



# Fuzzy logic-based simulation and modelling of grid integration renewable energy systems for sustainable energy

## Sürdürülebilir enerji için şebekeye entegre yenilenebilir enerji sistemlerinin bulanık mantık tabanlı simülasyonu ve modellenmesi

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### Abstract

There has been a more significant trend from fossil fuels to renewable energy sources in recent years due to energy crises, environmental problems and sustainability. Renewable energy systems have become very useful and important especially photovoltaic and wind. This study focuses on a hybrid energy system. This hybrid system includes photovoltaic and wind energy systems as a renewable energy source. In addition, a diesel generator as a backup power source and battery storage system is used. The system is controlled with a fuzzy logic control (FLC) and optimizes energy distribution and maintains balance. A maximum power point tracking controller is developed using the perturb and observe algorithm and FLC. The photovoltaic and wind energy, has been analyzed weather conditions. The photovoltaic system produces about 3.5 kW. The wind turbine produces about 3.5 kW at 12 m/s wind speed. The diesel generator provides 5 kVA of backup power during periods of low renewable energy production. The 1000 Ah battery ensures energy balance and supports peak demand with 90% efficiency. The simulation results represent a 30% reduction in fuel consumption. In addition, this provides a 15% increase in system efficiency. The proposed approach effectively demonstrates the integration of renewable energy for sustainable power production.

**Keywords:** Distributed energy systems, Fuzzy logic control, Hybrid power system, Renewable energy, Energy management.

### 1 Introduction

The fossil fuel-based energy crises experienced in recent years have revealed the benefits of renewable energy sources (RES) regarding energy security. Following the global energy crisis, many countries are placing greater emphasis on policies that support RES [1]. However, it is well-known that RES may not consistently perform at peak levels under all conditions [2]. There has been a growing trend towards hybrid energy systems (HES) to overcome this challenge. HES include combinations of fossil fuels and RES [3,4].

### Öz

Son yıllarda enerji krizleri, çevresel sorunlar ve sürdürülebilirlik gibi faktörlerden dolayı fosil yakıtlardan yenilenebilir enerji kaynaklarına doğru önemli bir eğilim gerçekleşmiştir. Özellikle fotovoltaik ve rüzgâr enerjisi sistemleri, yenilenebilir enerji sistemleri içerisinde oldukça kullanışlı ve önemli hale gelmiştir. Bu çalışma, bir hibrit enerji sistemine odaklanmaktadır. Bu hibrit sistem, yenilenebilir enerji kaynakları olarak fotovoltaik ve rüzgâr enerjisi sistemlerini içermektedir. Ayrıca, bir yedek güç kaynağı olarak dizel jeneratör ve bir batarya depolama sistemi kullanılmaktadır. Sistem, bulanık mantık kontrol (BMK) sistemi ile kontrol edilmekte olup enerji dağıtımını optimize etmekte ve dengeyi sağlamaktadır. Bir maksimum güç noktası takip kontrolörü, pertübasyon ve gözlem algoritması ve BMK kullanılarak geliştirilmiştir. Fotovoltaik ve rüzgâr enerjisi, hava koşulları altında analiz edilmiştir. Fotovoltaik sistem yaklaşık 3,5 kW üretim sağlamaktadır. Rüzgâr türbini, 12 m/s rüzgâr hızında yaklaşık 3,5 kW enerji üretmektedir. Düşük yenilenebilir enerji üretimi dönemlerinde, dizel jeneratör 5 kVA yedek güç sağlamaktadır. 1000 Ah kapasiteli batarya, enerji dengesini sağlamakta ve %90 verimlilikle talep artışlarını desteklemektedir. Simülasyon sonuçları, yakıt tüketiminde %30 oranında bir azalma olduğunu göstermektedir. Buna ek olarak, sistem verimliliğinde %15'lik bir artış sağlanmıştır. Önerilen yaklaşım, sürdürülebilir enerji üretimi için yenilenebilir enerjinin entegrasyonunu etkili bir şekilde göstermektedir.

**Anahtar Kelimeler:** Dağıtık enerji sistemleri, Bulanık mantık kontrol, Hibrit güç sistemleri, Yenilenebilir enerji, Enerji yönetimi

These systems generally have the potential to provide optimum performance throughout the year. RESs are very important in managing climate change and sustainably meeting the increasing global energy demand. These systems use energy from renewable sources such as solar, wind, geothermal, biomass, etc., to reduce dependence on fossil fuels and environmental impacts. For example, photovoltaic (PV) panels perform very well on summer days. Also, wind energy systems (WES) produce its highest power on windy days. PV systems have low maintenance costs and are less

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prone to potential failures due to having few or no moving parts. On the other hand, WES with moving components are more susceptible to failures. It leads to increased operating expenses [5].

HES reduce energy costs while increasing overall performance. Electricity production from PV and wind sources varies seasonally. In winter, it is impossible to meet all energy demands with PV energy alone. Similarly, wind energy production may be insufficient in summer or windless days. Different solutions can be developed to prevent these seasonal fluctuations. The system to be installed should include different alternative energy sources and energy storage systems. Battery systems, usually the most selected storage options, come to the fore. However, battery systems should also be designed in a way that takes into account the supply-demand balance. Rather than installing a battery system to meet demand power, it would be more appropriate to install it in a way that manages critical loads for a certain period. Because increasing the battery group capacity significantly increases the cost. Unlike battery packs, diesel generators can be a suitable backup energy source for situations where the electrical energy obtained from PV panels or wind turbines is insufficient [6]. While integrating battery packs increases the initial installation costs, using diesel generators increases the operating costs. Here, any increase in system costs can be kept to a minimum by correctly configuring the component dimensions and control strategies. It can sometimes even be reduced depending on the regional characteristics.

### 1.1 Literature survey

Microgrid systems integrating RES have the potential to provide reliable and sustainable power, especially in remote or underserved areas. These systems often combine solar, wind and energy storage technologies supported by diesel generators to ensure stability during periods of insufficient renewable generation.

Optimize energy management strategies is vital to balance power generation, storage and distribution among various RES such as solar, wind, biomass, fuel cells, etc. Gopu and Nagaraj [7], highlighted the use of a novel power management algorithm that dynamically allocates power among various sources and optimizes resource use in a microgrid environment. The study presents control methods such as sliding mode control and dual Kalman filter-based disturbance methods. A power management algorithm in the island microgrid is explained. Al-Ani et al. [8], demonstrated the integration of PV, wind and fuel cell technologies. ANN optimize grid availability and efficiency in grid-connected hybrid system power management.

Moreover, frequency stability is very important since RES is an irregular system. It is also necessary to maintain stability during transitions between grid-connected and island modes [9]. In general, integrating multiple renewable sources into grids increases energy resilience. It also contributes to lower greenhouse gas emissions by reducing dependence on fossil fuels [10]. Additional components in hybrid energy production systems incorporating multiple renewable sources complicate the system's structure and

control [11,12]. Another challenge with HES is achieving optimal sizing to minimize initial costs and maximize reliability. In this regard, electrical installations for standalone residential buildings are currently designed for an average power capacity of around 10 kW. For this group of residences, designing a system that adequately meets power demands will be sufficient.

Distinguishing characteristics exist between HES interconnected with the electrical grid and those that operate independently without grid connectivity. When a hybrid system is integrated with a centralized electrical grid, such as in distributed generation applications, there is a degree of simplification in the system design, reducing the number of components. In this scenario, the grid system can manage voltage and frequency regulation, potentially obviating the need for the hybrid system to control these parameters [12]. The grid system can compensate for the deficiency if the hybrid system's energy output falls short of demand. Conversely, any surplus energy the hybrid system generates can be fed back into the grid. However, it's worth that there are situations where the electrical grid does not exhibit characteristics of an unlimited data pathway, necessitating the incorporation of additional components and control mechanisms [13].

Maximum power point tracking (MPPT) is important in optimizing the performance of both PV and WES, ensuring that they operate at their highest efficiency levels. The energy produced by these renewable sources varies depending on the intensity of irradiance, temperature and wind speed [13]. MPPT is an important technology used in renewable energy systems, especially to optimize energy capture from solar and wind sources. In solar energy applications, the Perturb and Observe (P&O) algorithm is widely used to adjust the voltage and current of solar panels. It ensures that they operate at maximum power points despite fluctuating light conditions. This method has been shown to effectively maintain optimum performance in solar cell charging systems, as demonstrated in MATLAB/Simulink simulations [14]. MPPT techniques such as super twist sliding mode control (STSMC) and modified P&O have been developed in wind energy systems to improve power extraction from variable-speed turbines. The STSMC method offers robustness against disturbances and minimizes energy losses, while the modified P&O technique provides faster tracking capabilities [15,16]. Furthermore, integrating AI with MPPT can further increase efficiency by providing more adaptive and responsive tracking strategies, especially in complex scenarios such as partial shading [17]. In general, developing MPPT techniques is essential to maximize the efficiency of renewable energy systems [16,18].

Different optimization algorithms are used to manage uncertainties in RES. One of them is the fuzzy logic control (FLC) system. Fuzzy logic helps to keep the variable nature of renewable energy under control. It has been shown that Fuzzy inference system control strategies can optimize the power flow in microgrids and increase efficiency and stability while meeting various energy demands and storage systems [19].

Versaci and La Foresta [20], proposed a heuristic fuzzy Takagi-Sugeno approach to manage energy flows in DC microgrids. Integration of PV and WES with energy storage is presented to provide system reliability. Sahoo et al. [21] studied the system stability during load disturbances with a fuzzy-based PID controller. The wild goat algorithm optimizes the controller gains for improved performance in the study. In addition, FLCs have been shown to improve the stability of grid-connected PV systems by effectively managing changes in renewable energy output [22]. FLC techniques have also been developed for synchronous load converters, which show superior performance in voltage regulation and transient response compared to traditional methods. This is very important for the dynamic nature of renewable energy applications [23].

Generally, FLC provides a robust framework to improve the performance and reliability of renewable energy systems. Huang et al. [24] designed a system to optimize investment strategies in renewable energy projects. The study proposed a fuzzy decision-making model that shows the importance of quality and innovation in improving efficiency. Giri and Roy [25] use a fuzzy-random robust programming approach to develop a closed-loop renewable energy supply chain that manages waste-related uncertainties and environmental impacts. Ganga Bhavani et al. [26] used an adaptive neuro fuzzy inference system (ANFIS) to control microgrid systems. They presented its effectiveness in improving power stability and efficiency. Giri et al. [27] used fuzzy graph theory for renewable energy resources in India. Singh et al. [28] presented the uncertain intuitive fuzzy sets algorithm that improves variety in RES applications. Collectively, these studies demonstrate different fuzzy methodologies used in optimizing and addressing the operational challenges of renewable energy systems.

FLCs can improve the performance of P&O and MPPT methods [29]. Ullah et al. [30] show that it can significantly increase system efficiency, reaching up to 97% in some simulations. Fuzzy MPPT systems are designed to track the maximum power point adaptively of PV modules, even in partial shading and rapid changes in insolation [31,32]. Comparative studies show that fuzzy controllers outperform traditional methods by reducing power fluctuations and increasing overall energy production [29,33]. One of the simplest methods is based on a PI controller and the P&O algorithm [34–38]. However, these methods may encounter challenges in delivering adequate performance. Another approach utilizes neural networks to predict wind speed. Generator speed is measured in advance, and then the control of generator speed is aimed at maximizing power extraction or deriving torque references for an operational point tracker [39]. In summary, fuzzy MPPT represents a robust solution to optimize PV system performance, addressing the limitations of traditional tracking methods while providing efficient energy conversion.

### 1.2 Contribution

This study presents an approach to optimizing grid-integrated RES performance by applying FLC and MPPT algorithms. It is developing and simulating a HES that

combines PV, WES, diesel generators and battery storage systems. The main contribution of the study is presented below.

- The study aims to provide uninterrupted and efficient energy under changing weather conditions.
- The research aims to protect the proposed system's energy balance and optimize resource use.
- It also demonstrates the system's durability, especially in stand-alone applications with limited or unavailable grid support.
- The system is essential in providing a cost-effective and environmentally friendly alternative to traditional energy systems, especially in rural or remote areas, to increase the sustainability of energy supply.

### 1.3 Organization

In this study, the structure of the hybrid power system and the descriptions are given in Section 2. The mathematical model of the PV system is first established and verified through simulations. In addition, FLC MPPT techniques are developed and analyzed under various weather conditions. Then, the wind energy conversion system and its performance analysis are examined according to the P&O algorithm. The diesel generator is modelled in the simulation environment and the results are presented. At the end of Section 2, the modelling of the battery group is given which acts as a backup power source and storage unit. Also, modelling for residential load applications is done in this section. Section 3 examines the microgrid integration of PV, WES, diesel generator and battery group systems. Performance analyses of these RESs under different operating conditions are performed. The developed models are explained separately for each source and the simulation results are evaluated. The discussion on the proposed HES is presented in Section 4. Lastly, the research conclusion and future studies are presented in Section 5.

## 2 Hybrid power system description

Design for a hybrid power system that can be installed for standalone residential loads via a low-voltage grid is presented in this study. The proposed system, integrated into the grid, comprises PV energy, wind energy, a diesel generator, a battery bank for energy storage, power switching elements and loads. This architecture is visually depicted in Figure 1. PV panels and wind turbines are utilized as primary power sources, designed to supply power to the loads and simultaneously charge the battery. The diesel generator serves as a backup power source and only activates when the battery falls below the minimum charge level. The electrical rated powers of all components used are designed as follows: the PV panel array is 3500 W, wind turbine is 4000 W, diesel generator is 5 kVA, battery capacity is 1000 Ah-24V and the total installed power for the loads is 10 kW.

### 2.1 PV System

PV panel production operates on the fundamental principle of the PV effect exhibited by semiconductors. This phenomenon enables the direct conversion of PV energy into electrical energy. PV cells, when exposed to sunlight,

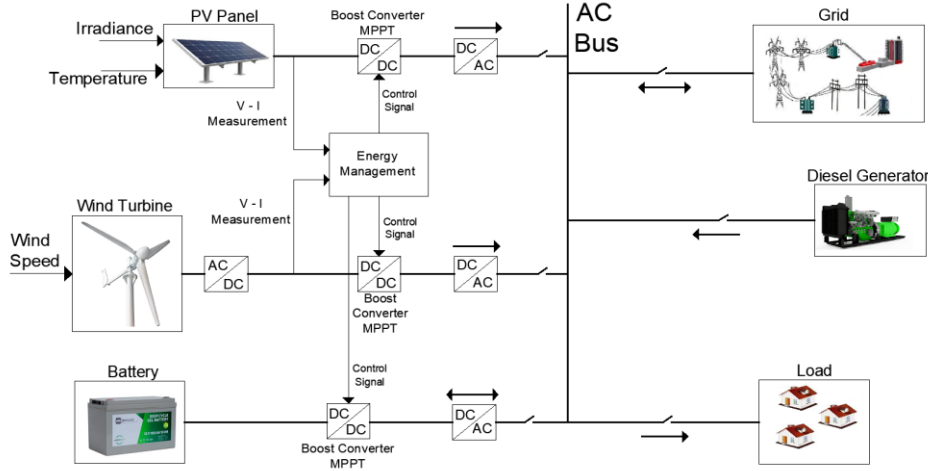


Figure 1. Distributed power system

produce an electric current as a result of this effect [40–42]. The output current of PV is dependent on the sunlight incident on the PV cell. Consequently, energy production from PV systems is not constant throughout the day due to weather variations. The efficiency of power generation varies with changes in PV irradiance and ambient temperature [43]. Hence, MPPT technologies play a significant role in optimizing power generation from PV systems under various weather conditions. The mathematical model of the modelled PV system in this study was obtained using Equations (1,5) [44,45]. The current at the output of the PV panel is provided in Equation (1).

$$I_{pv} = I_{ph}N_p - I_d - I_{sh} \quad (1)$$

$$I_{ph} = G_k[I_{sc} + K_I(T_{op} - T_{ref})] \quad (2)$$

$$I_d = I_s N_p \left[ e^{\left( \frac{V + I_{pv} R_s}{n V_T N_s C} \right)} - 1 \right] \quad (3)$$

$$I_{sh} = \frac{V + I_{pv} R_s}{R_p} \quad (4)$$

$$V_T = \frac{N_s n k T}{q} \quad (5)$$

Here,

$V_T$  = Thermal voltage (V)

$I_{pv}$  = PV panel output current (A)

$I_{ph}$  = PV panel terminal phase current (A)

$N_s, N_p$  = Number of PV panels

$I_d$  = Diode current (A)

$I_{sh}$  = Shunt current (A)

$n$  = Diode constant

The designed PV system, featuring a fuzzy-based MPPT comprises two inputs and one output. Trapezoidal

membership functions were employed for the input and outputs. The defuzzification of the proposed fuzzy controller was carried out using the center of gravity method. The simulation was based on the parameters of a 260W CW brand PV panel manufactured in Türkiye.

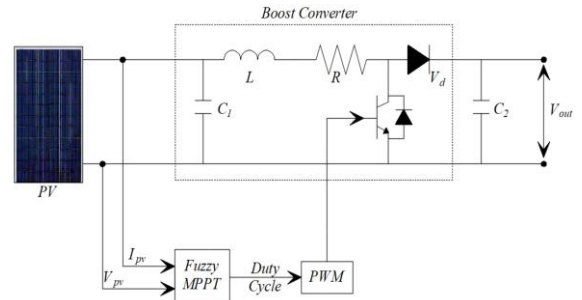


Figure 2. PV system

The MPPT fuzzy controller possesses two inputs, specifically the PV voltage and current. Figure 3 (a) provides the fuzzy logic controller diagram illustrating the voltage and current inputs. Based on these inputs, the MPPT fuzzy controller calculates the duty cycle and supplies it to the support converter shown in Figure 2. Figure 3 (b) presents the output fuzzy logic function. Ultimately, the fuzzy input-interference rules are devised by considering alterations in both PV voltage and current across a range of weather conditions.

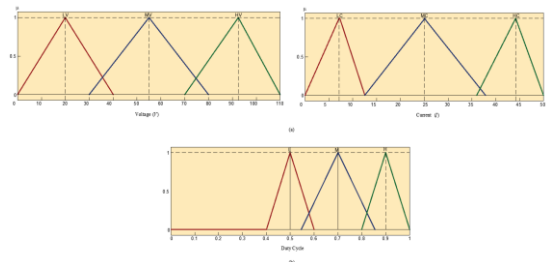


Figure 3. Fuzzy logic

The developed fuzzy logic controller was implemented and tested in a simulation environment, evaluating its performance under various weather conditions, including different levels of irradiance and temperature. Figure 4 shows the performance of the PV system for output power under various irradiance conditions. The above-designed fuzzy controller has been successfully implemented in a simulation program for a 3.5 kW PV system. At 1000 W/m<sup>2</sup> solar radiation, MPPT output power gives approximately 3600 W. These simulations demonstrate the effectiveness of the fuzzy controller in optimizing PV power generation. This study significantly contributes to developing renewable energy integration and offers alternative solutions for future energy management and efficiency.

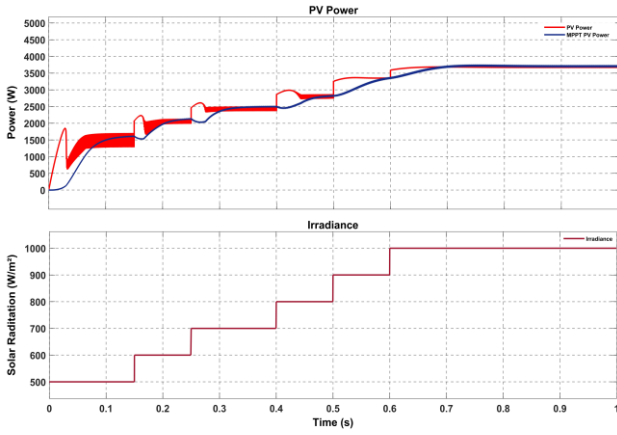


Figure 4. PV performance

### 2.2 Wind turbine system

WES stand out as one of the most abundant and promising resources for generating electrical energy. These systems harness the kinetic energy of the wind by utilizing turbines to convert it into mechanical energy. Subsequently, generators are employed to transform this mechanical energy into electrical energy. Consequently, the amount of wind energy produced is directly linked to the wind speed. The power generated by a wind turbine can be mathematically expressed through the following Equation (6) [46].

$$P_w = \frac{1}{2} C_p(\lambda, \beta) A \rho v^3 \quad (6)$$

Here,

$P_w$  = Power generated by the wind turbine (W)

$\rho$  = Density of the atmospheric gas (kg/m<sup>3</sup>)

$A$  = Cross-sectional area of the wind turbine blade (m<sup>2</sup>)

$V$  = Wind speed (m/s)

$C_p$  = Wind turbine energy conversion coefficient

The energy conversion coefficient  $C_p$  are expressed as follows in Equation (7) [37].

$$C_p(\lambda, \beta) = \frac{1}{2} \left( \frac{116}{\lambda_i} - 0.4\beta - 5 \right) e^{-\frac{21}{\lambda_i}} \quad (7)$$

The MPPT control unit functions by continuously monitoring and tracking the maximum power point corresponding to each wind speed. It is important to note that the optimum power output of a wind turbine does not follow a linear pattern. It is somewhat similar to a bell-shaped curve. The system attempts to determine the highest power output for each wind speed to find the ideal rotation speed. An adjustment is made to provide the maximum power output for a given wind speed based on the rotation speed of the turbine. The wind generator includes three main components: a wind turbine, a permanent magnet synchronous generator (PMSG) and a power converter. All these components are controlled by an MPPT system as shown in Figure 5.

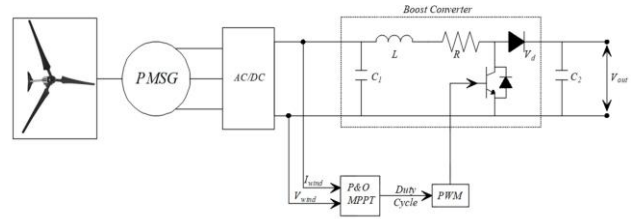


Figure 5. Wind energy system with MPPT controller

During power generation, a control strategy known as MPPT is utilized to manage the rotor speed of wind turbines by regulating the torque generated. This control approach, as depicted in Figure 5, focuses on optimizing power output. However, the blade pitching mechanism introduces a time delay in responding to changes in wind conditions, including turbulence and strong winds. This delay can impact energy production and subject the wind turbine structure to mechanical stress. In contrast, by applying electrical control to the generator rotor speed, improved electrical energy production can be achieved. MPPT-based control methods have been developed with the primary objective of reaching the highest possible power coefficient. In variable-speed WES, power electronics-based converters have proven to be effective in efficiently managing the generator's output power. The MPPT-based control technique for wind turbines involves adjusting rotor speed by regulating the production torque. Conversely, optimizing generator rotor speed through electrical control mechanisms can enhance electrical energy production.

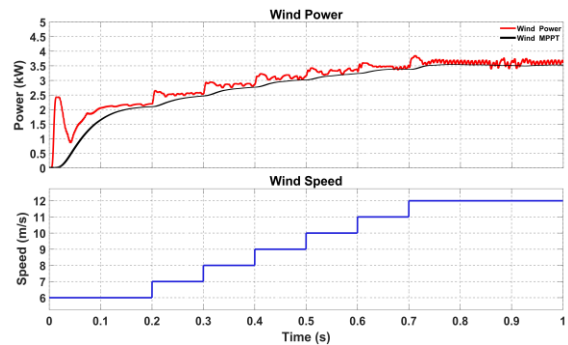


Figure 6. Wind performance

These methodologies based on MPPT principles play a crucial role in improving the efficiency and performance of variable-speed WES. The simulation results of wind energy conversion systems without MPPT and based on MPPT are analyzed. Figure 6 shows the output power of WES. The graph reveals that the wind turbine reaches an output of 3500 W when the wind speed reaches 12 m/s.

### 2.3 Diesel generator system

In this study, the focus has been on using a diesel generator to provide backup power. All energy sources, individually or in combination, are insufficient to meet the energy demand, an automatic controller with a selective switch has been used. In this scenario, the controller triggers a selective switch that activates the diesel generator when needed. If the main power source, i.e., the normal electrical source, is ready to supply the load, then the activation of the generator is automatically canceled. The output of the diesel generator is in the form of alternating current (AC). Figure 7 shows the block diagram of the diesel generator system. The voltage, current and power output performances of the diesel generator are given in Figure 8 and 9, respectively.

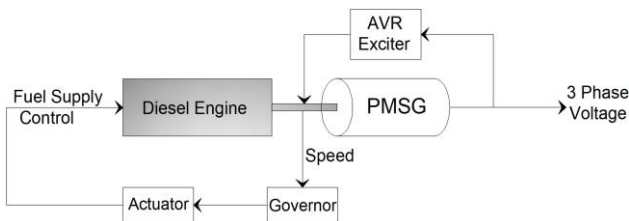


Figure 7. Block diagram of the diesel generator model

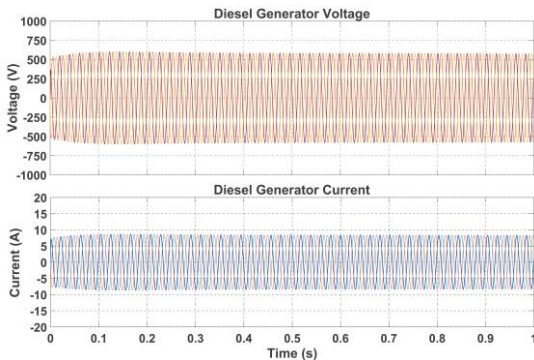


Figure 8. Diesel generator voltage and current output

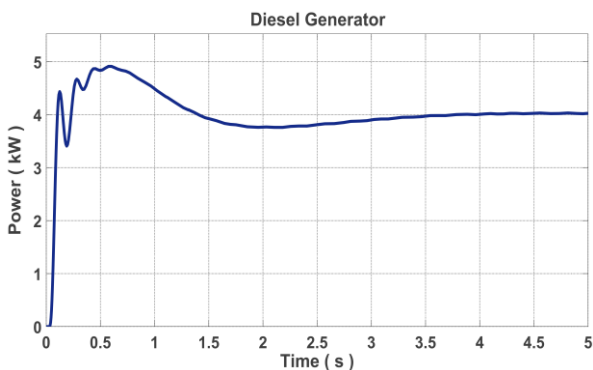


Figure 9. Diesel generator power output

### 2.4 Battery storage system

Battery storage systems play a critical role in scenarios where renewable energy sources prove inadequate to meet the electricity demand. These systems serve as backup power sources while simultaneously functioning as storage units for surplus electricity, allowing for its storage and subsequent use. The performance of the 1000Ah battery bank, which was subjected to simulation in this study, is depicted in Figure 10.

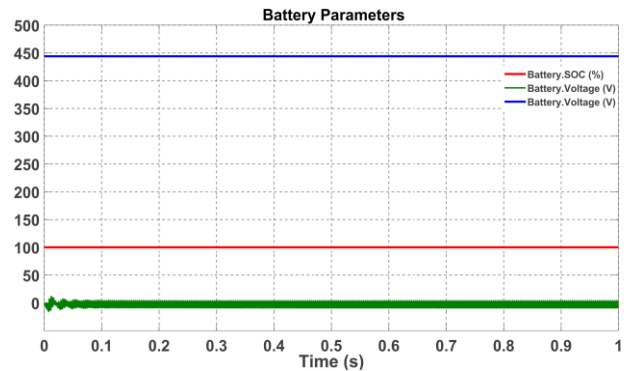


Figure 10. Battery output

### 3 Management of the distributed energy system and results

The proposed distributed energy system incorporates 3.5 kW PV, 4 kW WES, diesel generator and battery energy storage device that are connected to the electric distribution system. The above model was simulated in a simulation environment. Voltage source inverters play a crucial role in the grid integration of the PV system because PV generates only DC power, necessitating the conversion of DC power to AC power using inverters. The presented model is illustrated in Figure 11.

In this research study, fuzzy logic is employed as an energy management technique. In the designed system, the objective is to maximize power extraction from the PV system. This is achieved by connecting the PV system to the DC bus via a DC/DC converter controlled by an MPPT block.

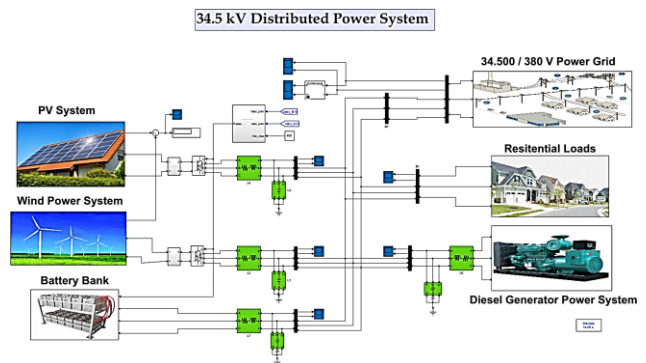


Figure 11. Proposed system simulation model

The generated power is transferred to the grid. To maximize the power output from the wind turbine integrated

into the system, an MPPT block and multiple converters are utilized to optimize it for the DC bus. Additionally, the battery system is linked to the microgrid through DC/AC conversion, ensuring effective energy management. Importantly, the energy management strategy in this system ensures that each component within the grid operates with its own controller. This setup provides independent control signals for each element, enabling them to function autonomously without relying on other energy sources. The waveform depicting the total output power is shown in Figure 12.

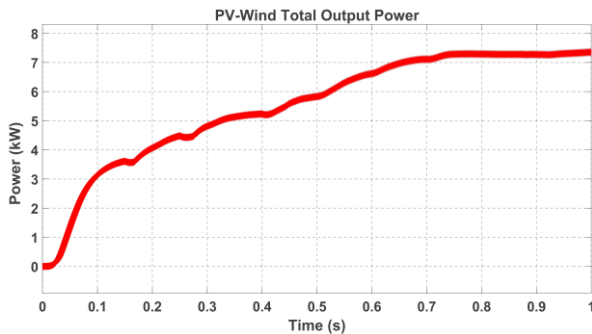


Figure 12. Total output power of the proposed system

Voltage and current profiles obtained from the battery bank are shown in Figure 13. These profiles provide information about the performance and behavior of the battery storage system under the proposed hybrid energy model. Analyzing these voltage and current profiles allows a comprehensive assessment of the battery's charging and discharging patterns, shedding light on its efficiency, state of charge and overall contribution to the system's energy supply.

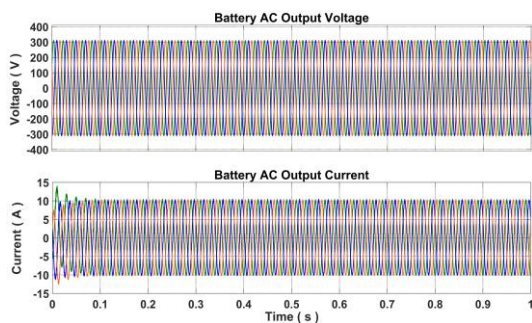


Figure 13. Energy storage system voltage and current output waveform

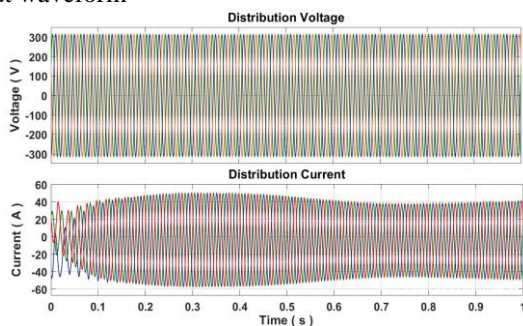


Figure 14. Distributed system voltage and current

The voltage and current waveforms of the proposed system are shown in Figure 14. The active and reactive power data obtained are presented in Figure 15. The graphical representation provides important information regarding power production and consumption, allowing evaluation of system performance in various operational scenarios.

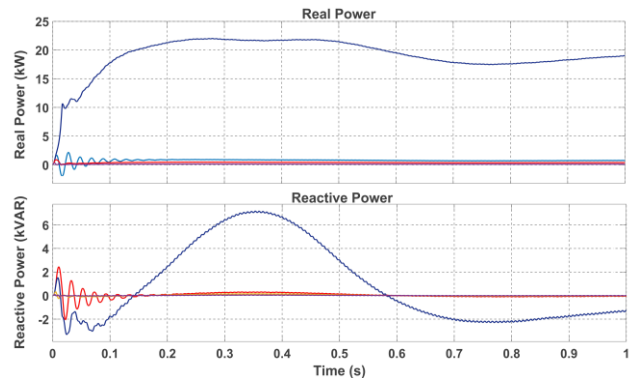


Figure 15. Proposed system real and reactive power waveform

#### 4 Discussion

This study proposes a FLC system to optimize grid-integrated renewable energy sources in sustainable energy systems. The distributed energy system used in the study at a voltage level of 34.5 kV includes various energy sources such as PV, WES, diesel generators and battery banks. One of the most striking aspects of the study is integrating the MPPT algorithm with FLC to optimize energy production under different weather conditions. This system increases energy efficiency by dynamically managing the energy flow and ensures the most efficient use of resources. Simulation results show that this hybrid system provides fuel savings of 30% and increases system efficiency by 15% compared to traditional systems.

Usanova et al. [47] shows that a FLC energy management model optimizes RES integration in smart grids. This model provides a 20% improvement in energy usage, a 25% improvement in energy storage reliability and a 22% increase in overall system efficiency. These findings show that FLC is effective in the integration and management of variable energy resources. Farhan et al. [48] presented simulation results for a DC system consisting of only PV and battery groups. Shakir and Salem [49] examined a residential electrical energy system for a standalone grid fed by an FLC-based PV and battery group. Our study differs from other studies in this field and provides a more cost-effective and applicable solution to increase energy efficiency. At the same time, a grid-integrated system is proposed in the study using many different energy sources. However, one of the study's shortcomings is that the simulation results were evaluated only under certain conditions. Examining the performance of this approach in different climatic regions and larger-scale systems is essential for the generalizability of the findings.

## 5 Conclusion and suggestions

This study investigates a structure consisting of PV, Wind and battery systems along with a diesel generator system under different operational conditions and explores smart controller-based grid integration. The proposed system is modelled in a simulation environment. The MPPT algorithm is developed for the PV system with a FLC and evaluated under changing weather conditions. The energy management system is developed and tested under various power demands. The grid integration of the WES and PV system is simulated and analyzed under different operational conditions. A hybrid power system combining wind and PV energy is examined through simulations. Fuzzy logic-based MPPT control is applied to efficiently utilize wind and PV resources. This hybrid power system is designed to supply AC loads and can be used both grid-connected and off-grid, making it suitable for various applications, including remote areas, rural locations, and hill stations.

The Fuzzy logic-based effective energy management controller manages the hybrid power system, ensuring uninterrupted power supply, minimizing diesel generator usage, optimizing energy resource utilization and extending battery life. Reducing diesel generator usage helps minimize harmful gas emissions. The diesel generator increased the system's reliability by providing five kVA of backup power during low renewable energy production periods. Therefore, it can be successfully employed in any region or country, offering an environmentally friendly green energy system. The FLC algorithm achieved a 15% increase in energy efficiency and a 30% decrease in fuel consumption. These results were achieved by analyses in a simulation environment. When the performance of the PV system was examined, it was seen that the system was optimized with the MPPT algorithm and could produce 3.5 kW power. This situation allowed the PV system to maintain maximum power production even under variable radiation conditions. The wind turbine was optimized to produce about 3.5 kW power at 12 m/s wind speed. These optimizations led to an increase in energy production. The 30% decrease in fuel consumption is directly related to the system's energy management strategy. The diesel generator's activation only when renewable energy sources were insufficient significantly reduced fossil fuel use. This proposed system can be effectively used in any location requiring stable voltage and continuous power supply.

In future studies, there is a consideration to focus on different energy management approaches, especially with the rapid integration of electric vehicles into the system. The focus will be on studies to optimize the integration of electric vehicles with energy storage systems. In this context, studies can be carried out on using vehicle batteries for transportation and grid-supported energy storage solutions. In this way, the efficiency of renewable energy sources can be increased. It can contribute to the energy system with vehicle-grid integration technology.

### Conflict of interest

The author declares that there are no conflicts of interest.

Similarity rate (iThenticate): 13%

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