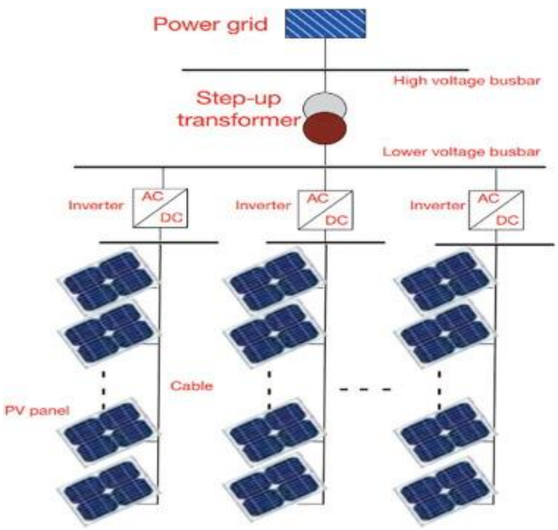

Figure 1. Diagram of a PV power station

Because of their crucial role, inverters are sometimes referred to as the "brains" of a project and are an integral part of any solar energy system. An inverter's primary function is to "invert" the direct current (DC) output into alternating current (AC), which powers all commercial equipment. Regardless of the load conditions, inverters have to keep a constant voltage and frequency, and they have to supply or absorb reactive power as needed (Behrsin et al., 2022; Hakizimana et al., 2020). To fulfill these needs, inverters are required. Apart from inverting, the main purpose of inverters is to synchronize the different systems and make sure that solar energy is sent into the grid as efficiently as possible. Consequently, the orientation, connectivity, and quality of the PV modules, as well as the inverter's dependability and efficiency, have a significant impact on a photovoltaic system's yield (Biktash, 2017; Chong et al., 2011; Yesilbudak & Colak, 2018), and (Kaveh & Dadras, 2017).

Summing up, the Solar-Grid system represents a forward-thinking approach to energy generation, seamlessly integrating solar and wind power into a single-phase grid. This synergy not only harnesses the clean and abundant energy from the sun and wind but also contributes to a more sustainable and resilient energy infrastructure. The incorporation of a Parameterized Fractional-Order PID controller adds a layer of sophistication, ensuring optimal performance and grid stability. As the world continues to grapple with the challenges of energy security and environmental sustainability, the Solar-Grid system stands out as a beacon of innovation, paving the way for a greener and more efficient energy landscape.

4. WIND SOLAR HYBRID MODEL

The hybrid wind and solar energy system, or HWSES for short, is a solar incorporated wind energy conversion technology that has been designed. As shown in the photo, this system uses a DFIG to convert wind speed into electrical energy. The electrical energy is then combined with a solar PV system and connected to the DC link of back-to-back converters.

The Wind-Solar Hybrid Model represents a novel approach in the renewable energy sector, aiming to harness the complementary characteristics of wind and solar power generation for enhanced overall system efficiency. The integration of these two abundant and sustainable energy sources into a single-phase grid demands a comprehensive understanding of the model's constituent parts and their functions.

At its core, the Wind-Solar Hybrid Model consists of two primary components: the wind power system and the solar power system. The wind power system incorporates a wind turbine, which converts the kinetic energy of the wind into mechanical energy through the rotation of its blades. Subsequently, this mechanical energy is transformed into electrical energy using a generator. The generator output is then rectified to produce direct current (DC), and an inverter is employed to convert it into alternating current (AC) suitable for integration into the grid. The wind power system is equipped with sensors and control mechanisms to optimize the turbine's orientation and blade pitch for maximum energy capture.

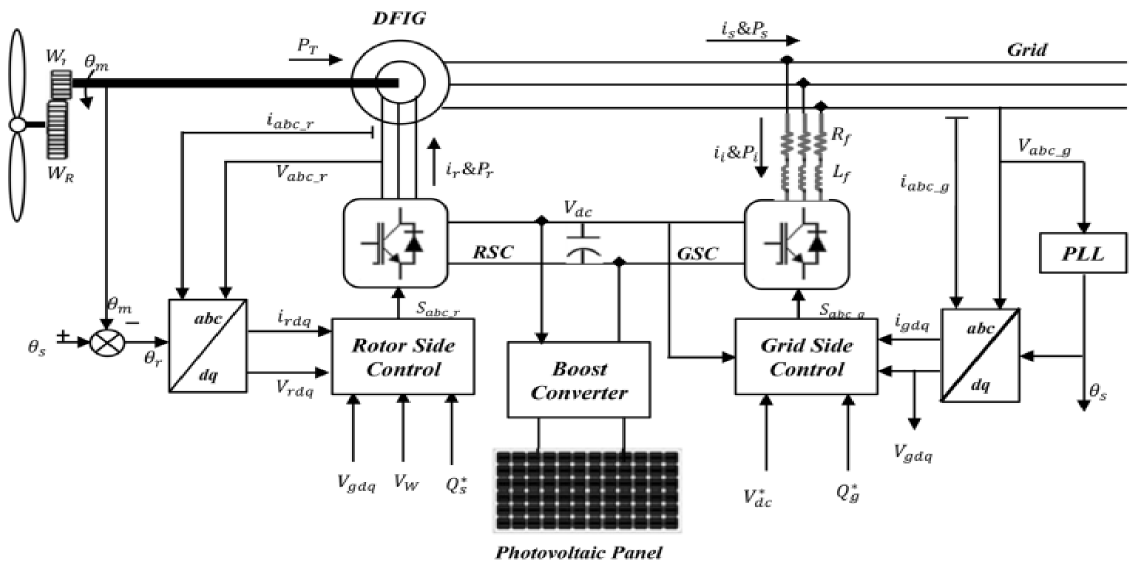

Figure 2. Wind solar hybrid model displaying the integration of the wind and solar components.

Kinetic energy is produced by wind power and can be put to use. The actuator disc hypothesis, which uses the wind as a driving force, can be used to explain how this energy was taken from it. It is established on energy balance theory equations along with the Bernoulli's theory principle. Prior to delving into the theory of momentum of wind turbines behaviour, a few presumptions must be made. The below figure depicts these suppositions.

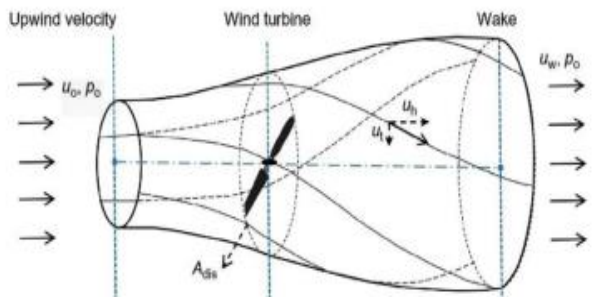

Figure 3. Momentum theory/Actuator disk theory

The amount of solar radiation that is available depends on the position of the earth's exterior, the time of day, and the date. The right amount of radiation exposure will be determined after taking these traits into account. The amount of radiation below the optimal level is influenced by various factors, including height above sea level, the amount of water vapor or contaminants in the atmosphere, and cloud cover. Short-term variations in solar radiation may occur even though it is not subject to the same level of turbulence as wind. These are often associated with cloud movement in the sky. Solar photovoltaic systems (PVS) offer several benefits over wind energy systems. Among the most significant are lower maintenance conditions, the lack of moving parts, and easier setting up.

5. RESULT AND ANALYSIS

The hybrid system is simulated to operate at a wind speed of 4 metres per second, which mimics the system to operate at speeds that are below synchronous. During this simulation, a Trina Solar module was employed. Table 1 is a detailed listing of the parameters for the solar device in question.

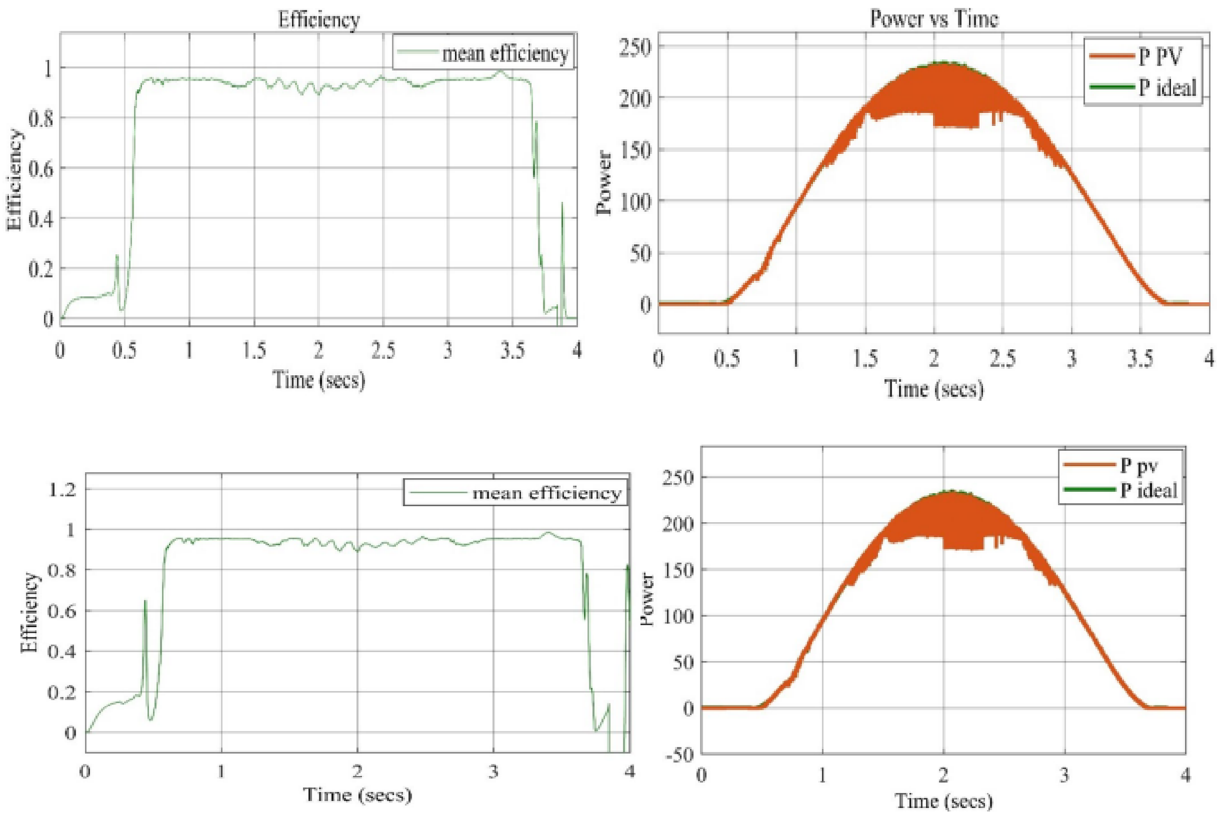

Figure 4. Power produced by the solar cell under ideal and real-world conditions, as well as the solar cell's efficiency

By holding all of the parameters of the standalone solar energy system at their initial values and only modifying the MPPT algorithms, we were able to attain the graphs depicted in the figure. The efficiency graphs in the image show significant spikes at 0.5 second and 3.5 second to 4 second intervals. This implies that the system is unsteady as it searches for the greatest power output point. This also implies that the system is highly sensitive to all kinds of noises, which could lead to the creation of local maxima points and, thus, a delay in the expected output.

Therefore, it is abundantly obvious from the graphs that the proposed technique has been validated by making use of real data. The actually recorded wind power profile from the chosen location is given in the picture for 500 different samples so that the presentation may be as clear as possible.

The performance of the model is assessed in terms of how closely it matches the real power demand, and the outcome of this evaluation can be seen up above. It is essential to keep in mind that the power profile for the hybrid wind and solar system is scaled to correspond with the specified demand.

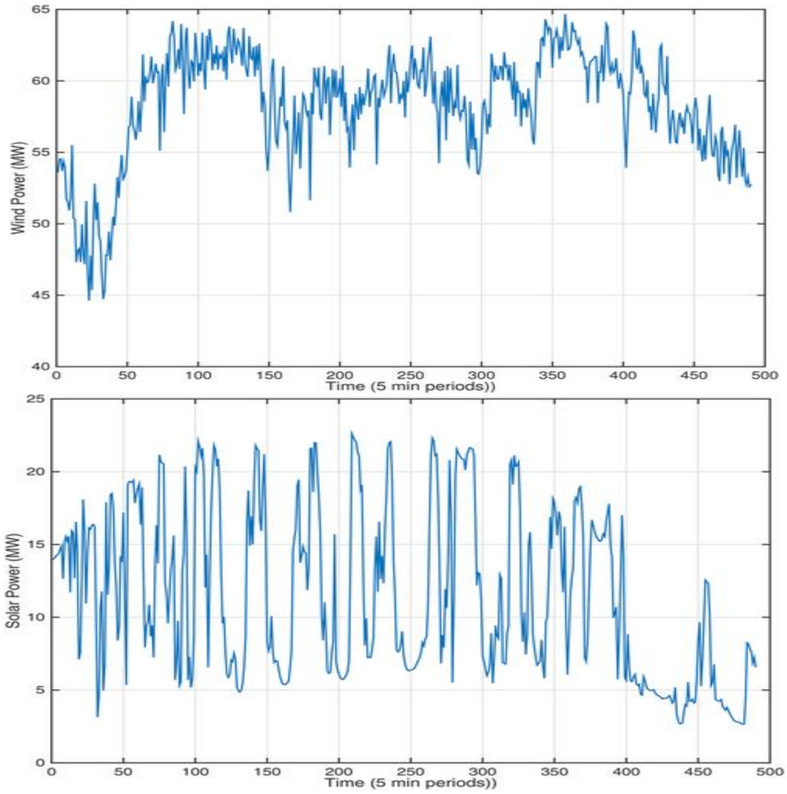

Figure 5. Model performance

6. CONCLUSION

Photovoltaic (PV) systems emerge as a pivotal solution in addressing multifaceted challenges within the energy landscape. These systems contribute significantly to reducing losses incurred during the transmission and distribution of power, thereby fostering an environment of heightened grid stability. By seamlessly integrating into national networks, PV systems exhibit the remarkable potential to curtail generation running and installation costs, offering a cost-effective alternative that minimizes the imperative for utilities to invest extensively in additional generation capacity.

A comprehensive examination of the study's findings underscores the remarkable capacity of combined wind and solar power output to intricately align with the dynamic demand profile over specified durations. The synergy between these renewable sources is particularly evident during periods of surplus power production, effectively meeting and, at times, surpassing the requisites of demand. Concurrently, the study illuminates instances when the generated power falls short of meeting the demand, requiring intervention from Battery Energy Storage Systems (BESS) to bridge the deficit. This nuanced understanding of the integrated wind and solar system's performance nuances highlights its adaptability and resilience in catering to the fluctuating energy needs of the grid.

In essence, the amalgamation of wind and solar power in a unified framework, coupled with the strategic deployment of PV systems, represents a transformative paradigm in the energy sector. The dual benefits of mitigating losses in the transmission and distribution systems and enhancing grid stability position PV systems as key enablers in the pursuit of sustainable and efficient energy solutions. The study's revelations not only affirm the capability of integrated renewable systems in meeting demand but also underscore the vital role of complementary technologies, such as BESS, in ensuring a continuous and reliable power supply. This nuanced perspective reinforces the importance of a diversified and integrated approach to renewable energy, signaling a promising trajectory for a resilient and sustainable energy future.

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