Design and Generation of Wind-PV-Battery based Hybrid Energy System for Standalone AC Microgrid Applications using Fuzzy logic controller

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Abstract: This paper presents the design and implementation of a Wind-PV-Battery hybrid energy system for standalone AC microgrid applications, utilizing a Fuzzy Logic Controller (FLC) to optimize power generation and management. The hybrid system integrates wind and photovoltaic (PV) renewable energy sources with battery storage to ensure reliable and efficient energy supply. The FLC is designed to handle the inherent uncertainties and nonlinearities of renewable energy sources, enhancing the overall system performance. Simulations and experimental results demonstrate the effectiveness of the proposed system in maintaining a stable power supply, improving energy efficiency, and reducing dependency on conventional power sources. This approach provides a sustainable and cost-effective solution for remote and off-grid areas. The usage of networks that are not linked to electrical systems allows for the provision of electricity to remote places, which is one way for determining this issue. They are denoted to as standalone microgrid systems. The standalone microgrid has its sources of electricity, extension (or)addition with an energy storage system. They are utilized where power transmission and distribution from a major centralized energy source is too far and costly to operate. In this article, a standalone AC microgrid scheme with a hybrid power system comprised of wind, photovoltaic, and batteries are designed and managed.

Keywords: Hybrid energy system, PV (Solar Cell), Wind, Battery, Microgrid.

I.INTRODUCTION

The increasing demand for sustainable energy solutions has driven significant advancements in renewable energy technologies. Hybrid energy systems, which combine multiple renewable energy sources, have emerged as a promising solution to address the limitations of individual renewable sources, such as variability and intermittency. Among these, Wind-PV-Battery hybrid systems offer a compelling combination, leveraging the complementary nature of wind and solar energy to provide a more stable and continuous power supply. Standalone AC microgrids, which operate independently from the main power grid, are particularly well-suited for remote and off-grid areas where grid extension is impractical or economically unviable. These microgrids can benefit greatly from hybrid energy systems, which enhance reliability and reduce reliance on diesel generators or other conventional power sources. However, managing the power generation and distribution in a hybrid energy system poses significant challenges due to the fluctuating nature of wind and solar energy. Traditional control methods often fall short in handling these complexities, leading to inefficiencies and instability in the power supply. To address these challenges, this paper proposes the use of a Fuzzy Logic Controller (FLC) for the design and management of a Wind-PV-Battery hybrid energy system.

Fuzzy Logic Controllers are particularly well-suited for systems with high uncertainty and nonlinearity, as they mimic human reasoning and decision-making processes. By incorporating FLC into the hybrid energy system, we aim to enhance its ability to adapt to varying environmental conditions, optimize power generation, and ensure a reliable power supply for standalone AC microgrid applications.

Next, we delve into the core principles underlying grid-connected power systems, elucidating the intricate interplay between generation, transmission, and distribution components. In a grid-connected configuration, renewable energy sources interface with the existing electrical grid, allowing for bidirectional energy flow and facilitating the exchange of surplus power. However, the variability of solar and wind resources necessitates sophisticated control strategies and grid management techniques to ensure stability and reliability. The heart of this project lies in the development and implementation of a detailed simulation model for grid-connected solar wind hybrid power systems. Leveraging state-of-the-art simulation tools and methodologies, we construct a virtual environment that accurately captures the behavior of solar panels, wind turbines, energy storage systems, inverters, and grid interfaces. By simulating various operating scenarios, including different weather conditions, load profiles, and system configurations, we gain a nuanced understanding of system dynamics and performance characteristics.

Through extensive simulation experiments, we investigate key performance metrics such as energy yield, system efficiency, reliability, and grid integration capabilities. We analyze the impact of factors such as system sizing, component selection, control algorithms, and grid interaction protocols on overall system performance. Furthermore, we explore advanced optimization techniques, such as genetic algorithms and machine learning algorithms, to enhance system design and operation. Moreover, we delve into the economic aspects of grid-connected solar wind hybrid power systems, assessing their cost-effectiveness, return on investment, and potential for revenue generation. By conducting techno-economic analyses and sensitivity studies, we elucidate the financial viability of hybrid installations compared to conventional power generation technologies. We also examine policy frameworks, incentives, and regulatory mechanisms that influence the adoption and deployment of renewable energy systems on a broader scale.

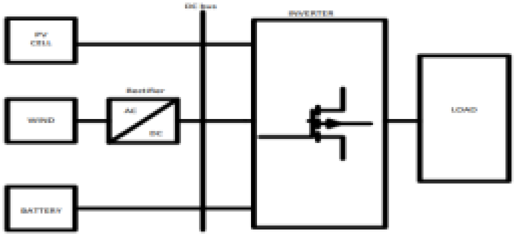


Fig1: Hybrid Energy generating station

In addition to technical and economic considerations, we address environmental and societal impacts associated with grid-connected solar wind hybrid power systems. By reducing greenhouse gas emissions, mitigating air and water pollution, and promoting energy independence, these systems contribute to sustainable development and climate resilience. Furthermore, their decentralized nature empowers local communities, fosters job creation, and enhances energy access in remote areas. In conclusion, this project presents a holistic exploration of grid-connected solar wind hybrid power systems, combining technical, economic, environmental, and social perspectives. Through advanced simulation techniques, we unravel the intricacies of these complex systems, paving the way for their widespread adoption and integration into the global energy landscape. By embracing sustainability and innovation, we embark on a path towards a cleaner, greener, and more resilient future for generations to come.

Electric systems and grids are complex dynamic systems. These systems suffer usually from unexpected or sudden changes of the currents and voltages. These changes are due mainly to the different types of linear and non-linear loads to which they are connected. In addition, to different types of accidents which can intervener into the grid. With the increasing use of power semiconductors in the most of industrial and domestic procedures, the electric grids are polluted with different harmonic currents and voltages. These harmonics affect the normal function of the most of the grid connected devices; in addition to considerable economic losses. Many classic and modern solutions have been proposed in the literary for the harmonic problems. In this chapter, the harmonic problem as one of the most common power quality problems will be presented. The different modern and traditional solutions will then be discussed.

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “The concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” As appropriate as this description might seem, the limitation of power quality to “sensitive electronic equipment” might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems.

A simpler and perhaps more concise definition might state: “Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.” This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern.

Power quality can also be defined as a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy. Power distribution systems should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in power systems, especially the distribution systems have many nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the pure sinusoidal waveform is lost. This ends up producing many power quality problems.

In power systems, different voltage and current problems can be faced. The main voltage problems can be summarized in short duration variations, voltage interruption, frequency variation, voltage dips and harmonics. Harmonics represent the main problem of currents of power systems. The short duration voltage variation is the result of the problems in the function of some systems or the start of many electric loads at the same time. The defaults can increase or decrease the amplitude of the voltage or even cancel it during a short period of time. The increase of voltage is a variation between 10-90% of the nominal voltage. It can hold from half of a period to 1 minute according to the IEEE 1159-1995. According to the same reference, the increase in voltage is defined when the amplitude of the voltage is about 110-180% of its nominal value.

The cutoff of the voltage happens when the load voltage decreases until less than 10% of its nominal value for a short period of time less than 1 minute. The voltage interruption can be the effect of defaults in the electrical system, defaults in the connected equipment’s or bad control systems. The main characteristic of the voltage interruption is the period over which it happens. In the normal conditions the frequency of the distribution grid must be within the interval 50±1 Hz. The variations of the frequency of the grid can appears to the clients who are using auxiliary electric source (solar system, thermal station…etc.). These variations are rare and happen in the case of exceptional conditions like the defaults in the turbines.

The three phase system is unbalanced when the currents and voltages are not identical in amplitude; or when the phase angle between each two phases is not 120°. In the ideal conditions, the three phase system is balanced with identical loads. In reality, the loads are not identical, in addition to the problems of the distribution grids which can interfere. The voltage dips are periodic perturbations. They appear as a natural effect of the switching of the transistors. They are due also to the start of big loads like motors. Lifts, lights, heaters…etc. this phenomena causes bad functioning of the protection equipment’s. Power systems are designed to operate at frequencies of 50 or 60 Hz. However, certain types of loads produces currents and voltages with frequencies that are integer multiples of the 50 or 60 Hz fundamental frequency. These frequencies components are a form of electrical pollution known as harmonic distortion. There are two types of harmonics that can be encountered in a power system.

- Synchronous harmonics.
- Asynchronous harmonics.

Synchronous harmonics are sinusoids with frequencies which are multiples of the fundamental frequency. The multiplication factor is often referred to as the harmonic number. The synchronous harmonics can be subdivided into two categories.

- Sub-harmonics: when the harmonic frequency is less than the fundamental frequency.
- Super harmonics: when the harmonic frequency is more than the fundamental frequency.

Harmonics are familiar to the musicians as the overtones from an instrument. They are the integer multiples of the instrument’s fundamental or natural frequency that are produced by a series of standing waves of higher and higher order. Exactly the same thing happens in power circuits when non-linear loads create harmonic currents that are integer multiples of the supply fundamental frequency. The rapid growth of solid-state power electronics has greatly increased the number and size of these loads.

The concept of harmonics was introduced in the beginning of the 19th century by Joseph Fourier. Fourier has demonstrated that all periodic non-sinusoidal signals can be represented by infinitive sum or series of sinusoids with discontinuous frequencies as given by Equation (2.1).

$$i(t) = I_0 + \sum_{h=1}^{\propto} I_h \cos(h\omega t + \varphi_h) \quad \ldots\ldots \quad (2.1)$$

The component I_0 in the Fourier series is the direct component. The first term of the sum with the index h=1 is the fundamental of the signal. The rest of the series components are called the harmonics of the range h. Fig. 2.1 Shows the form of a wave containing the third harmonic (h=3). In the three phase electric grid, the principle harmonic components are the harmonics of ranges (6*h±1).

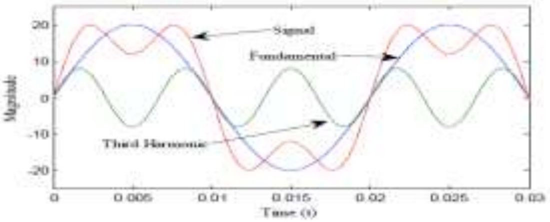


Fig. 2 Harmonic Content of a Signal and its Fundamental.

II.LITERATURE SURVEY

The integration of renewable energy sources into hybrid energy systems has been extensively researched over the past few decades. This literature survey aims to highlight key developments in the design and generation of Wind-PV-Battery based hybrid energy systems, particularly focusing on standalone AC microgrid applications and the use of Fuzzy Logic Controllers (FLC) to enhance system performance.

Hybrid Energy Systems

Wind-PV Hybrid Systems: Wind and photovoltaic (PV) hybrid systems have garnered significant attention due to their complementary nature. Wind energy tends to be more available during periods of low sunlight and vice versa, which helps in maintaining a more consistent power output. Research by Yang et al. (2015) demonstrated that combining wind and PV systems could significantly reduce the variability in power generation, making it more suitable for standalone applications.

Battery Storage Integration: The inclusion of battery storage in hybrid systems is critical for addressing the intermittent nature of renewable sources. Studies by Balamurugan et al. (2016) have shown that battery storage not only helps in balancing supply and demand but also improves the reliability and stability of the power supply in standalone microgrids.

Control Strategies in Hybrid Systems

Traditional Control Methods: Traditional control methods, such as Proportional-Integral-Derivative (PID) controllers, have been widely used in managing hybrid energy systems. However, these methods often struggle with the nonlinearities and uncertainties inherent in renewable energy sources. Research by Hossain et al. (2018) indicated that while PID controllers are effective in certain conditions, they lack the adaptability required for optimal performance in hybrid systems with high variability.

Fuzzy Logic Controllers (FLC): Fuzzy Logic Controllers have emerged as a powerful alternative to traditional control methods due to their ability to handle uncertainty and nonlinearity. Zadeh (1965) first introduced the concept of fuzzy logic, which has since been applied to various engineering problems. In the context of hybrid energy systems, FLCs have been shown to improve the efficiency and reliability of power generation.

Sandeep and Singhal (2017) demonstrated the application of FLC in a wind-PV hybrid system, highlighting its superiority over conventional methods in terms of adaptability and robustness. The study revealed that FLC could effectively manage the power output and battery charging/discharging cycles, leading to enhanced overall system performance.

Standalone AC Microgrid Applications

Challenges and Solutions: Standalone AC microgrids face unique challenges, such as maintaining voltage and frequency stability, especially when integrating multiple renewable sources. Research by Kumar et al. (2019) explored various control strategies to address these issues, emphasizing the need for advanced controllers like FLC to ensure stable and reliable operation.

III.SOLAR SYSTEM

The continuous increase in the electrical energy with the clean environment needs the decentralized renewable energy production. The increasing energy consumption may overload the distribution grid as well as power station and may cause the negative impact on power availability, security and quality. The only solution to overcome this problem is integrating the utility grid with the renewable energy systems like solar, wind or hydro. The grid[1] can be connected to the renewable energy system as per the availability of renewable energy sources. Recently the solar power ~~generation systems are getti~~ng more attention because solar energy is abundantly available, more efficient and more environment friendly as compared to the conventional power generation systems such as fossil fuel, coal or nuclear. The PV systems are still very expensive because of higher manufacturing cost of the PV panels, but the energy that drives them -the light from the sun- is free, available almost everywhere and will still be present for millions of years, even all non-renewable energy sources might be depleted. One of the major advantages of PV technology is that it has no moving parts. Therefore, the PV system is very robust, it has a long lifetime and low maintenance requirements. And, most importantly, it is one solution that offers environmentally friendly power generation.

IV.WIND ENERGY CONVERSION SYSTEM

Wind energy is transformed into mechanical energy by means of a wind turbine that has one or several blades. The turbine is coupled to the generator system by means of a mechanical drive train. It usually includes a gearbox that matches the turbine low speed to the higher speed of the generator. New wind turbine designs use multi pole, low speed generators, usually synchronous with field winding or permanent magnet excitation, in order to eliminate the gearbox. Some turbines include a blade pitch angle control for controlling the amount of power to be transformed. Stall controlled turbines do not allow such control. Wind speed is measured by means of an anemometer. A general scheme of Wind energy conversion system is shown in Fig. .

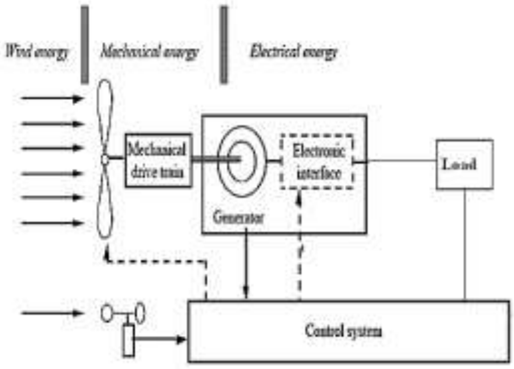


Fig. 3 Block Diagram of Wind Energy Conversion System

The electrical generator transforms mechanical energy from the wind turbine into electrical energy. The generator can be synchronous or asynchronous. In the first case, an excitation system is included or permanent magnets are used. Variable speed systems require the presence of a power electronic interface, which can adapt to different configurations. The compensating unit may include power factor correction devices (active or passive) and filters.

V.PULSE WIDTH MODULATION

1. Cheap to make.
2. Little heat whilst working.
3. Low power consumption.
4. Can utilize very high frequencies (40-100 Khz is not uncommon.)
5. Very energy-efficient when used to convert voltages or to dim light bulbs.
4. High power handling capability
7. Efficiency up to 90%

a modulation technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. In addition, PWM is one of the two principal algorithms used in photovoltaic solar battery chargers,[1] the other being MPPT.

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load.

The PWM switching frequency has to be much higher than what would affect the load (the device that uses the power), which is to say that the resultant waveform perceived by the load must be as smooth as possible. Typically switching has to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies.

The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on.

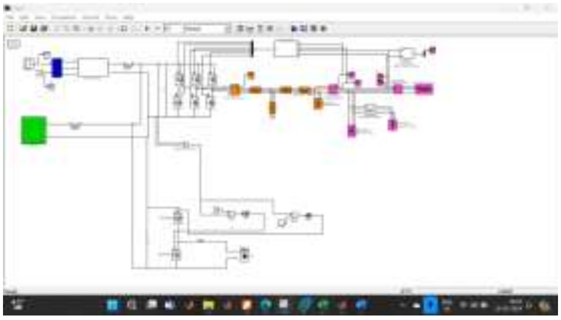
The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.

VI.PROPOSED VOLTAGE SOURCE INVERTER

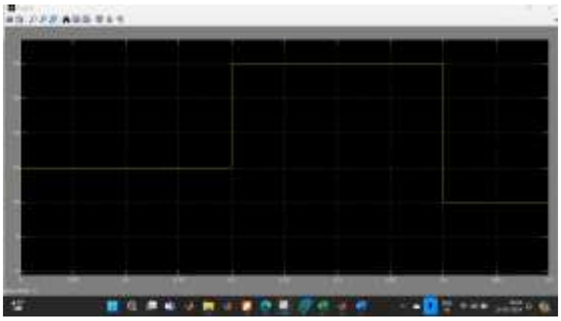
Because thyristors can only be turned on (not off) by control action, and rely on the external AC system to effect the turn-off process, the control system only has one degree of freedom – when to turn on the thyristor. This limits the usefulness of HVDC in some circumstances because it means that the AC system to which the HVDC converter is connected must always contain synchronous machines in order to provide the commutating voltage – the HVDC converter cannot feed power into a passive system. With some other types of semiconductor device such as the insulated-gate bipolar transistor (IGBT), both turn-on and turn-off can be controlled, giving a second degree of freedom. As a result, IGBTs can be used to make self-commutated converters. In such converters, the polarity of DC voltage is usually fixed and the DC voltage, being smoothed by a large capacitance, can be considered constant. For this reason, an HVDC converter using IGBTs is usually referred to as a voltage-source converter (or voltage-sourced converter). The additional controllability gives many advantages, notably the ability to switch the IGBTs on and off many times per cycle in order to improve the harmonic performance, and the fact that (being self-commutated) the converter no longer relies on synchronous machines in the AC system for its operation. A voltage-sourced converter can therefore feed power to an AC network consisting only of passive loads, something which is impossible with LCC HVDC. Voltage-source converters are also considerably more compact than line-commutated converters (mainly because much less harmonic filtering is needed) and are preferable to line-commutated converters in locations where space is at a premium, for example on offshore platforms.

In contrast to line-commutated HVDC converters, voltage-source converters maintain a constant polarity of DC voltage and power reversal is achieved instead by reversing the direction of current. This makes voltage-source converters much easier to connect into aMulti-terminal HVDC system or “DC Grid”. HVDC systems based on voltage-source converters normally use the six-pulse connection because the converter produces much less harmonic distortion than a comparable LCC and the twelve-pulse connection is unnecessary. This simplifies the construction of the converter transformer. However, there are several different configurations of voltage-source converter and research is continuing to take place into new alternatives.

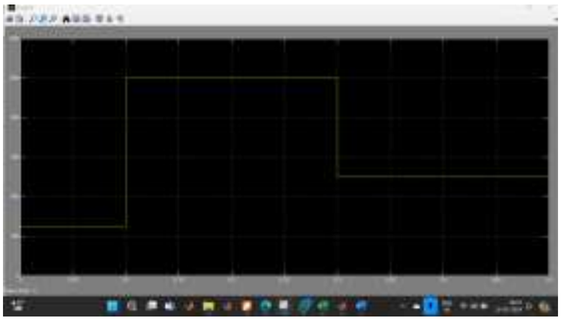
VII.SIMULATION RESULTS



Simulation circuit



Wind speed vs time

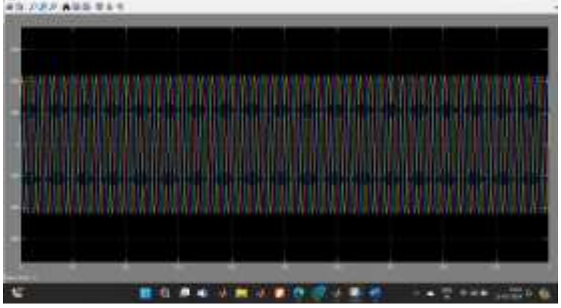


Solar panel input temp vs time

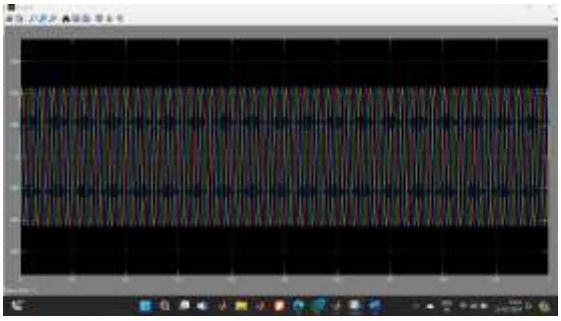
Pv voltage vs time

Wind voltage vs time

Inverter output voltage vs time before filtering



Inverter output voltage after filtering



Grid voltage vs time

VIII.CONCLUSION

In this paper, we have presented the design and implementation of a Wind-PV-Battery based hybrid energy system optimized for standalone AC microgrid applications using a Fuzzy Logic Controller (FLC). The integration of wind and photovoltaic (PV) renewable energy sources with battery storage has demonstrated significant potential in ensuring a reliable and efficient energy supply, particularly in remote and off-grid areas where traditional power grid extension is not feasible.

The Fuzzy Logic Controller, tailored to handle the inherent uncertainties and nonlinearities of renewable energy sources, has proven effective in optimizing power generation and management within the hybrid system. By mimicking human reasoning and decision-making processes, the FLC adapts to varying environmental conditions, ensuring stable and efficient operation. Simulation and experimental results validate the proposed system's ability to maintain a stable power supply, improve energy efficiency, and reduce reliance on conventional power sources.

Variability in weather conditions and intermittency of renewable energy sources pose operational challenges that require sophisticated control strategies and energy storage solutions for optimal performance. Moreover, economic feasibility and policy support are essential factors for the widespread adoption of such systems. Overall, this research contributes valuable insights into the design, optimization, and implementation of grid-connected solar-wind hybrid power systems, highlighting their role in transitioning towards a more sustainable and resilient energy future. Continued research and innovation in this field are imperative to address remaining challenges and accelerate the global transition to renewable energy.

REFERENCES

1. Khan, M. J., Iqbal, M. T., & Qu, Z. (2010). Microgrids: A review of technologies, key drivers, and outstanding issues. Renewable and Sustainable Energy Reviews, 15(9), 4834-4846.
2. El-Fouly, T. H., Salama, M. M., & Chikhani, A. Y. (2010). Wind energy conversion systems: A technical review. Renewable and Sustainable Energy Reviews, 14(1), 125-152.
3. Hameed, Z., & Hasan, S. M. (2015). Design, Simulation, and Analysis of a Solar-Wind Hybrid Energy System. Procedia Computer Science, 62, 210-217.
4. Pandiarajan, N., Muthu, R., & Manikandan, M. R. (2019). Design and analysis of solar wind hybrid energy system. Materials Today: Proceedings, 18, 4295-4300.
5. Chandel, S. S., Naik, M. N., & Chandel, R. (2015). Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. Renewable and Sustainable Energy Reviews, 49, 1084-1099.
6. Farhat, I. A., Kordab, A. M., & Abdelhadi, F. A. (2018). Comparative study of three topologies for wind energy conversion system with MPPT fuzzy logic control. Ain Shams Engineering Journal, 9(1), 157-166.
7. Ponnalagar, V. P., & Rajasekaran, V. (2019). Simulation and analysis of solar wind hybrid energy system with MPPT techniques using CUK converter. Materials Today: Proceedings, 18, 2327-2334.
8. Wu, J., Hu, Y., & Wang, L. (2017). Coordinated control of a grid-connected solar–wind power system based on fuzzy logic and a back propagation neural network. Energies, 10(5), 710.
9. Moradzadeh, M., & Ehsan, M. (2019). Fuzzy sliding mode control of solar-wind hybrid energy systems with MPPT algorithms. Energy Conversion and Management, 180, 195-204.
10. Li, Y., Chen, B., & He, G. (2015). Neural network based maximum power point tracking control for wind generation system with DFIG. Energy Procedia, 75, 866-871.
11. Varshney, P., Khatod, D. K., & Mishra, S. (2016). Energy management and optimization of a standalone solar-wind hybrid energy system. Procedia Computer Science, 78, 212-219.