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DESIGN AND SIMULATION OF WIND TURBINE ENERGY SOURCES FOR A CELLULAR BASE STATION IN A RURAL AREA

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Abstract- The increasing demand for wireless communication services in rural areas has necessitated the installation of more base stations. The challenge in these regions is to provide a reliable and sustainable energy source for the base stations. For powering these stations, wind turbines have emerged as a feasible option. With the growing demand for cellular network coverage in remote areas, it is important to consider sustainable energy solutions that can provide reliable power to these locations. In this study, wind turbines are investigated as a potential source of renewable electricity for rural areas' cellular base stations. By analyzing the feasibility, cost-effectiveness, and technical requirements of implementing wind turbine energy systems for base stations, this paper provides recommendations for future deployments in rural environments. The results of this research demonstrate the potential for wind turbines to significantly aid in conquering the obstacle of powering rural cellular base stations. In distant areas, it is difficult to offer dependable mobile phone service without a consistent power source. Mobile towers and Base Transceiver Stations now use traditional diesel generators with battery banks for backup power (BTSs). The design, installation, and testing of a system that integrates wind turbines with a cellular base station will be the main topics of this paper. The system will be designed to optimize the energy generation from the wind turbines and provide a reliable and sustainable power source for the base station. The project will also consider the challenges associated with installing and maintaining wind turbines in rural areas, such as the lack of infrastructure and access to maintenance services. Simulation results indicate that compared to the use of a standard diesel generator, a hybrid energy system may significantly cut power generation expenses and greenhouse gas emissions.

Keywords: Wind Turbine, Diesel Generator, Energy Source, Renewable Energy, Wind Power, Wind Generation, Inverter.

1. INTRODUCTION

Off-grid power systems, also known as standalone or independent systems, are constructed from the ground up to provide remote places with energy. Off-grid systems differ greatly in size and functionality since they are not connected to the normal power grid [1]. Energy may be produced by hybrid power systems from a variety of sources, including wind turbines, solar panels, micro hydropower generators, and conventional generators. Hybrid power systems have become more popular in recent years. In addition, power electronics and an energy storage battery bank are included in the design. Implementing RES [1-4] comes with a plethora of benefits, some of which include having instant and uninterrupted access to energy whenever it is required, being less susceptible to swings in the price of oil and the cost of transporting fuels, increasing economic output, and fighting climate change. Individuals' professional and personal lives have been profoundly altered owing to the expansion of communication networks.

Wind energy has proven to be an effective and sustainable source of power, with numerous benefits including low operating costs, low emissions, and low dependence on fossil fuels. However, the implementation of wind turbine energy systems for cellular base stations in rural regions presents several technical and logistical challenges that need to be addressed. This paper's goal is to examine the viability and cost-effectiveness of, and technical requirements of using wind turbines as a source of energy for powering cellular base stations in rural regions [5-7].

Wind turbines are machines that use the kinetic energy of the wind to produce electricity. They are a crucial factor in lessening our reliance on fossil fuels and have gained popularity as a source of renewable energy. Wind turbines typically consist of three main components: the nacelle, which houses the generator, gearbox, and other electrical components; the rotor, which is made up of blades that catch the wind; and the tower, which holds up the nacelle and rotor. Wind causes the rotor blades to revolve, turning a shaft that powers the generator to generate electricity. The efficiency of wind turbines relies on several variables, including wind direction and speed, wind turbine location, tower height, and the design of the rotor blades. Modern wind turbines are capable of producing electricity at competitive prices and have a low environmental impact.

Wind turbines are commonly used in large wind farms, where multiple turbines are grouped to produce a significant amount of electrical energy. They can also be used in small-scale installations, such as in remote villages or individual homes. In addition to reducing greenhouse gas emissions, wind turbines have several other benefits, such as creating jobs, reducing the need for expensive transmission infrastructure, and providing a reliable source of energy for communities [5, 7-11]. Overall, wind turbines are an important component of a sustainable energy future and will be crucial in solving the global issues of energy security and climate change.

In a world where so many people rely on mobile networks, telecommunications service providers need to respond to the challenge of supplying steady, cost-effective electricity to networks that are geographically dispersed and always increasing. The operation of mobile networks in Africa is hindered by several challenges and cannot reach its full potential. Only 43 percent of people living in African nations are wired into the electrical grid, making this region's electrification rate among the lowest in the world. Any location that obtains its energy from a single, centralized source is susceptible to experiencing blackouts that may last for several hours or even many days [12-14]. The production of renewable energy on the African continent, such as that derived from the sun and the wind, is an excellent match. However, fewer than 2% of Africa's renewable resources (excluding hydro) are currently being used in the production of power. As a consequence of this, it would seem that there is a significant amount of unmet potential for both large-scale renewable energy projects and more modest off-grid power systems and mini-grids [15, 16].

In addition, off-grid systems are notoriously difficult to maintain. Telecom companies are also under pressure to identify an alternative energy source for these due to the rising popularity of renewable energy technology in some geographic and the need to minimize greenhouse gas emissions. This pressure resulted from the requirement to reduce greenhouse gas emissions. In order to fulfill the demands for the typical continuous load that it must supply, a mobile base station needs to utilize a broad variety of different energy sources to be active for an extended length of time. Therefore, the development of Ethio-telecom tower sites utilizing renewable energy technology is ideally fitted to satisfy the consequent rise in demand for off-grid power supply in rural areas. This need is because rural areas are becoming more populous. The broad use of solar and wind power in Ethiopia, which are both plentiful and cost-effective to put into action, would be of great advantage to the country's underdeveloped rural areas as well as to the expanding telecommunications industry. This project intends to build a system for generating and supplying electricity to the Base Transceiver Station (BTS) that is independent of the main power grid and, if possible, uses renewable energy sources [17-19].

Since at least 5000 BC, mankind has been utilizing wind energy. In Persia and China, people used wooden wind-powered water mills to pump water and grind grain around 200 BC. When power lines were established to deliver electricity, the popularity and use of small wind turbines started to decline, and in the 1990s, new ways to harness wind energy appeared. The Wright Brothers' achievement in building the first airplane in 1903 served as the impetus for the development of commercial onshore wind turbines. About the subject of the paper, several literature reviews will be given.

A. Jahid, et al. [20] demonstrated that data-oriented services have evolved safely during the previous five years, including multimedia communication, online gaming, and HD video streaming over cellular networks, in 2018. To handle the constantly growing amount of data and users, mobile network providers had to expand their base station network (BSs). There are currently more than four million bachelor's degrees available in the world. M.J. Farooq, et al. [21], presented that the cellular networks' energy consumption has increased significantly, leading to increased opera rely costs of $22 billion in 2014. To cover more rural areas, cellular service companies are expanding their networks and breaking into new markets, but are now forced to use diesel generators to power their base stations in remote locations due to geographical restrictions and financial issues.

According to V. Chamola, et al. [22], the most economical way to power BSs in remote places is by using renewable energy produced nearby. However, because the availability of sources is so erratic and subject to alteration at any time, it is difficult to develop a functional renewable energy generating system for remote areas. Inconsistencies between the amount of energy harvested and changes in BS load might result in power outages and poorer service. K. Kanwal, et al. [23], presented that cellular network operators are under pressure to fulfill environmental conservation and OPEX reduction requirements due to the predicted economic and environmental impact of the next few years. A new field of study called "green communication" has been created to improve BSs' energy efficiency, save OPEX, and get rid of GHG emissions. Cellular network operators are attempting to implement green practices in two key ways: energy-efficient hardware and low-cost power sources.

S. Dutta, et al. [24] According to current projections, stated in 2015 that global mobile traffic is predicted to increase by 45 percent per year to 69 exabytes per month by 2020. As a result, the annual power consumption of the global telecommunications industry increased by 10% every year, from 219 Tira watts per hour in 2007 to 354 Tira watts per hour in 2012. Under this scenario, between 2013 and 2018, energy consumption will increase by 10% each year. In the study of A. Bousia, et al. [25], the telecom industry has been highlighted as the most energy-dense consumer in the ICT sector, which results in greater operational costs and greenhouse gas emissions. It is widely known that between 2.5 and 4% of the carbon dioxide emissions from the telecommunications sector are linked to global warming pollution. In light of the global decline in demand for ICT services, wireless carriers are coming under increasing pressure to reduce their energy consumption.

G.H.S Carvalho, et al. [26] reported that Due to dependability issues, high operational costs, and environmental concerns, commercial network growth and the use of diesel generators (DG) have lost their attractiveness. Rural BSs frequently employ diesel generators to supply electricity due to the commercial grid being nonexistent or unreliable. The most crucial problem for cellular carriers to reduce high costs is energy efficiency (EE). and carbon emissions while maintaining their footprint and ensuring service quality (QoS).

According to P. Gandotra, et al. [27], The amount of energy required by the ICT sector is growing exponentially, necessitating the use of renewable energy sources in place of fossil fuels because they are non-polluting, sustainable, and affordable. Transporting non-renewable energy sources is very expensive and challenging in remote BS because of the high cost of transportation and the steep terrain. H. Hassan, et al. [28] presented that Next-generation cellular networks' base stations are built to run on hybrid power, which can improve the network's overall efficiency in the long term. To improve cellular network energy efficiency (EE), A smart grid or external physical power lines may be used to distribute energy among several collocated BSs, according to researchers. Resistance power lines are very expensive to install, making them unsuitable for long-distance communication connections, enormous resistive power losses, and the correct way of limiting.

J. Gong, et al. [29] proposed the use of solar PV/WT hybrid technology to power far-flung LTE base stations, but the results showed that BS does not meet the criteria for a realistically high arrival volume. A greedy algorithm based on tempo-spatial properties is proposed as a way to reduce traditional grid energy. For macro-BSs, researchers examined the viability of a combination PV/DG/Battery power supply solution to maximize green energy use. Only renewable energy generated at the site can meet the site's needs, and BS will never compromise its performance in return for sharing green energy. However, BS energy usage might be particularly inefficient during low or off-traffic hours.

2. LIMITATIONS OF WIND TURBINES

There are several drawbacks to use wind turbines as an energy source for remote cellular base stations, including:

1. Wind Variability: The fluctuation of wind patterns is one of the main drawbacks of using wind turbines as a source of energy. Periods of minimal or no energy production may arise from this, necessitating the usage of backup energy sources or energy storage systems.
2. Initial Cost: Switching distant cellular base stations to wind turbines as an electrical source is difficult since the initial cost of building wind turbines might be considerable compared to other energy sources, such as diesel generators.
3. Maintenance and Repair: Despite having low maintenance needs, wind turbines may need specialized knowledge and tools, which can be hard to come by in isolated rural places.
4. Integration with other Technologies: In some situations, a consistent and dependable energy supply may need the integration of wind turbines with other technologies, such as energy storage systems or diesel engines. The energy system may become more expensive and complex as a result.
5. Public Perception: Because of their effects on the environment and the potential for noise pollution, wind turbines can be divisive. In some rural regions, it may be challenging to obtain the required permissions and clearances for installation.
6. Grid Connection: Wind farms may need to be connected to the grid in some cases to offer a consistent and reliable supply of energy. In remote places where grid connections may not be available or dependable, this can be difficult.
7. Installation and Maintenance: Due to the lack of access to necessary tools and expertise, installing and maintaining wind turbines in isolated rural regions can be difficult. The cost and complexity of energy system may rise as a result.

3. THE METHODOLOGY

The methodology for a wind turbine project will typically involve the following steps:

1) Site Selection and Assessment: This entails locating and assessing potential locations for the wind turbine based on elements including wind direction and strength, local laws, and the distance from the current and the electricity infrastructure.

2) Resource Assessment: This entails gathering information on wind direction and speed over a long period of period a few months to a year. The information is utilized to simulate the wind resource and estimate the wind turbine's potential for electricity production.

3) Design and Simulation: To enhance the performance and efficiency of the wind turbine, design, and simulation are used. This pertains to the layout of the rotor blades, the height of the tower, the placement of the generator, and other electrical parts.

4) Component Manufacturing and wind Turbine Construction: This includes the installation of the tower, rotor blades, and electrical components as well as the manufacture of the component parts.

5) Testing and Commissioning: This entails putting the wind turbine through a series of tests to make sure it operates safely and satisfies performance requirements. Testing in laboratories and on ground may be part of this.

6) Monitoring and Maintenance: This entails continuing to watch the wind turbine for any potential difficulties as well as routine maintenance to maintain the device's dependability and longevity.

While using wind turbines as a source of power for remote cellular base stations has numerous advantages, there are also significant disadvantages that must be considered when determining whether it is viable and feasible to do so.

4. WIND TURBINE CONDITIONS

The majority of the time, wind turbines are employed to produce electricity. Wind power is a popular, ecologically beneficial energy source that can replace burning fossil fuels. In the past, wind energy was used to drive sails, windmills, and wind pumps. Nowadays, wind energy is primarily used to generate electricity. Wind farms are collections of independent wind turbines linked to the electrical power transmission network. In this part, the most important basic equations for designing any wind energy system will be discussed.

4.1. The Swept Area

The swept area of a wind turbine is a crucial design parameter, as it determines the amount of wind energy that can be captured by the turbine blades. The Equation (1) for the swept area is;

$$A = \pi r^2 \tag{1}$$

where, r is the square meters of the swept area and m is the radius of the rotor blades in meters. Simply said, the swept area is the sphere that is swept by the spinning blades as they move with the wind. More wind energy can be collected by the turbine with a larger swept area. Therefore, either lengthening the blades or adding additional blades to the rotor will often increase the swept area. The structural stresses on the turbine also rise as the swept area grows, therefore this must be taken into consideration while designing the turbine.

4.2. Wind Speed

For wind turbines, wind speed is a crucial design factor since it affects how much energy the turbine can produce. It is customary to measure Given that wind speed varies with height, what the wind speed is at a 10-meter height, However, because wind turbines are often installed on towers that are higher than 10 meters, the wind speed at the height of the turbine hub must be calculated using the equation for the power law of the wind.

The equation represents the power law for the wind profile, Equation (2):

$$V = V_{ref}\left(\frac{H}{h_{ref}}\right)^{\alpha} \tag{2}$$

where, V, where V_{ref} is the wind speed at height H, and is the wind speed at reference height h_{ref}. (often 10 meters), and is the exponent for the wind profile, which is influenced by the abrasiveness of the terrain. A common exponent value is between 0.1 and 0.4, where the lower values indicate smoother terrain. The Betz limit, which is the highest potential quantity of energy that may be taken from the wind, is another crucial wind speed equation for wind turbines. The Betz limit formula is in Equation (3);

$$C_p \le \frac{16}{27} \le 0.5923 \tag{3}$$

where, C_p is a measure of the turbine's efficiency known as a measure of power. The turbine's power to weight ratio, or power coefficient actual power output to its highest feasible output calculated using the Betz limit. When a wind turbine's power coefficient is near to the Betz limit, it is said to be working at its most effective capacity.

4.3. The Aspect Ratio

A design parameter for wind the turbine blades, aspect ratio affects the efficiency and form of the blades. The aspect ratio is determined in Equation (4): where the chord length is the breadth of the blade and the rotor blades' radius is equal to the blade length.

$$AR = R/c \tag{4}$$

where, R is the rotor blades' radius, c is their chord length, and AR is their aspect ratio. When the aspect ratio is high, the blades are long and narrow, and when it is low, the blades are short and broad.

High aspect ratio blades are often more effective because they have a greater lift-to-drag ratio, which enables them to provide more lift while generating less drag. High aspect ratio blades might be more vulnerable to wear and wind gust damage due to their increased flexibility. On the other side, blades with a low aspect ratio are more robust and can support heavier weights, but they may not provide lift as well.

The ideal aspect ratio for a wind turbine blade relies on a number of variables, including wind speed, blade size and weight, and intended power output. For a particular application, wind turbine designers often utilize computer models and wind tunnel tests to optimize the aspect ratio and other blade characteristics.

4.4. Speed-to-Tip Ratio

An element of the design that enhances the tip-speed ratio measures a wind turbine's efficiency. The equation may be used to compute it by dividing the blade tip speed by the wind speed (5);

$$\lambda = V_{tip}/V_{wind} \tag{5}$$

where, λ is the tip speed ratio, V_{tip} denotes the speed of the blade tip, V_{wind} denotes the wind speed, and denotes the tip speed ratio.

The quantity of energy that can be taken from the tip speed ratio is an important measure since it determines the wind. When the blade tip is traveling faster than the wind, the tip speed ratio is high, which enables the turbine to harness more wind energy. Too high of a tip speed ratio, however, might cause the blade to stop and lose effectiveness. A low tip speed ratio, on the other hand, indicates that the blade tip is moving more slowly than the wind, which may lead to poor power production.

The ideal tip speed ratio relies on a number of variables, including the blade size and weight, the planned power output, and the wind's velocity. For most wind turbine designs, tip speed ratios between 6 and 8 are often regarded as ideal. The tip speed ratio and other blade characteristics are often optimized for a particular application by wind turbine designers using computer models and wind tunnel tests.

4.5. The Solidity

The quantity of blade material per unit area of swept area is a design factor related to the solidity of a wind turbine blade. The Equation (6) for it states that it is the proportion of the swept area of the rotor to the total blade area:

$$\sigma = BA/SA \tag{6}$$

where, σ is the solidity, *BA* (blade area) is the total area of the blades (both sides) and *SA* (swept area) is the area of the circle swept by the blades as they rotate.

If the solidity is, the entire area of the blades (both sides), and the circle's area that is swept by the rotating blades are denoted by the terms blade area and swept area, respectively. A blade with a greater solidity will be thicker and contain more material per square inch of swept surface. This may lead to greater structural stability in the blades and enable them to withstand greater wind loads, but it may also increase drag and reduce efficiency. Less material per unit of swept area and narrower blades are indicators of poorer solidity. As a result, efficiency may rise and drag may be reduced, but the blades may become more vulnerable to damage from strong winds.

The ideal solidity relies on several variables, including the wind speed, the weight and size of the blades, and the intended output of power. Solidities between 0.05 and 0.15 are often found in the majority of wind turbine designs. To maximize the solidity and other blade characteristics for a particular application, wind turbine designers often conduct computer models and wind tunnel tests.

4.6. The Wind Power

Blade tip speed is calculated as in Equation (7);

$$V_{tip} = \pi \times R \times \omega \tag{7}$$

where, V_{tip} is the blade tip speed in meters per second, *R* is the rotor blade radius and ω is the rotational speed of the turbine blades in radians per second.

Rated power is defined as in Equation (8);

$$P = 0.5 \times rho \times A \times C_p \times V^3 \times \eta \tag{8}$$

where, *P* is the wind turbine's rated power output and is the generator efficiency, *rho* is thermal resistivity, *A* is a swept area, *Cp* is the power coefficient, *V* is the voltage and η presents the efficiency.

The lowest and highest wind speeds are cut-in and cut-out, respectively, at which a wind turbine will start and stop working. The particular turbine type and the site circumstances are generally what decide these speeds. Size of the turbine tower: The rotor diameter often determines the height of the turbine tower, which is generally engineered to optimize power production while reducing structural stresses. To determine the ideal tower height for a certain rotor diameter and site circumstances, empirical formulae are available.

4.7. The Torque

A wind turbine's torque is a measurement of the rotational force generated when the blades spin against the wind. It is provided by Equation (9), which means the product of the force of the wind acting on the blades and the radius of the rotor.

$$T = 0.5 \times \rho \times A \times V^2 \times C_P \times R \tag{9}$$

where, *T* is the torque, the air density, and swept area of the rotor blades are *A*, *V*, C_p, and *R*, respectively. The C_p measures the power coefficient, which compares the amount of wind power that is retrieved with the power that is really in the wind.

The quantity of power that can be collected from the wind is determined by a wind turbine's torque, which is a crucial metric. A high torque indicates that the blades are generating a strong rotating force, which has the potential to produce more power, while a low torque indicates that the blades are generating a weaker rotational force, which has the potential to produce less power. Torque and other design characteristics are optimized for a particular application by wind turbine designers using computer models and wind tunnel tests. The ideal torque relies on several variables, including the wind speed, the weight and size of the blades, and the required output of power.

5. RESULTS OF THE SYSTEM AND SIMULATION

There will be two sections to this section. The first is to show and discuss all aspects of the simulation program that the MATLAB program was used for simulation purposes. The second is to display all the results obtained from the simulation program.

5.1. Simulation Program

This part presents all parts of the wind energy simulation program that was designed for this research as shown in Figure 1.

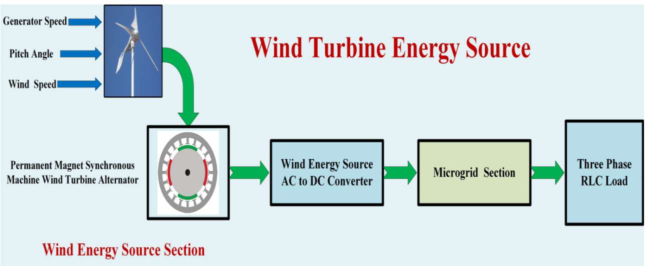

Figure 1. The parts of the wind energy simulation program

5.2. Wind Energy Source Part

Table 1 shows the characteristics of the wind power source that was used in this paper's simulation program. Wind power or wind energy, as seen in Figure 1, generates mechanical or electrical energy from the wind. the power coefficient, which contrasts the amount of wind energy recovered with the actual wind energy.

Table 1. Properties of the wind energy source

Description	Specification
Phases Number	3
Back EMF waveform	Sinusoidal
Type of Rotor	Round
Mechanical input	Torque Tm
Preset model	No

The range of wind speeds that the model will function in is established. Then the power curve is determined (The link between wind speed and the volume of energy that can be produced by wind turbines is shown graphically by the power curve) as in Figure 2. You can speak with the manufacturer about the wind turbine's power curve.

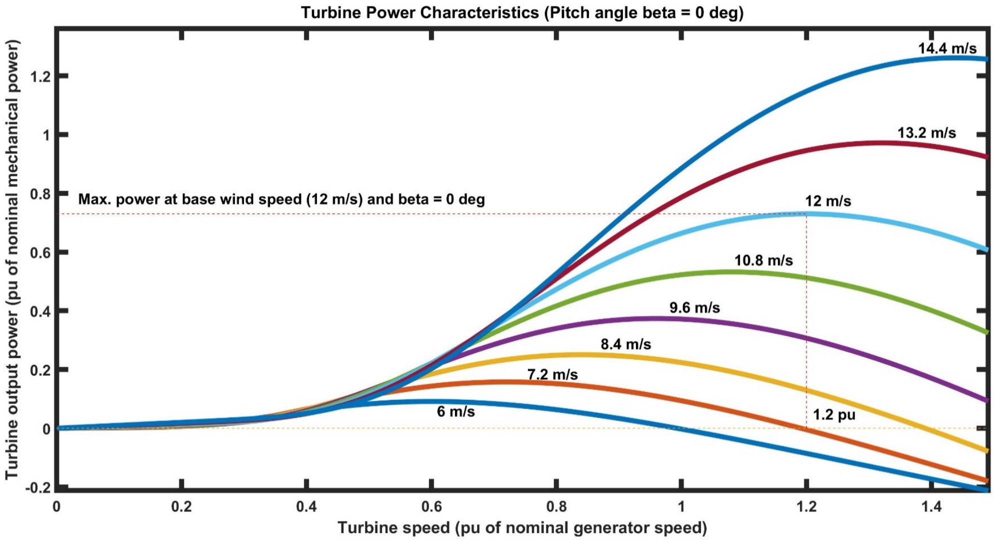

Figure 2. Wind turbine power characteristics

The permanent-magnet synchronous machine (PMSM) drive is one of the best solutions for several motion control applications. The PMSM, for instance, is often utilized in actuators, machine tools, and robotics, and high-power applications like industrial motors and vehicle propulsion are being studied. Table 2 presents the main properties of the PMSM of the simulation program.

Table 2. Properties of the permanent-magnet synchronous machine

Description	Value
Mechanical output power, nominal (W)	200
The electrical generator's starting power (VA)	200/0.9
(m/s) base wind speed	12
The highest output at the basic wind speed (p.u. of nominal mechanical power)	0.73
Rotational speed at rest (p.u. of base generator speed)	1.2
Pitch angle beta (*beta* ≥ 0) to show wind turbine power characteristics (deg)	0

5.3. Three-Phase AC-to-DC Converter

Before being used in a wind turbine, the generator's Either DC power conversion or electrical grid connection is required for AC output. For this, an AC-to-DC converter, also known as a rectifier, is utilized. Normally, the rectifier is situated near the generator in the wind turbine's nacelle. Its primary purpose is to transform converting the generator's AC power into DC electricity, which may then be utilized to power the electrical parts of the turbine or supplied to the grid.

Several rectifier types may be used in wind turbines, including:

1. The simplest sort of rectifier is a diode rectifier, which transforms an AC voltage into a pulsing DC voltage. Despite their inexpensive cost and dependability, they have a poor power factor and considerable harmonic distortion.
2. Thyristor rectifiers: These rectifiers employ thyristors, sometimes referred to as silicon-controlled rectifiers (SCRs), to convert AC voltage to DC voltage. Compared to diode rectifiers, they have a better power factor and less harmonic distortion, but they are more complicated and costly.
3. Active rectifiers: These rectifiers use power electronics to actively regulate the DC output's voltage and current. While they have lower harmonic distortion and higher power factor than a diode and thyristor rectifiers, they are also more complicated and costly.

MATLAB allows us to simulate an AC-to-DC transformer using several different methods, depending on the amount of complexity and depth we choose. Using the SimPower Systems package in MATLAB to create the diode rectifier model, as shown in Figure 3, is one straightforward method.

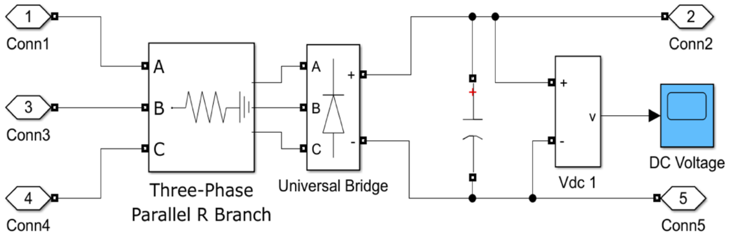

Figure 3. Three Phase AC-to-DC converter circuit diagram

5.4. DC-to-AC Inverter Circuit

An inverter circuit is used to transform DC electricity into AC power. The inverter circuit is very useful for producing high voltages using a low-voltage source or battery as shown in Figure 4. In this part, the circuit will be divided into two main parts.

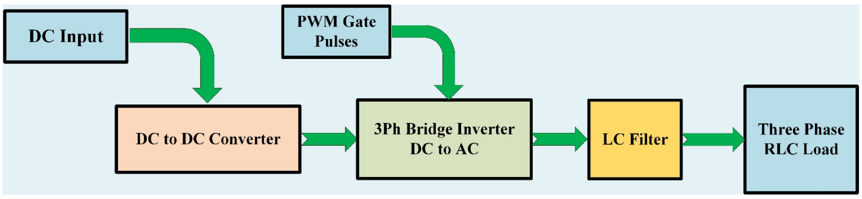

Figure 4. Full circuit diagram of DC-to-AC inverter

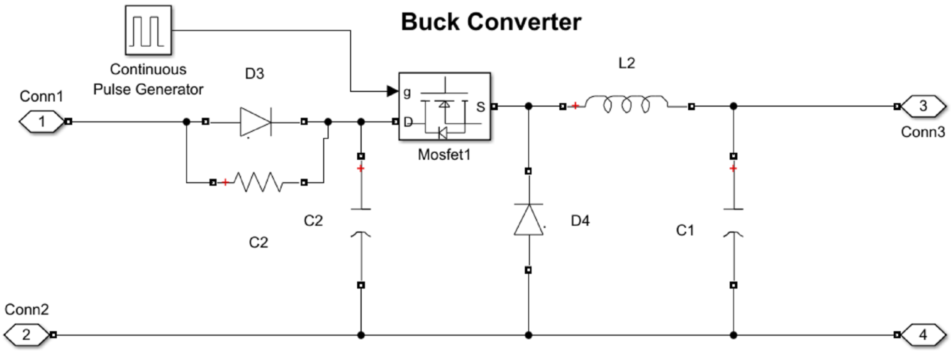

Figure 5. DC-to-DC Buck converter circuit diagram

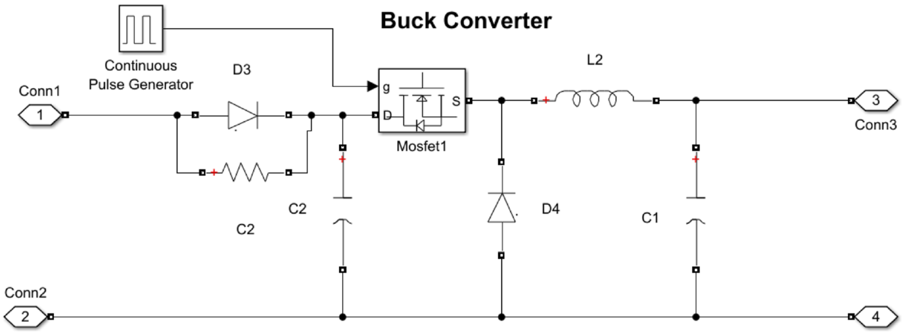

Figure 6. The main circuit diagram of three phase inverter

The first part is to use a DC-DC converter circuit, as in Figure 5, using the Buck converter circuit. The second part is the use of a three-phase DC-to-AC inverter circuit, as shown in Figure 6. After that, any load that needs to be used is connected to the output of a three-phase circuit for its use depending on the application of the system.

6. SIMULATION RESULTS

The most important results obtained from the simulation program of the wind turbine in Figure 1 will be presented in this section.

6.1. DC-to-AC Inverter Circuit

As shown in Figure 5, a DC-to-DC buck converter is a kind of power converter that transforms a greater DC voltage into a lower DC voltage. A buck converter's operation may be divided into four stages:

1. Switch closed: At the first stage of the buck converter, the switch (usually a transistor) is shut, enabling current to go from the input voltage source (V_{in}), via the inductor (L), and to the output load (V_{out}). The inductor stores energy in its magnetic field during this phase.
2. Switch opened; inductor current continues to flow through load: At the second step, the switch is opened, allowing the inductor current to keep flowing. The output voltage exceeds the input voltage as a result of the inductor discharging its stored energy into the load.
3. The diode linked in parallel with the inductor conducts in the third stage, enabling the inductor current to continue flowing and preventing any reverse voltage from developing across the inductor. The inductor's energy is now delivered to the output load during this phase.
4. Switch closed, recharging of the inductor current: At the last phase, the switch is once again closed, replenishing the inductor current and resuming the cycle.

Figure 7 shows the buck converter circuit's DC voltage output result. A pulse-width modulation (PWM) circuit manages the buck converter's functioning by controlling how long the switch is open and closed for the output voltage of the buck converter may be adjusted to a specified value by altering how often PWM signal pulses.

6.2. Three-Phase PWM Signals

Three-phase DC-to-AC power inverters employ three-phase pulse-width modulation (PWM) signals as a sort of control signal as shown in Figure 8. Three separate square waves with a similar frequency and a phase shift of 120 degrees between each wave are used to create the three-phase PWM signal. Three square waves with changing duty cycles make up the resultant signal, which controls a motor's or power converter's output current and voltage.

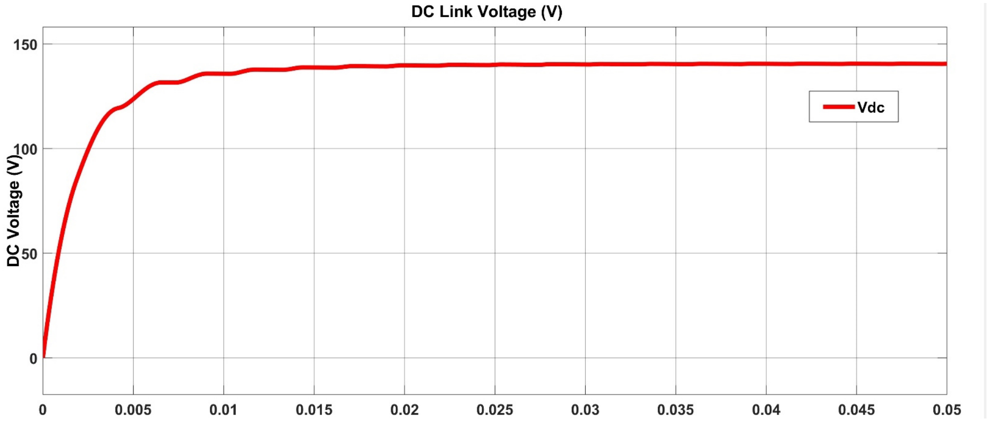

Figure 7. The buck converter circuit's DC voltage output result

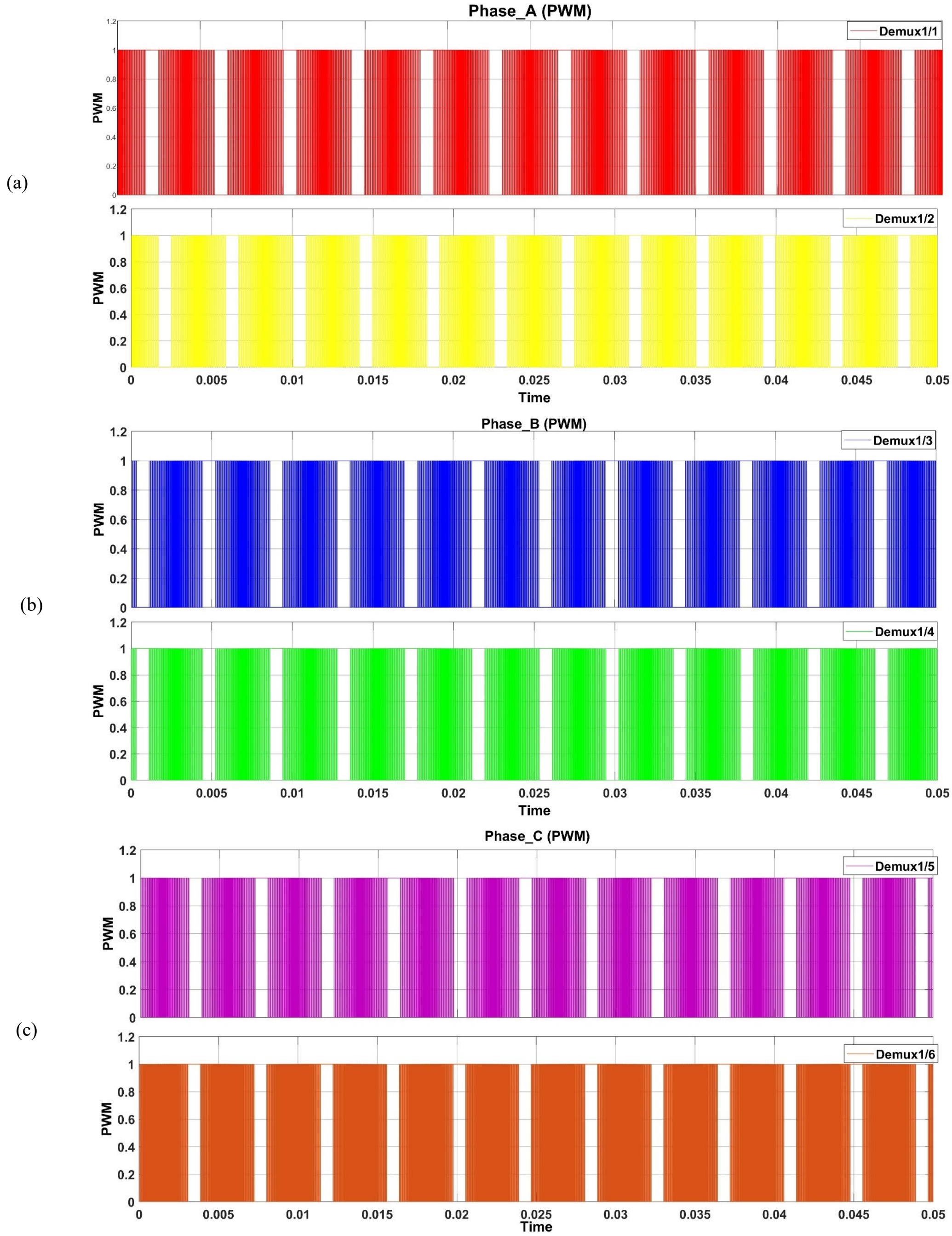

Figure 8. PWM signals for: (a) Phase A, (b) Phase B, (c) Phase C

6.3. Results of Three-Phase Inverter

The output of a three-phase DC-to-AC converter depends on the inverter's particular settings and operational circumstances. Figure 9 depicts the outcomes of a three-phase DC-to-AC converter used in this paper. Output voltage and frequency:

A three-phase DC to AC inverter may provide a regulated output voltage and frequency that nearly resembles the required AC waveform. Adjusting the input DC voltage and the inverter control signals may modify the output voltage and frequency.

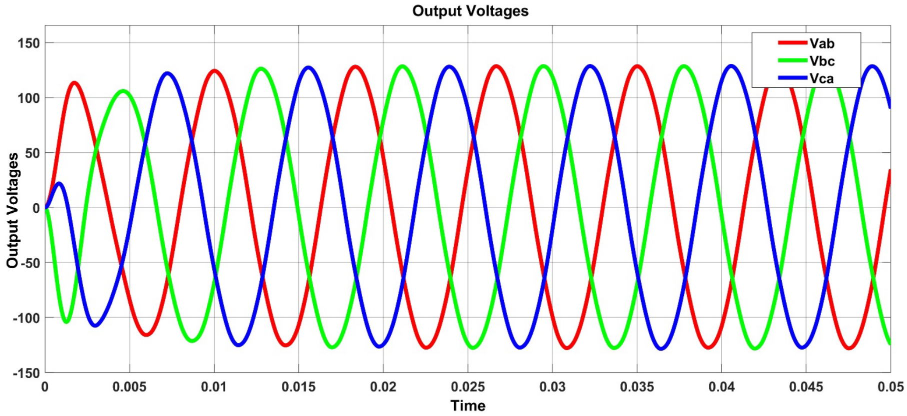

Figure 9. Three Phase output Line-to-Line voltage

7. CONCLUSIONS

Rural locations may use wind energy as a reliable source of renewable energy to power cellular base stations. Depending on the specific location and wind conditions, a wind turbine system could provide a reliable and sustainable source of electricity to keep the base station running. The research based on the controller's creation and use in the wind energy system led to the following conclusion that the system's architecture is robust and exhibits optimum performance despite the impact of inertia disturbances on the wind turbine system. System development is carried out via a technical and meticulous design procedure. For the purpose of ensuring output simulation and obtaining output electrical power, a PMSM synchronous permanent magnet generator was utilized to measure the electrical output power and analyze the data. According to a detailed study and simulation-based testing of wind energy systems for wind turbines, the system is designed in a way that maintains resilient performance despite the effect of disturbances.

REFERENCES

[1] G.A. Taylor, M. Rashidinejad, Y.H. Song, M.R. Irving, M.E. Bradley, T.G. Williams, "Algorithmic Techniques for Transition Optimized Voltage and Reactive Power Control", International Conference on Power System Technology, Vol. 3, No. 2, pp. 1660-1664, 13-17 October 2002.

[2] A.E. Samani, A. D'Amicis, J.D. de Kooning, D. Bozalakov, P. Silva, L. Vandevelde "Grid Balancing with a Large-Scale Electrolyser Providing Primary Reserve", IET Renewable Power Generation, Vol. 14, No. 16, pp. 3070-3078, 2020.

[3] S. Asiaban, N. Kayedpour, A.E. Samani, D. Bozalakov, J.D.M. De Kooning, G. Crevecoeur, L. Vandevelde, "Wind and Solar Intermittency and the Associated Integration Challenges: A Comprehensive Review Including the Status in the Belgian Power System", Energies, Vol. 14, No. 9, 2021.

[4] F.C. Quintero, J.F. Medina Padron, E.J. Medina Dominguez, M.A.A. Santana, "Renewable Hydro-Wind Power System for Small Islands: The El Hierro Case", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 27, Vol. 8, No. 2, pp. 1-7, June 2016.

[5] D.V. Bozalakov, J. Laveyne, M.J. Mnati, J. Van de Vyver, L. Vandevelde, "Possible Power Quality Ancillary Services in Low-Voltage Grids Provided by the Three-Phase Damping Control Strategy", Applied Sciences, Vol. 10, No. 21, November 2020.

[6] D. Celik, M.E. Meral, "Power Management Strategy of Grid Connected Solar Power Generation", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 36, Vol. 10, No. 3, pp. 14-18, September 2018.

[7] H. Uzmus, N. Genc, I.H. Dilber, "Application of an Off-grid PV System to Meet the Electrical Energy of a House", Issue 33, Vol. 9, No. 4, pp. 16-20, 2017.

[8] D. Bozalakov, M.J.M. Al Rubaye, A. Van den Bossche, L. Vandevelde, "Voltage Unbalance Mitigation by Using the Three-Phase Damping Control Strategy in Active Rectification Mode", Young Researchers Symposium (YRS2018), pp. 1-6, Brussels, Belgium, 24-25 May 2018.

[9] N.M. Tabatabaei, S.R. Mortezaei, S. Shargh, B. Khorshid, "Electro Search Algorithm for Probabilistic Multi-Objective Optimal Power Flow Considering Wind Power and Load Uncertainties", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 33, Vol. 9, No. 4, pp. 52-59, December 2017.

[10] J. Wang, S. Yiliao, F. Liu, R. Hou, "Analysis and Application of Forecasting Models in Wind Power Integration: A Review of Multi-Step-Ahead Wind Speed Forecasting Models", Renewable and Sustainable Energy Reviews, Vol. 60, 2016.

[11] N.D. Bokde, Z.M. Yaseen, G.B. Andersen, "Forecast TB-an R Package as a Test-Bench for Time Series Forecasting-Application of Wind Speed and Solar Radiation Modeling", Energies, Vol. 13, No. 10, Article ID 2578, 2020.
[12] M.J. Mnati, D.V. Bozalakov, A. Van den Bossche, "New Pulse Width Modulation Technique to Reduce Losses for Three-Phase Photovoltaic Inverters", Active and Passive Electronic Components, Vol. 2018, 2018.
[13] Y. Zhang, N. Tang, Y. Niu, X. Du, "Wind Energy Rejection in China: Current Status, Reasons and Perspectives", Renewable and Sustainable Energy Reviews, Vol. 66, 2016.
[14] H. Shayeghi, M. Alilou, B. Tousi, R.D. Doltabad, "Multi-Objective Allocating the Protective Devices Beside Wind Turbine and Photovoltaic Panel in the Distribution System", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 43, Vol. 12, No. 2, pp. 51-57, June 2020.
[15] J. Bilbao, E. Bravo, O. Garcia, C. Rebollar, C. Varela, "Designing and Projecting a Wind Generator Based on the Emplacement: Power Coefficient", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 45, Vol. 12, No. 4, pp. 91-96, December 2020.
[16] F. Balduzzi, J. Drofelnik, A. Bianchini, G. Ferrara, L. Ferrari, M. S. Campobasso, "Darrieus Wind Turbine Blade Unsteady Aerodynamics: A Three-Dimensional Navier-Stokes CFD Assessment", Energy, Vol. 128, pp. 550-563 2017.
[17] F. Kaytez, M.C. Taplamacioglu, M. Ari, "Investigation of the Relationship between Solar and Wind Power Development in Electrical Grids and Cost Changes in The Related Technologies", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 42, Vol. 12, No. 1, pp. 99-104, March 2020.
[18] L. Diaz, L. Ramirez, J. Fabregas, "Green Logistics in Off-Grid Renewable Energy Projects for the Rural Localities", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 48, Vol. 13, No. 3, pp. 119-124, September 2021.
[19] J.M.V. Bikorimana, M.J. Mnati A. Van den Bossche, "Frequency Synchronization of a Single-Phase Grid-Connected DC/AC Inverter Using a Double Integration Method", Automatika, Vol. 58, No. 2, pp. 141-146, 2017.
[20] A. Jahid, M.K.H. Monju, M.E. Hossain, M.F. Hossain, "Renewable Energy Assisted Cost Aware Sustainable Off-grid Base Stations with Energy Cooperation", IEEE Access, Vol. 6, pp. 60900-60920, 2018.
[21] M.J. Farooq, H. Ghazzai, A. Kadri, H. El Sawy, M. Alouini, "A Hybrid Energy Sharing Framework for Green Cellular Networks", IEEE Trans. Commun., Vol. 65, No. 2, pp. 918-934, 2017.
[22] V. Chamola, B. Sikdar, "Solar Powered Cellular Base Stations: Current Scenario, Issues and Proposed Solutions", IEEE Commun. Mag., Vol. 54, No. 5, pp. 108-114, 2016.
[23] K. Kanwal, G.A. Safdar, M. Ur Rehman, X. Yang, "Energy Management in LTE Networks", IEEE Access, Vol. 5, pp. 4264-4284, 2017.
[24] S. Dutta, T. Geiger, B. Lanvin, "The Global Information Technology Report: ICTs for Inclusive Growth", World Economic Forum Tech. Rep., Geneva, Switzerland, 2015.
[25] A. Bousia, E. Kartsakli, A. Antonopoulos, L. Alonso, C. Verikoukis, "Multiobjective Auction-Based Switching off Scheme in Heterogeneous Networks to Bid or not to Bid?", IEEE Trans. Veh. Technol., Vol. 65, No. 11, pp. 1-1, 2016.
[26] G.H.S. Carvalho, I. Woungang, A. Anpalagan, E. Hossain, "QoS-aware Energy-Efficient Joint Radio Resource Management in Multi-Rat Heterogeneous Networks", IEEE Trans. Veh. Technol., Vol. 65, No. 8, pp. 6343-6365, 2016.
[27] P. Gandotra, R.K. Jha, S. Jain, "Green Communication in Next Generation Cellular Networks: A Survey", IEEE Access, Vol. 5, pp. 11727-11758, 2017.
[28] H.A.H. Hassan, A. Pelov, L. Nuaymi, "Integrating Cellular Networks, Smart Grid, and Renewable Energy: Analysis, Architecture, and Challenges", IEEE Access, Vol. 3, pp. 2755-2770, 2015.
[29] J. Gong, J.S. Thompson, S. Zhou, Z. Niu, "Base Station Sleeping and Resource Allocation in Renewable Energy Powered Cellular Networks", IEEE Trans. Commun., Vol. 62, No. 11, pp. 3801-3813, November 2014.

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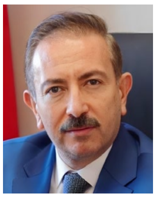

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