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ORIGINAL

Realizing smart microgrid electricity solutions for rural communities using a hybrid microgrid system based on renewable energy sources

Realización de soluciones inteligentes de microrred eléctrica para comunidades rurales mediante un sistema híbrido de microrred basado en fuentes de energía renovables

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ABSTRACT

Hybrid renewable energy sources are combined in microgrids to feed rural areas and remote locations where grid power is unavailable. This study aims to feed remote areas and newly established projects or factories far from the power source using renewable energy sources to continuously satisfy various load demands and supply power. A smart microgrid design is proposed for a hybrid system that includes solar energy with an artificial neural network (ANN), a wind turbine, an energy storage system that stores energy in a photovoltaic battery and uses it when needed, and an emergency diesel generator. To verify the effectiveness of the proposed approach, a mobile generation station consisting of diesel generators, solar PV systems, wind turbines and an energy storage system that stores energy in a bank of batteries is designed as an additional service source in MATLAB Simulink. The model has a capacity of 1MW and can handle loads of up to 800KW. With ANN, a stable output voltage solar without ripples was obtained. Load priority algorithm (LPA) was also used to coordinate between three loads: High, Medium, and Low Load priority, and the actual diamond for each load was achieved. The first load with the highest priority was fed 100 %, and the remaining loads were fed to cover their needs, proving the design's validity. It demonstrates the effectiveness of the proposed solution in mitigating power outages. The station can serve all loads by using renewable energy sources (RES) to meet the energy demands of the loads.

Keywords: Microgrid; RES; SoC; ANN; LPA.

RESUMEN

Las fuentes de energía renovables híbridas se combinan en microrredes para alimentar zonas rurales y lugares remotos en los que no se dispone de energía de red. El objetivo de este estudio es alimentar zonas remotas y proyectos o fábricas de nueva creación alejados de la fuente de alimentación utilizando fuentes de energía renovables para satisfacer de forma continua diversas demandas de carga y suministrar energía. Se propone un diseño de microrred inteligente para un sistema híbrido que incluye energía solar con una red neuronal artificial (RNA), un aerogenerador, un sistema de almacenamiento de energía que almacena energía en una batería fotovoltaica y la utiliza cuando es necesario, y un generador diésel de emergencia. Para comprobar la eficacia del planteamiento propuesto, se diseña en MATLAB Simulink una estación de generación móvil compuesta por generadores diésel, sistemas fotovoltaicos solares, turbinas eólicas y un sistema de almacenamiento de energía que almacena energía en un banco de baterías como fuente de servicio adicional. El modelo tiene una capacidad de 1 MW y puede manejar cargas de hasta 800 kW. Con la RNA se obtuvo una tensión de salida solar estable y sin ondulaciones. También se utilizó el algoritmo de prioridad de carga (LPA) para coordinar las tres cargas: Alta, Media y Baja prioridad de carga, y el diamante real para cada carga se logró. La primera carga con mayor prioridad se alimentó al 100 %, y el resto de cargas se alimentaron para cubrir sus necesidades, demostrando la validez del diseño. Esto demuestra la eficacia de la solución propuesta para mitigar los cortes de energía. La estación puede dar servicio a todas las cargas utilizando fuentes de energía renovables (FER) para cubrir las demandas energéticas de las cargas.

Palabras clave: Microgrid; RES; SoC; ANN; LPA.

INTRODUCTION

The reality is that energy access is critical to society's overall growth and elevated demand for electrification. Enormous efforts are being made to put the globe on the path of social, environmental, and economic sustainability. As fossil fuel plants continue to have an increasingly negative impact on the environment, Researchers are putting a lot of effort into coming up with ways to eliminate pollution worldwide. Promoting the development of renewable energy source technology is one such action. Recently, the Iraqi government became a part of the Paris Climate Agreement, which attempts to lower global warming.[1] The government now encourages large and small consumers to participate in power production using renewable energy sources. Electricity is one of the main remedies to change people's energy situation from lack of energy to complete energy provision, especially in remote or rural areas. Two strategies could be implemented for electricity in rural areas: Grid-connected and off-grid modes. First, a new building can be added to the current one to link the village with the central city.[2] More time and money must be invested in this. The second plan is centred on enabling off-grid energy access from renewable energy sources. When using off-grid mode, an uninterrupted continuous power source can be provided via a hybrid system that combines solar biodiesel production with battery banks as a backup. With developments in solar photovoltaic technology and a range of inverters and controllers, renewable energy is more suitable for electrifying remote rural areas and agricultural fields. Recent years have seen a gradual exploration of solar PV-based mini and microgrids because of their benefits, which include an abundance of energy, environmental factors, and simple power withdrawal due to the absence of a rotating component. Various Maximum Power Point Tracking (MPPT) methods are being utilized and investigated to harvest more power from photovoltaic systems. Several investigations, including those using artificial intelligence techniques, hill climbing, perturbation and observation (P&O), and incremental conductance (IC), have been conducted to look into effective MPPT methods.[3] The growth of rural areas depends heavily on electricity, particularly in developing nations. Conventional energy sources like coal and fossil fuels are used to generate power. Because of the rising demand, power consumption is rising daily, causing traditional sources to run out. So, to keep up with the growing demand, power must be produced. Therefore, renewable energy sources offer a remedy to this power generation problem, and they are reliable, eco-friendly, and free of cost. Additionally, remote area electricity distribution is essential for economic growth, better living conditions, the creation of jobs, and the elimination of poverty. In remote areas, the majority of people experience issues with power outages. Due to the traditional power grid's distance from the considered location, there is poor power quality and frequent power outages. Due to the reduced possibility for economic growth, it is not practicable or affordable to expand the utility grid to isolated rural areas. Therefore, implementing a smart microgrid hybrid renewable energy system (HRES) can help these regions overcome energy-related problems. Under such circumstances, the most common ways to economically meet electrical load demands have been via PV arrays, wind turbines, and diesel engines, which Are viable and reliable power sources.[4] Those who live in rural places can receive reliable, affordable power with this grid-independent HRES. Furthermore, the stand-alone HRES developed in urban and rural areas may increase economic growth and electricity use while resolving issues related to limited fossil fuel supplies.

Much study has been done on HRESs and smart microgrids incorporating two or more renewable energy sources. Furthermore, a wealth of research demonstrates the advantages and difficulties involved. The earlier research by José Luis Domínguez-García et al.[5]. This study makes a proposal based on research conducted in northeastern Romania, investigating how such a system behaves experimentally under actual operational circumstances, considering photovoltaic and wind energy as two sustainable energy sources. There are three different situations based on the charge state. According to the results, the battery SoC was set to 30 %, 50 %, and 70 %. The energy that can be utilized is 5,544 kWh, 3,960 kWh, and 2,376 kWh, representing 30 %, 50 %, and 70 %, respectively, of the entire storage capacity of the system of 7,920 kWh.[6] In this study, a grid-independent

Hybrid Renewable Energy Management (HREM) system was designed to cater to the electricity demands of a remote community in South India. The HOMER software tool was utilized for the analysis. A specific case of HREM, configured with a photovoltaic, wind turbine, diesel generator, and battery energy storage system, was developed to fulfil the community's residential electric load requirements. Conclusions were derived from a techno-economic-environmental analysis. The model yielded numerous feasible solutions. Sensitivity analysis determined the most effective solution from the four optimized outcomes. The results indicated that a PV + DG + BESS-based HREM was the most cost-effective configuration for the particular location.[7] To develop an optimal hybrid renewable energy system, the design incorporates a photovoltaic (PV) system with a capacity of 1476 kW, 417 batteries, an electrolyze with a total of 200 kW, 20 kg hydrogen tanks, and a 59,6 kW converter. This design is evaluated by comparing the lowest net present cost of $7,01 million and the levelized energy costs of 0,244 dollars per kilowatt-hour.[8] His paper centers on using renewable energy sources to electrify isolated remote populations. Suggests an electrification plan. In the plan, the entire town is centrally powered, Using a biodiesel generator, solar photovoltaic panels, and battery banks for storage. To lessen frequency fluctuations, the study presents the design of a frequency controller that incorporates a battery. According to the results, Reference and expected values agree, and Total Harmonic Distortion (THD) percentages are under 1 %.[9] This research described an intelligent microgrid system (MGs) using an AI-based Icos ϕ controller to integrate several microgrids with renewable energy storage for power sharing and quality enhancement. The grid is interconnected with two distinct renewable energy sources (RESs): solar for the first Microgrid and wind for the second Microgrid. This study uses an AI-based intelligent integrated controller (IIC) to manage energy by considering multiple factors, including the MGs' tariff, source current, and SoC of their batteries. The hardware prototype was used to test and validate the suggested AI-based IIC's design under all K factor scenarios, and the load current, filter current, and reference source current validate the IIC's productive function, which can be applied to new research projects. After examining the system's economic viability, it was found that its 8,7-year payback period was sufficient for an integrated renewable energy system.[10] In this scholarly article, two hybrid renewable energy systems are compared; one is off-grid and standalone, while the other is on-grid. This research was done in the northern Iraqi province of Duhok. According to the suggested system's modelling results, a hybrid solar-wind energy system linked to the local grid is more economical for a similar load than an off-grid design. The hybrid system is more cost-effective than the Duhok home power grid. Duhok residential electricity is 0,1 $\kWh. However, the system cost unit is 0,0618 $\kWh. The expansion of the smart grid has created more chances to enhance customer demand response. The cleverest methods for organizing electrical energy scheduling are taken into consideration. Drawing from analogous studies conducted on electrical systems, intelligent controller-based smart grid systems that integrate multiple microgrids (MGs) with the grid without compromising power quality will be essential for future generations. The previous works presented did not address all aspects, and our study dealt with the use of ANN with solar energy and LPA to coordinate loads, which needed to be discussed in those studies.

This paper will focus on developing a smart microgrid system with renewable energy sources, including an ANN-enabled photovoltaic system, a wind farm, an energy storage system, and an emergency diesel generator. LPA is used to coordinate between loads and battery charging. This paper is organized as follows: the first section is about smart microgrid systems, the second section presents the suggested approach, the third section deals with simulation results, and the final section describes the conclusion.

Smart Microgrid Systems

A smart microgrid system is a grouping of several intelligent microgrids connected by a powerful controller. As shown in figure 1, it can be operated independently or connected with the grid. The smart microgrid system includes a range of energy sources, both renewable and non-renewable, together with load centers for the commercial, industrial, and residential sectors.

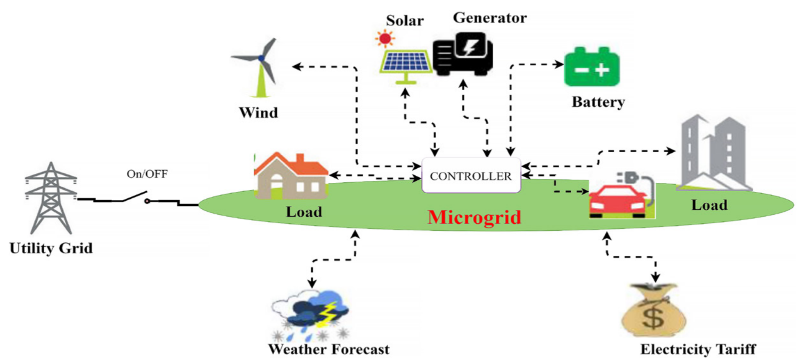

Figure 1. Smart microgrid systems

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To manage electric power systems in real-time, Data analytics and artificial intelligence (AI) techniques are required to analyses the obtained consumer energy usage data and weather forecasts for various RESs. The AI-based controller processes information from the power users in conjunction with additional modules like power flow management and tariff control.

Energy Management Strategy

With the aid of the test platform's equipment (MPPT converters and inverters), the amount of energy generated by the two renewable sources is calculated in figure 2. The HRES operation flowchart is shown. As a result, the total power production (P_{PV} + P_{WT}) and the consumer's (P_L) needed power level are balanced in the storage system.[11]

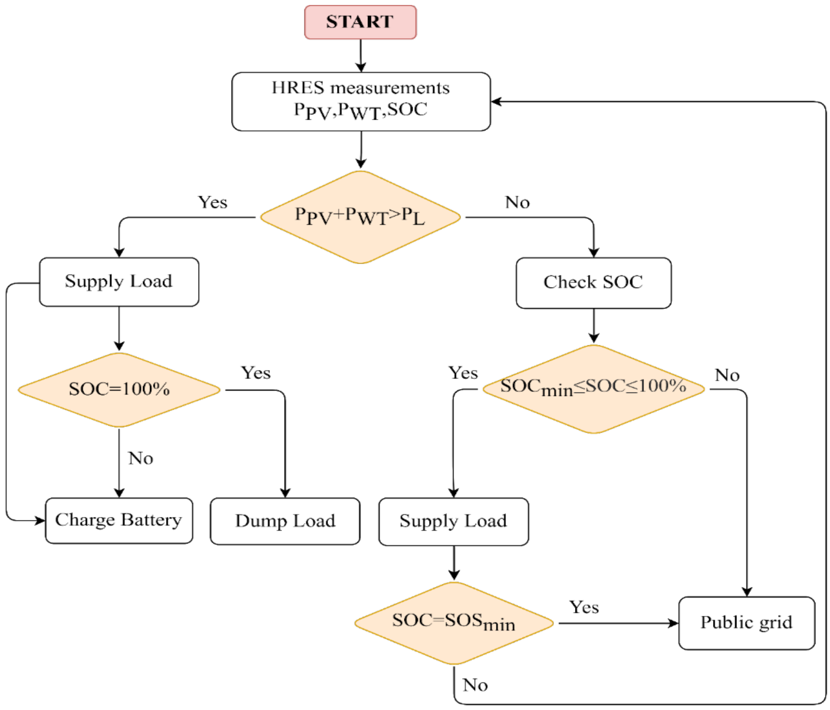

Figure 2. Flow chart of hybrid renewable energy system

Consumers are fed if $P_{PV} + P_{WT} > P_L$, and the surplus energy is utilized to charge the battery. There will be extra energy that dissipates on a dump load if the load threshold of 100 % is achieved. If $P_{PV} + P_{WT} > P_L$, the batteries' level of charge is determined, and the consumers are fed if it is higher than the minimum value (SOC_{min}) set in the scenario undergoing analysis. In this scenario, the energy generated (partially) by renewable sources and stored in the batteries will be delivered to the users. Suppose the battery's minimum charge threshold (SOC_{min}) is achieved, and the combined energy output from the two sources is insufficient to meet the users' needs. In that instance, energy is obtained from a backup energy production source, such as a diesel generator.

Artificial Neural Network ANN

An artificial neural network (ANN) is a complex network of interconnected nodes that can simulate the functioning of the human brain. ANNs are among the most celebrated machine learning models and present significant advantages in learning complex non-linear relationships. The block diagram of ANN is shown in figure 3.

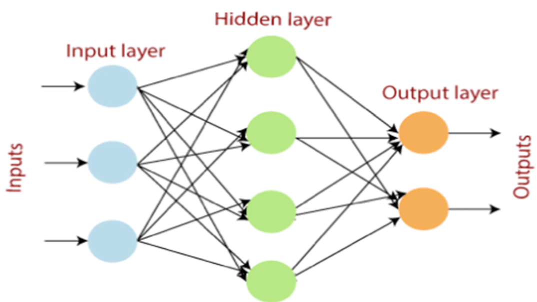

Figure 3. Block diagram of ANN

ANNs have found application in many areas within smart grid research, such as asset management, energy management systems, forecasting techniques, security and reliability evaluation, state estimation, and data-driven decision-making systems. ANNs are used in smart grids to predict energy consumption patterns, considering various factors such as time of day, weather conditions, and historical data.(12) Using ANNs in smart grids aims to optimize energy usage and improve the grid's stability. ANNs have also been used for load forecasting in smart grids, essential for efficient energy management. ANNs are employed in smart grid optimization by implementing the algorithm of ANNs. However, Substantial obstacles persist in the realm of information administration and data confidentiality, along with the susceptibility and resilience of these methods to malevolent data.

Suggested System

The solar system generates energy when the sun rises (when the sky is clear). On the other hand, wind systems will replace solar panels at night and on very cold, often cloudy days to fill the shortage of electrical energy. Here is a design of a smart microgrid for a hybrid system that includes solar with ANN, wind turbines, and an energy storage system that stores energy in a photovoltaic battery and uses it when needed, as well as an emergency diesel generator, as shown in figure 4. When the amount of energy produced by renewable sources is decreased, when energy demand is at its highest, a diesel generator serves as a backup source to continually produce and supply electricity to consumers. The design is a mobile renewable energy station that serves and feeds remote areas far from the power source (the local grid) and newly established projects such as laboratories, factories, and agricultural fields, which often find it difficult to deliver electrical power to them. The suggested smart microgrid configuration uses a PV system, wind turbine, battery energy storage system, diesel generator, and power converter. Consideration was given to three distinct electric load buses working with a load priority system to ensure that electrical power was supplied to a load of most significant importance continuously and without interruption. The diesel generator was connected to the alternating current (AC) busbar, while the PV system and Wind turbine systems used the power converter to connect it to the direct current (DC) busbar.

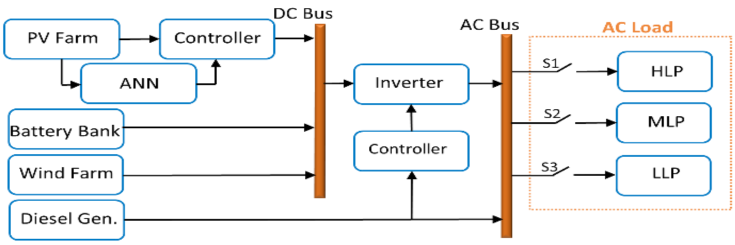

Figure 4. Block diagram of Suggested system

The solar PV and wind turbine systems generate DC electricity. The power outputs were thus controlled using a DC/DC power converter. The energy storage system was designed to store any extra power produced by any power-generating sources in HRES; the energy stored in the batteries can be used without energy. The smart microgrid schematic diagram in figure 4 illustrates the visual flow of energy from the generating units to electric loads via the power conversion systems.

The ANN Controller of PV consists of six layers, shown in figure 5.

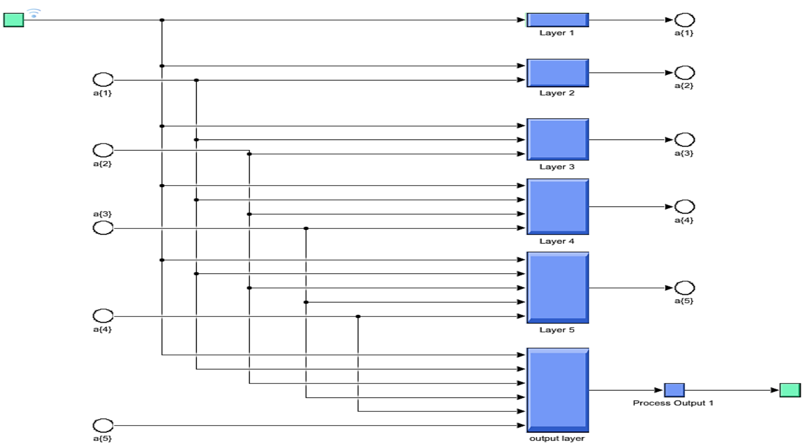

Figure 5. Model of ANN

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The block diagram of the wind turbine shows three-phase synchronous machines connected to the rectifier to convert the machine's output to the DC output to control it, as shown in figure 6.

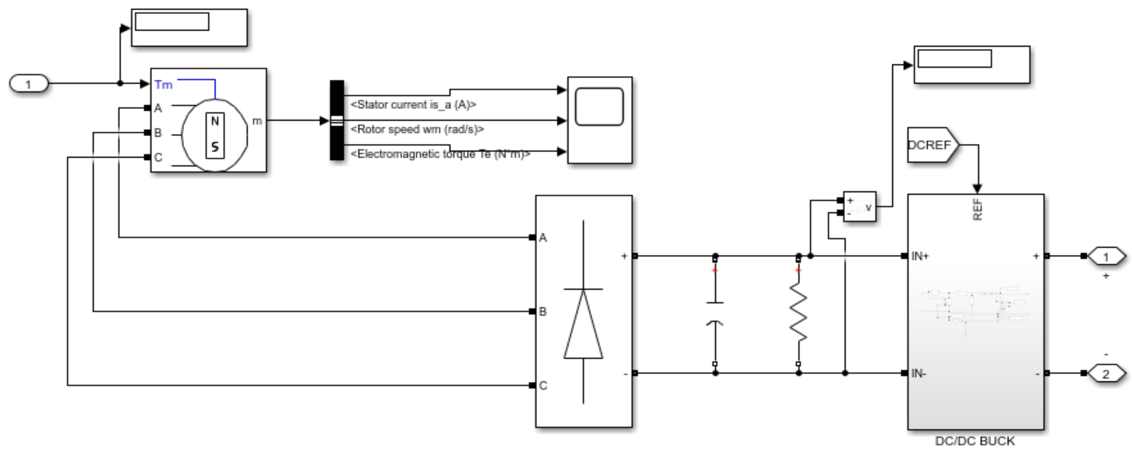

Figure 6. The block diagram of the wind turbine

The DC-DC buck circuit design operates as a voltage stabilizer for wind turbine as shown in figure 7.

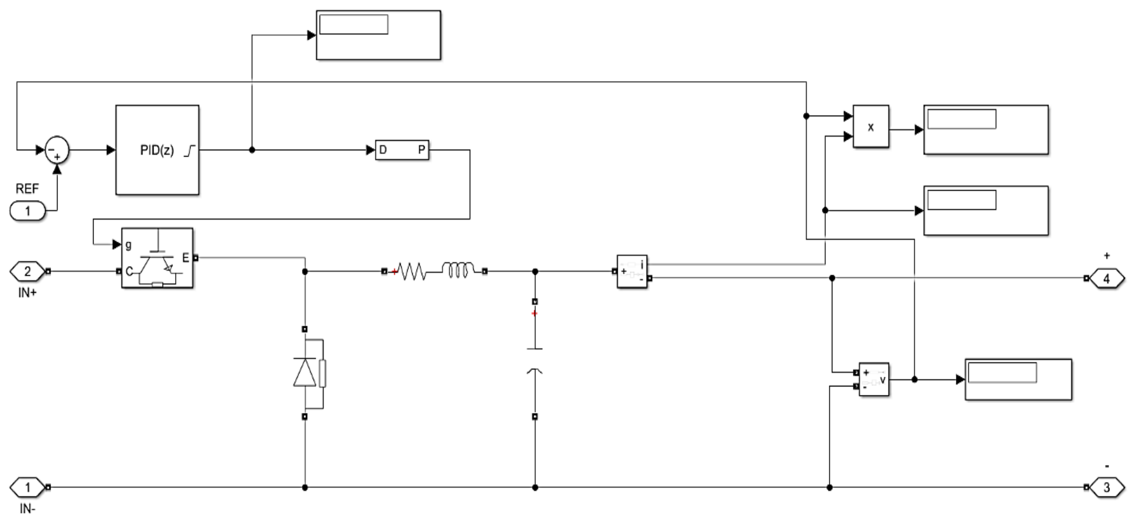

Figure 7. Model of DC-DC buck circuit

The structure of the inverter consists of two upper switches and two lower switches for one phase, as shown in figure 8.

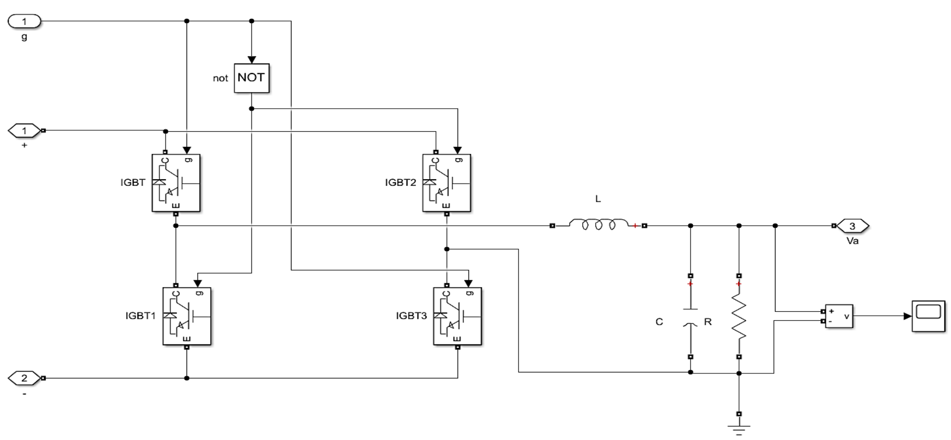

Figure 8. Model of Inverter

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Simulation and Result

Smart microgrid simulation is a technique used to explore the opportunities and drawbacks of smart microgrids, which are a promising concept for structuring the future power grid. The MATLAB Simulink can be used to model, simulate, and optimize the performance of the individual grid components and the grid system. Our simulation model depicts the design of a smart microgrid through MATLAB Simulink, as shown in figure 9, which emulates a hybrid renewable energy system comprising a solar farm and wind energy, along with an electrical energy storage system that employs batteries to store excess electrical power and utilize it when required, in addition to a diesel generator. A solar farm is a large group of photovoltaic cells that convert solar radiation into clean electrical energy at sunrise and when the sky is clear. Wind energy consists of a group of turbines that convert wind energy into electrical energy.

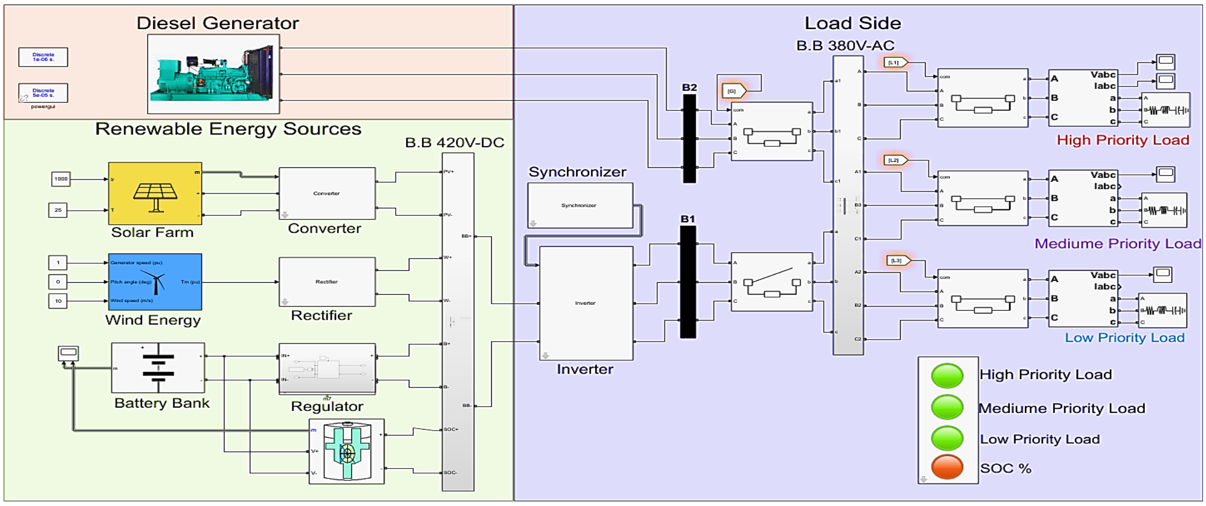

Figure 9. Smart Microgrid MATLAB Simulation

The increase in wind speed leads to increased energy production rates from turbines. Solar panels are made from semiconductor materials and convert sunlight to DC electricity. A solar PV cell's practical efficiency is about 17 %, although its theoretical efficiency can range from 25 % to 30 %. Reflectors, positioned at a 60-degree angle to reflect light toward the panel, can be utilized to optimize the amount of sunlight that reaches solar panels.

Wind turbines harness the kinetic energy in the wind to produce mechanical energy. They can be categorized into two basic types based on the axis around which the turbine rotates. Combining wind turbines and solar panels offers significant advantages for generating green energy. The synergy between wind and solar power maximizes energy output and enhances energy generation. This combination increases efficiency, reliability, and flexibility. The capacity of the solar farm is 1 Mw, and the wind energy is 1,5 Mw. In contrast, the ability of the diesel generator is 1Mw, which is considered an available energy source ready to fill the electrical energy deficit, as well as any emergency that occurs with renewable energy sources. On the other side, i.e., the side of the load, we assumed the presence of three electrical loads: a load of utmost importance, a load of medium importance, and a light load, so that priority is given to the first load, which must be fed continuously and without interruption. Figure 10 demonstrates a MATLAB simulation diagram of a photovoltaic system with ANN.

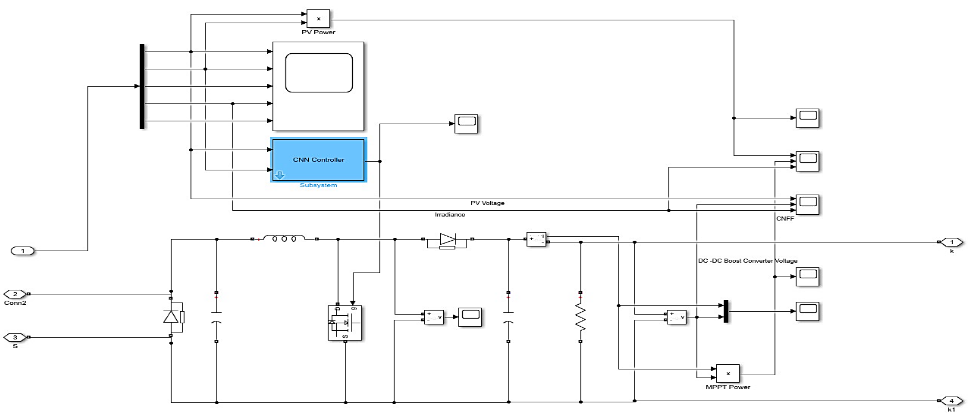

Figure 10. Simulation Diagram For DC-DC Boost Converter

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The output plus width modulation of the ANN controller controls the output voltage of the DC-DC converter according to the status PV, as shown in figure 11 below.

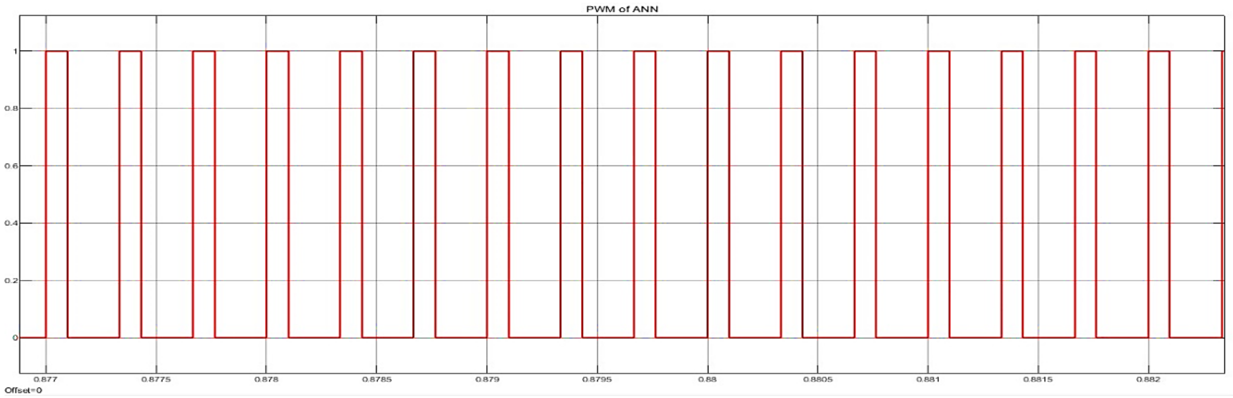

Figure 11. PWM of Artificial Neural Network

The output voltage of the DC-DC Boost converter also notices the stability of the DC with time that is free of voltage ripple, which indicates the accuracy of the ANN and the correctness of its work with the Boost converter, as shown in figure 12 below.

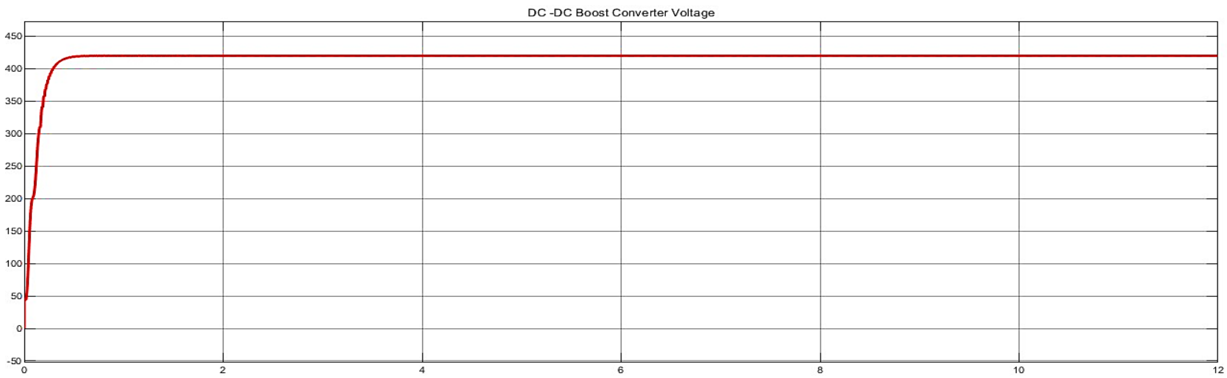

Figure 12. DC-DC Boost Converter Voltage

Solar irradiance is high during mid-day, so solar PV power output also increases during this time, figure 13. Below is the solar PV active power(w).

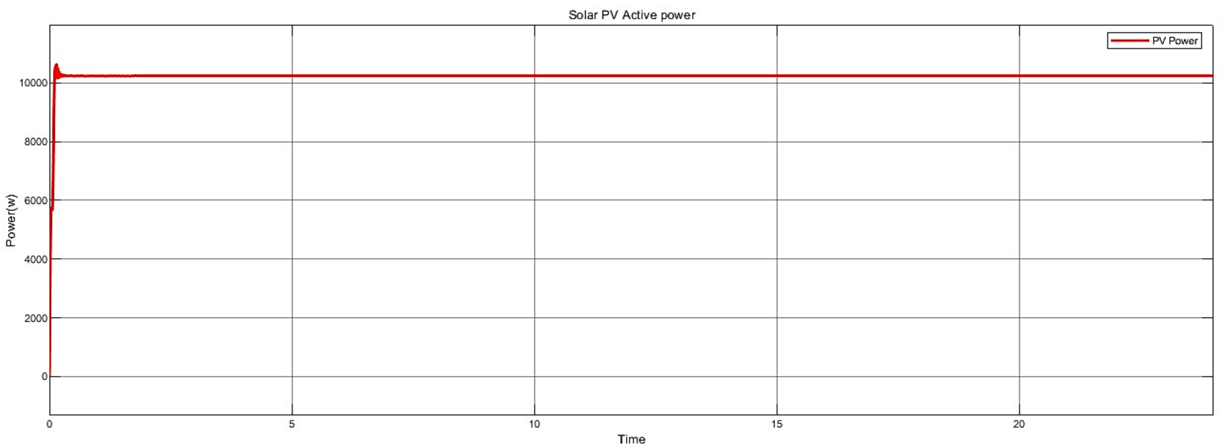

Figure 13. Solar PV Active Power

The output of three-phase AC voltage 380V and frequency 50 HZ is shown in figure 14 below.

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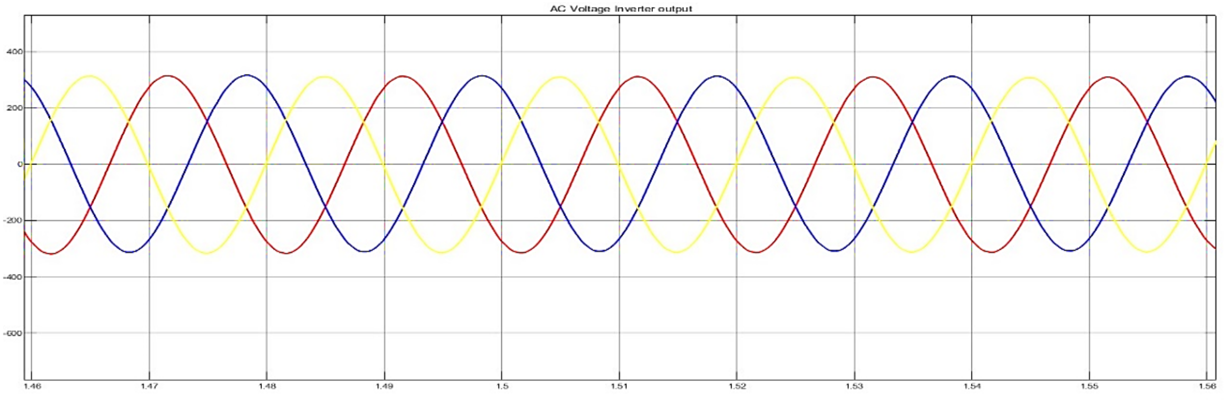

Figure 14. Three-Phase AC Voltage Inverter Output

The LPA monitors the state of the energy resulting from sources. All loads are fed when sufficient power is available. However, sufficient energy is unavailable. Load 1 is delivered continuously throughout the day. The second load is provided most of the time, and the feeding source is separated from load 3 for a few periods, as shown in figure 15 below.

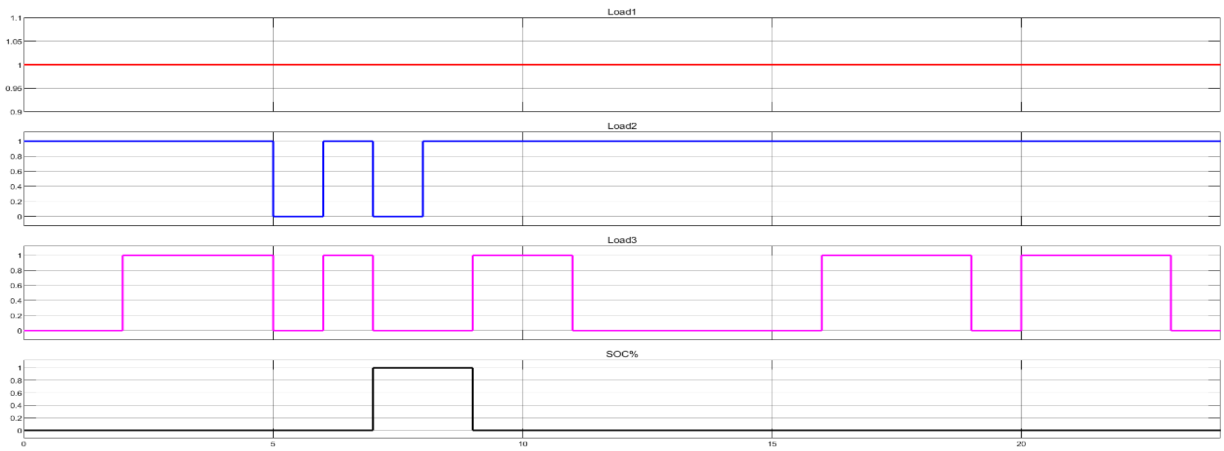

Figure 15. Load Status Throughout the day

CONCLUSIONS

The model proposes establishing a mobile station to alleviate the shortage of electrical energy and a promising solution for supplying remote areas with electrical power. A smart hybrid PV–wind–based microgrid system is modelled, simulated, and analyzes in this work. MATLAB software was used for modelling and simulation. The ANN controller was used in the PV system to extract the most power by making constant output DC voltage without any ripple. LPA was used to coordinate between three loads, and the actual diamond for each load was achieved according to its priority, such as the first load was continuously fed as compared to other loads. Additionally, it was to save energy to 400 kw by charging the battery when power was available and using it when needed. The microgrid produces 1MW as output power. The presented results confirm the effectiveness and suitability of the system's operation and its applicability in addressing power outage issues.

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The authors declare that there is no conflict of interest.

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Data curation: Murtadha Hameed Jabbar, Ahmed Kareem Abdullah, Faris Mohammed Ali.
Formal analysis: Murtadha Hameed Jabbar, Ahmed Kareem Abdullah, Faris Mohammed Ali.
Research: Murtadha Hameed Jabbar, Ahmed Kareem Abdullah, Faris Mohammed Ali.
Methodology: Murtadha Hameed Jabbar, Ahmed Kareem Abdullah, Faris Mohammed Ali.
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