WIND-POWERED AGRICULTURE: ENHANCING CROP PRODUCTION AND ECONOMIC PROSPERITY IN ARID REGIONS

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ABSTRACT

Over an extended duration, small-scale farmers have been contending with the persistent issue of electricity scarcity, which adversely affects crop production, particularly during dry seasons. The dependence on generators, despite being expensive and environmentally harmful due to oil spillage and Carbon dioxide (CO2) emissions, remains a prevalent yet unsustainable solution. Wind energy emerges as a promising alternative with diverse benefits for farmers, addressing concerns related to irrigation, storage, and water management, ultimately leading to significant yield increases during dry periods. This study investigates the performance of a small-scale wind energy conversion system tailored for the irrigation needs of farmers in arid regions, focusing on Zaria Local Government, Kaduna State, Nigeria as a case study. Utilizing wind speed data from the Nigeria Meteorological Agency (NIMET), the system's electrical parameters, including voltage, current, frequency, and power, were analyzed to assess fluctuations resulting from wind speed variations. Results show significant variability in electrical parameters: wind speed ranged from 3.10 m/s to 9.83 m/s, resulting in fluctuations in generated voltage (98 volts to 250 volts), current (51 amps to 103 amps), frequency (39 Hz to 65 Hz), and power (5.1 kW to 20.6 kW). Converter systems were found effective in stabilizing output for grid integration: the AC/DC converter converted fluctuating AC signals into stable DC output (200 volts, 93 amps), while the subsequent DC/AC inverter produced non-fluctuating AC output (voltage: 200 volts, current: 92 amps, frequency: 50 Hz, power: 18.3 kW). These findings emphasize feasibility of implementing wind energy solutions in remote agricultural areas.

Keywords: *Wind turbine, Sustainability, NIMET, CO_2 emissions, Converter System, Farmers*

I. INTRODUCTION

WIND energy stands at the forefront of the global transition towards sustainable and renewable power sources. The utilization of wind as a clean and abundant energy resource has gained significant attention due to its environmental benefits and potential to address the escalating energy demands worldwide. Wind energy, characterized by its abundance and sustainability, has emerged as a pivotal component in the global shift towards renewable energy sources [1]. Wind turbines, pivotal in converting wind kinetic energy into electricity, have garnered widespread attention for their potential to address the escalating energy demands while mitigating environmental degradation [2]. Nigeria, particularly its northern region, stands at the cusp of an unprecedented opportunity to harness wind energy and revolutionize its energy landscape [3].

The vast expanse of the Nigerian northern region, characterized by expansive plains and consistent wind patterns, presents an ideal environment for wind energy development [4]. The unique geographical features of this region, including its proximity to the Saharan Desert, contribute to the prevalence of strong and consistent wind currents, making it an optimal location for wind turbine installations [5]. Moreover, Nigeria's northern region, despite its abundant renewable energy potential, has historically faced challenges in accessing reliable and sustainable electricity [6]. The integration of wind energy infrastructure holds the promise of addressing these energy deficits, providing a clean and renewable source of power to communities that have long been underserved [7].

As Nigeria strives to diversify its energy mix and reduce its reliance on fossil fuels, wind energy emerges as a viable solution [8]. The adoption of wind turbines not only aligns with Nigeria's commitment to sustainable development but also offers economic benefits, including job creation and infrastructure development [9].

One of the most promising renewable energy sources that is making a major contribution to the world's electricity output is wind energy [10]. The modelling of wind turbines, which involves intricate interactions between aerodynamics, mechanical systems, and control techniques, is essential to effectively use wind energy [11]. An overview of the several modelling techniques used in wind turbine analysis and optimization is given in this paper. Utilizing the Blade

Element Momentum (BEM) hypothesis, aerodynamic modelling is frequently used to forecast airflow around turbine blades and harvest wind energy [12]. Furthermore, sophisticated computational fluid dynamics (CFD) models provide in-depth examination of intricate flow phenomena as wake effects and turbulence [13]. For the purpose of evaluating mechanical integrity and forecasting fatigue loads in wind turbines, structural dynamics modelling—primarily using Finite Element Analysis (FEA)—is indispensable [14]. In order to capture the relationships between airflow and turbine response, coupled aero elastic simulations combine structural dynamics with aerodynamic forces [15]. Real-time adjustments to blade pitch and rotor speed are made via control systems, especially Model Predictive Control (MPC), which is essential for maximizing turbine performance [16]. Predictive maintenance and performance optimization are made possible by digital twin-based modelling, which combines real-time data with physics-based simulations [17].

Aerodynamics, structural dynamics, and control systems are all incorporated into the interdisciplinary modelling method for wind turbines [18]. Accurate turbine performance prediction and optimization are made possible by sophisticated approaches [19]. To improve wind energy systems' dependability and affordability, modelling methodology research must continue [20]. The use and analysis of wind turbine load models have been investigated in detail, as the extensive review [21]. The authors evaluated wind turbine control systems in great detail, taking into account models, procedures, and future directions [22]. Furthermore, in order to provide a thorough understanding of the operational dynamics of variable-speed wind turbines with doubly fed induction generators and carefully examined these wind turbines [23]. In their critical evaluation of wind turbine bearing failure cases, authors extracted significant insights from failure analysis techniques [24]. Furthermore, methods for the long-term evaluation of wind resources, providing insight into existing procedures were outlined and analysed [25]. Review on recent advances and future prospects for wind turbine structural health monitoring [26]. Additionally, authors conducted a thorough analysis of models and techniques for predicting wind power and speed in wind farms, demonstrating a range of strategies [27]. An informative analysis of wind turbine drivetrain monitoring and defect diagnosis was carried out, providing an overview of current practices [28]. In parallel, innovative control systems specifically designed for wind turbines were evaluated for their appropriateness and effectiveness [29]. Furthermore, a comprehensive summary of wind turbine reliability prediction techniques, encompassing several approaches and their ramifications was proposed [30]. Highlighting recent discoveries, authors evaluated current developments and impending difficulties in the fault identification of wind turbines [31]. Examination of techniques for diagnosing defects and controlling the state of wind turbine gearboxes, emphasizing the significance of early identification and mitigation measures was conducted [32].

A study was conducted on the potential for renewable energy development in Nigeria, with a focus on the role that small and medium-sized enterprises (SMEs) play in driving adoption [33]. Modelling and assessment of renewable energy systems for Nigeria's distant rural areas was conducted in [34]. Moreover, a case study was conducted in Katsina State, Nigeria, to assess the viability of wind power generation, their findings helped to understand the country's localized potential for wind energy utilization [35]. Review of Nigeria's renewable energy resources and technology, providing information on the country's present situation, potential for the future, and legal structure [36]–[37].

Previously published works in the literature have frequently missed a thorough analysis of the electrical characteristics that fluctuate naturally in wind energy systems, especially when it comes to agricultural applications in arid areas like Zaria Local Government. While wind energy conversion has been the subject of various studies, few have examined the complex issues raised by variations in wind speed-related voltage, current, frequency, and power. Furthermore, the crucial role converter systems play in stabilizing output for grid integration has frequently been disregarded in previous research, which limits the application and dependability of wind energy solutions in isolated farming communities. The novelty of this work lies in its thorough analysis of these fluctuating parameters and the demonstration of converter systems' effectiveness in rectifying and stabilizing output, addressing a significant gap in the literature. By shedding light on these overlooked aspects and offering practical solutions, this research contributes to advancing the understanding and implementation of wind energy systems tailored for agricultural needs, ultimately fostering sustainability and resilience in energy-deprived regions. The contribution of this study resides in its effort to confront the enduring issue of electricity scarcity experienced by small-scale farmers in Zaria local government of Kaduna state, Nigeria, particularly affecting crop production during dry seasons. Acknowledging the constraints associated with reliance on generators, known for their costliness and environmental hazards stemming from oil spillage and Carbon dioxide emissions, the research underscores the promise of wind energy as a viable alternative offering manifold advantages to farmers.

Jurnal Elektrika Vol. 16 No. 1 2024 P-ISSN 2085-0565 | E-ISSN 2580-8486
Received 3 Maret 2024, Revised 17 April 2024, Accepted 24 April 2024.
DOI 10.26623/elektrika.v16i1.8999

More precisely, the study introduces a model of a small-scale wind energy conversion system tailored to address farmers' irrigation requirements during arid seasons.

II. Materials and Method

The MATLAB simulation procedure for this work involves several steps to model and analyse the performance of the small-scale wind energy conversion system.

Data Gathering and Pre-processing: To be used in the simulation, wind speed data is gathered and pre-processed from the Nigeria Meteorological Agency (NIMET) for the period of six years.

System Modeling: MATLAB/Simulink is used to simulate the wind energy conversion system, which includes the generator, converter, and wind turbine systems. This entails describing the elements of the system, their traits, and how they work together.

Wind Speed Input: The wind turbine model uses the pre-processed wind speed data as an input. The wind turbine model determines the power production by taking into account the efficiency and rotor diameter of the turbine as well as the wind speed profile.

Analysis of Electrical Parameters: At several locations in the system, such as the generator output and the output of the converter systems, the electrical parameters—voltage, current, frequency, and power—are examined. The simulation data are processed and analysed using MATLAB programs.

Modelling and simulating the AC/DC converter (rectifier) and DC/AC inverter is part of the Converter System Simulation. These converters are essential for maintaining grid compatibility and regulating the erratic electrical signals produced by the wind turbine system.

Performance Evaluation: A number of criteria, including power production, grid compatibility, and voltage and current stability, are used to assess the performance of the wind energy conversion system. Performance measurements are generated and simulation results are analysed using MATLAB functions and tools.

The following procedures was used in this study.

- Data Collection
- Mathematical Modelling of Wind Turbine
- Mathematical modelling of Permanent Magnetic Synchronous Generator (PMSG)
- Wind Energy Conversion System Model

A. Data Collection

Monthly mean wind speeds for Zaria were obtained from Nigerian Meteorological Agency, the mean monthly wind speed data considered in this project were ranged 2016 to 2021, and the minimum amount of wind speed is taking for the design of the WECS was 5.0m/s. The national organization in charge of meteorological services in Nigeria is the Nigerian Meteorological Agency (NIMET). NIMET, which was founded in 2003, is essential in providing the government, other industries, and the public with precise and fast meteorological information, forecasts, and alerts. The organization uses a nationwide network of weather stations and cutting-edge meteorological technology to track atmospheric conditions, forecast weather patterns, and send out early alerts for impending natural disasters including floods, droughts, and tropical storms. By providing specialized weather information to industries like agriculture, aviation, and water resources, NIMET also aids in the development of the country. The organization also works to improve Nigeria's meteorological capacities and foster climate resilience through research and capacity-building projects.

B. Mathematical Modelling of Wind Turbine.

The wind turbine model, shown in Figure 1, is an essential part of the small-scale wind energy conversion system's simulation framework. The wind turbine model, complete with important parameters and features that affect its performance, is shown in figure 1. To precisely mimic power generation, the model takes into account variables like rotor diameter, blade pitch angle, turbine efficiency, and wind speed profile. Furthermore, the illustration might depict the electrical generator connected to the wind turbine in addition to the mechanical parts of the turbine, like the rotor, hub, and gearbox.

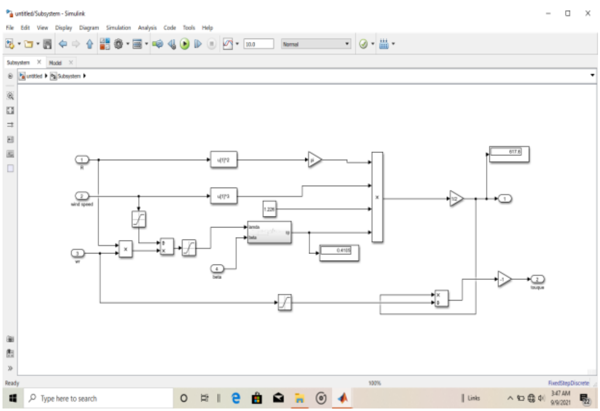

Figure 1. Wind turbine model

The output power of the turbine is given by;

$$P_m = \frac{1}{2} C_p(\lambda, \beta) \times \rho \times A \times V_w{}^3 \qquad (1)$$

Where

P_m= Mechanical power output

$C_p(\lambda, \beta)$= performance coefficient of the turbine

ρ = Air density

A = Turbine swept area

V_w= Wind speed

β = Blade pitch angle

λ = Tip speed ratio

The model of the coefficient of the turbine as shown in Figure 2 which is the determining factor of turbine efficiency is indicated in equation 2;

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda} - C_3\beta - C_4\beta^x - C_5\right)e^{\frac{-C_6}{\lambda}} \quad (2)$$

Where C_1 C_2, C_3, C_4, C_5 *and* C_6 are power coefficient and depend on turbine type. $C_p(\lambda,\beta)$ Is a function of tip speed ratio, blade pitch angle and x depends on turbine type. β Is defined as the angle difference between the plane of rotation and blade cross section chord.

C_1 Represents the power coefficient at low tip speed ratios and accounts for the turbine's efficiency in capturing wind energy.

C_2 Is the coefficient related to the turbine's blade design and aerodynamic properties.

C_3, Represents the power coefficient at high tip speed ratios and influences the turbine's performance at higher wind speed

C_4 Accounts for any power losses or inefficiencies in the turbine's drivetrain or mechanical components

C_5 Represents the power coefficient when the turbine is stalled, indicating the turbine's performance under certain conditions.

C_6 Is another coefficient related to the turbine's aerodynamic properties and performance characteristics.

Values for coefficients widely used in wind turbine design, such as C_1 C_2, C_3, C_4, C_5 *and* C_6, have been determined through experimentation and have over time become industry standards. Turbine designers can use these standardized numbers, which include 0.5, 116, 0.4, 0, 5, and 21, as dependable starting points to ensure consistency and comparability across various projects and manufacturers. They are based on a combination of theoretical analysis, such as aerodynamic modelling and computational fluid dynamics (CFD) simulations, and actual data gathered through field testing and performance assessments of current wind turbines.

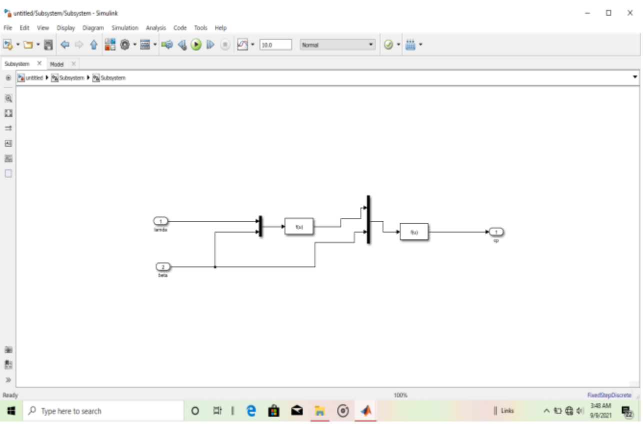

Figure 2. Turbine coefficient mode

$$C_p(\lambda,\beta) = 0.5\left(\frac{116}{\lambda} - 0.4\beta - 0\beta^x - 5\right)e^{\frac{-21}{\lambda}} \quad (3)$$

$$C_p(\lambda,\beta) = 0.41$$

$$\frac{1}{\lambda} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1+\beta} \quad (4)$$

$$\lambda = \frac{\omega_r R}{V_w} \quad (5)$$

Where ω_r= angular speed of the turbine measured in radian per second, V_w= wind speed measured in meter per second, R= Radius of the turbine measured in meter Since the average wind speed accessible in the area of study was 5.0m/s, therefore, ω_r and R have to be 16.2rad/sec and 2.5m for optimal design and the hence from equation (5)

$$\lambda = \frac{\omega_r R}{V_w} = \frac{16.2 \times 2.5}{5} = 8.1$$

Substituting λ in equation (4) to obtain β which was calculated to be 0.088

TABLE I
WIND TURBINE PARAMETER

Symbol	Parameters of wind turbine	Specification
. $C_p(\lambda,\beta)$	Power coefficient	0.41
C_1 C_2, C_3, C_4, C_5 *and* C_6	Wind constant	0.5, 116, 0.4, 0, 5, and 21
λ	Tip speed ratio	8.1
β	Blade pitch angle	0.088
V_w	Wind speed	5.0m/s
ω_r	Angular speed	16.2rad/sec
R	Radius of the turbine	2.5m

C. *Permanent Magnetic Synchronous Generator (PMSG)*

Particular design aspects and electrical properties define the three-phase generator model known as the Permanent Magnet Synchronous Generator (PMSG). With one end of each winding connected to an internal neutral point, the stator windings are arranged in a wye (or star) pattern as depicted in Figure 3. A balanced current distribution in the three-phase system is facilitated by this internal neutral point. Sinusoidal back electromotive force (EMF) waveforms are produced in the stator windings of the three-phase generator. Since the induced voltage in the stator windings exhibits a sinusoidal pattern over time, the back EMF is sinusoidal, indicating that the AC generators share this characteristic. A circular or cylindrical shape is also implied by the machine's rotor's spherical design. Typically, permanent magnets housed in this rotor form produce a continuous magnetic field, negating the need for an additional

Jurnal Elektrika Vol. 16 No. 1 2024 P-ISSN 2085-0565 | E-ISSN 2580-8486
Received 3 Maret 2024, Revised 17 April 2024, Accepted 24 April 2024.
DOI 10.26623/elektrika.v16i1.8999

excitation device and adding to the generator's simplicity and efficiency. Generally, a variety of applications, such as wind turbines and other renewable energy systems, use this PMSG arrangement with a wye-connected stator, sinusoidal back EMF waveform, and a round rotor.

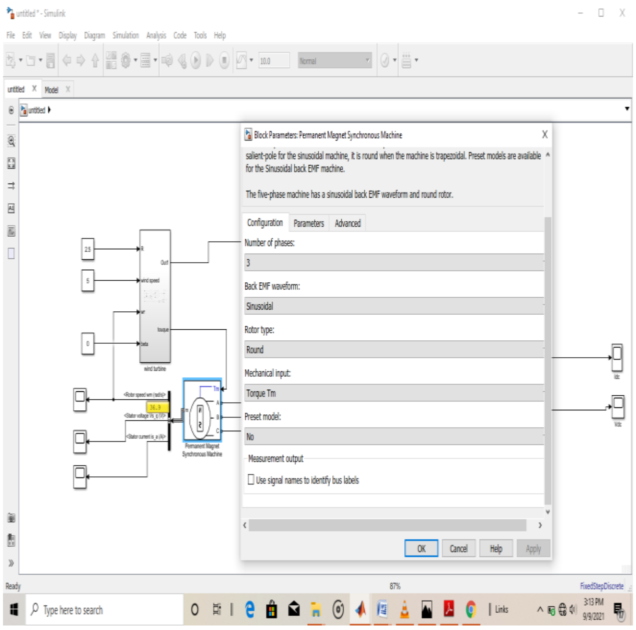

Figure 3. Permanent Magnet Synchronous Generator (PMSG) Model

Voltage Equation

$$V_S = I_S R_S + I_S \frac{di_S}{dt} + E \quad (6)$$

Where

Vs = Terminal voltage of the generator

Ls = Stator inductance

Is = Stator current

Rs = Stator resistance

E = EMF induced due to the rotation of rotor

Torque Equation

Since the rotor is driven by a wind turbine, the torque equation is

$$T_e = T_W - T_L \quad (7)$$

Where

Te = Electromagnetic torque generated by the generator

Tw = torque exerted by the wind turbine on the generator rotor

T_L= Load torque

Rotor Equation

$$J \frac{d\omega_r}{dt} = T_e - T_L \quad (8)$$

Where

J = Moment of inertia of the rotor

ω_r= Angular velocity of the rotor

T_L= Load torque

D. *Wind Energy Conversion System Model*

A critical component of the entire system is the integration of the proposed wind turbine with the Permanent Magnet Synchronous Generator (PMSG) and the addition of a converter circuit. As the wind speed is not steady, the electrical energy also fluctuates, hence the converter circuit is employed for providing steady electrical output, and the modelling was made using MATLAB software. The complete setup is shown in Fig. 4

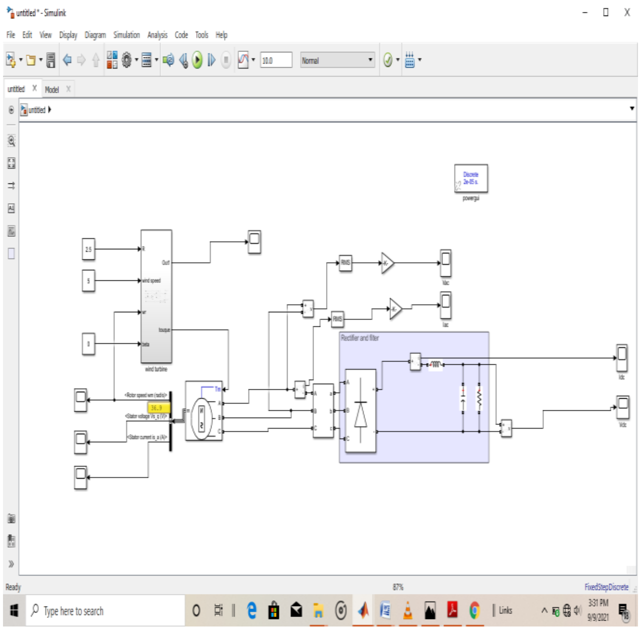

Figure 4. Wind energy conversion system model

III. RESULT AND DISCUSSION

Two crucial parameters were varied during the modeling process in order to analyze the power produced by the wind turbine system: the wind speed and the turbine's radius. The turbine's radius was first determined, and then the circuit was simulated with various wind speeds. In order to avoid making assumptions based on projected wind speeds and potential errors, the simulation testing for the small wind energy system was split into two segments: the first test used randomly chosen blade radii in conjunction with varying wind speeds, and the second test used actual wind speed data obtained from NIMET. The study utilized a blade diameter of 5 meters and a wind velocity of 5 m/s, which corresponds to the lowest monthly mean wind speed determined from NIMET data.

A. *Result of Wind Speed Data*

Table II presents the findings regarding the monthly mean wind speed observed in Zaria local government, Kaduna state. This data, sourced from NIMET, aids in determining the wind speeds utilized during the simulation of the wind energy conversion system.

TABLE II
MONTHLY MEAN WIND SPEED DATA FOR ZARIA IN M/S

	Jan.	Feb.	Mar	Apr.	May.	Jun.
	Jul.	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
2017	9.31	9.83	9.57	8.21	6.84	6.38
	6.02	4.52	7.72	4.53	7.72	5.92
2018	6.17	6.17	8.59	5.45	4.27	6.43
	5.50	5.42	5.35	4.58	6.84	8.13
2019	8.44	6.79	9.72	7.31	7.07	6.62
	6.17	5.09	4.37	7.20	6.43	7.25
2020	7.82	9.05	3.09	6.02	5.61	5.66
	7.77	7.72	5.07	6.15	6.44	6.85
2021	5.09	7.20	7.79	8.39	6.38	8.49
	6.53	6.43	5.76	5.09	6.78	6.61

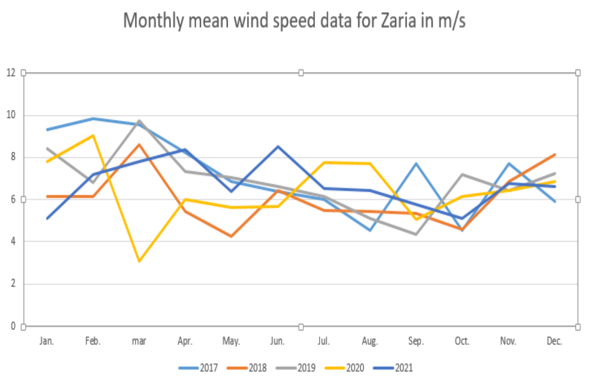

Figure 5. Monthly mean wind speed variation

B. Simulation Result

The figures below show the simulation results of the of the modeled wind energy conversion system using MATLAB.

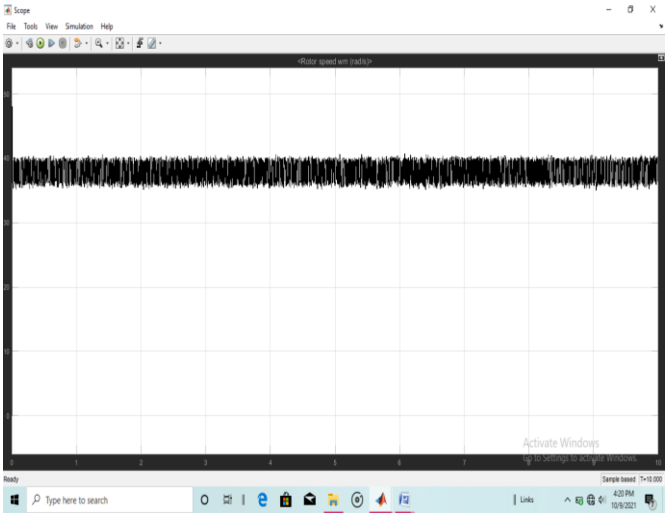

Figure 6. Rotor speed

Figure 6 depicts the fluctuating rotor speed of the wind turbine over a period of time, showcasing irregularities attributed to wind variations. The graph illustrates the dynamic nature of wind energy production, where changes in wind speed directly influence rotor speed. These fluctuations are integral to the operation of wind turbines, highlighting the necessity for robust control systems to optimize energy output amidst varying environmental conditions.

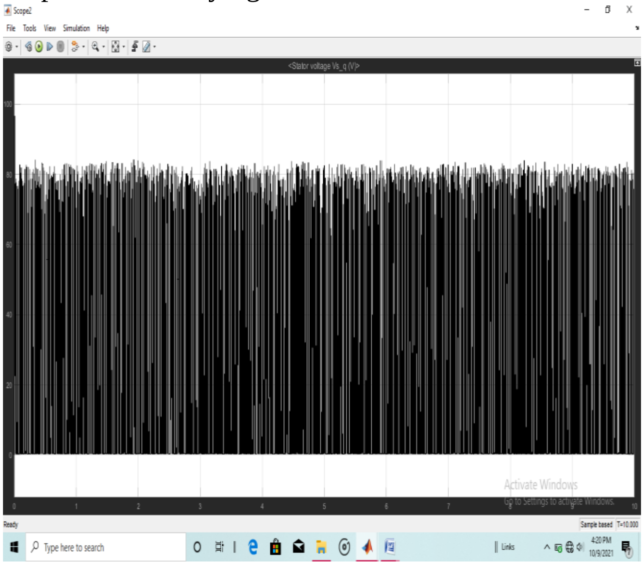

Figure 7. Stator voltage

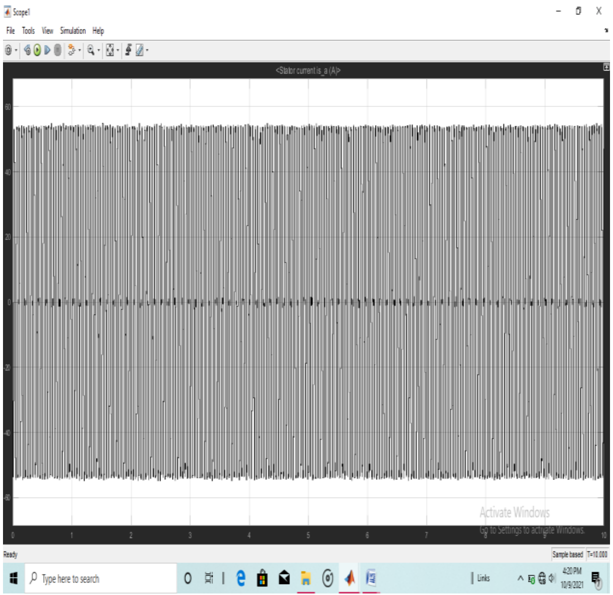

Figure 8. Stator current

Figure 7 presents the temporal pattern of generated voltage fluctuations, while Figure 8 showcases the corresponding fluctuating current in the wind turbine system. These graphs underline the inherent variability in electrical parameters due to the intermittent nature of wind energy. The fluctuating voltage and current profiles as shown in Table III, underscore the necessity for a converter system to regulate and stabilize the electrical output, ensuring compatibility with the grid and efficient utilization of wind-generated power. Implementing converters becomes imperative to

Jurnal Elektrika Vol. 16 No. 1 2024 P-ISSN 2085-0565 | E-ISSN 2580-8486
Received 3 Maret 2024, Revised 17 April 2024, Accepted 24 April 2024.
DOI 10.26623/elektrika.v16i1.8999

mitigate the impacts of voltage and current fluctuations, thereby enhancing the reliability and performance of the wind energy system.

TABLE III
FLUCTUATION OF GENERATOR OUTPUT DUE TO WIND VARIABILITY

Fluctuating parameters	**Minimum**	**Maximum**
Wind speed (m/s)	3.10	9.83
Generated voltage (volts)	98	250
Generated current (amps)	51	103
Frequency (Hz)	39	65
Electrical Power generated (KW)	15.1	19.6

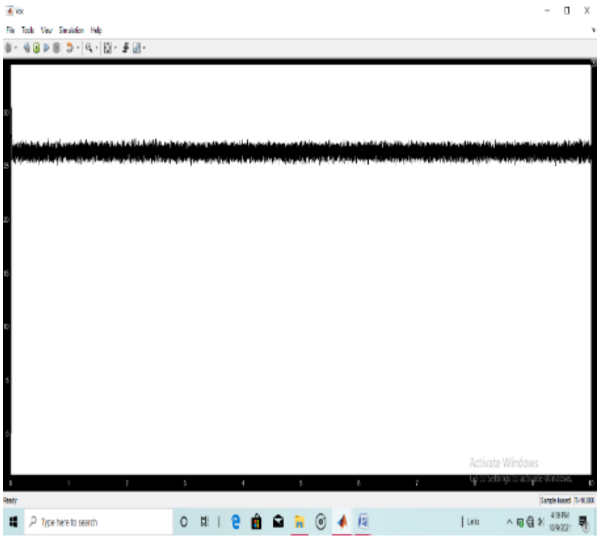

Figure 9. Voltage output of the converter

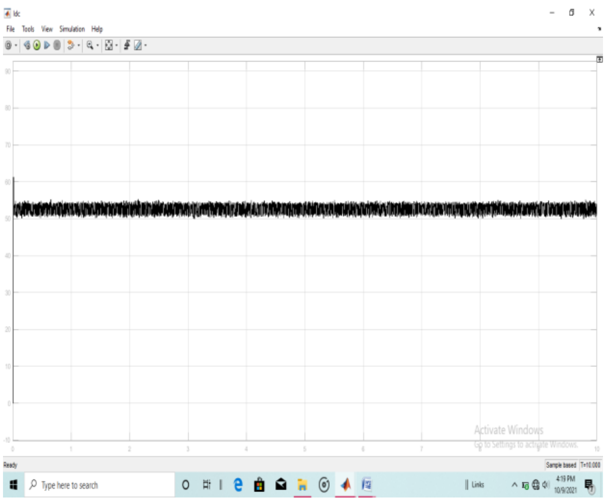

Figure 10. Current output of the converter

Figures 9 and 10 shown the voltage and current output of the AC to DC converter, respectively, showcasing the transformation process from variable AC input to constant DC output. The converter plays a vital role in rectifying the fluctuating electrical signals generated by the wind turbine system, converting them into stable forms suitable for grid integration as shown in Table IV.

TABLE IV
AC/DC CONVERTER RESULT

	AC/DC converter input	**DC output of the converter**
Fluctuating AC voltage (volts)	98 to 250	200
Fluctuating AC current (amps)	51 to 103	93
Fluctuating frequency (Hz)	39 to 65	0

Since AC output is required for the farming activities and possible grid connection as the may be, inverter circuit DC/AC converter was incorporated to the system, converting constant DC output of rectifier to non-fluctuating AC output with consistent voltage, current and frequency as depicted in Figure 11 and 12. This dual-stage conversion process ensures the delivery of consistent and synchronized electrical energy, facilitating seamless integration of wind power into the grid while maintaining grid stability and reliability.

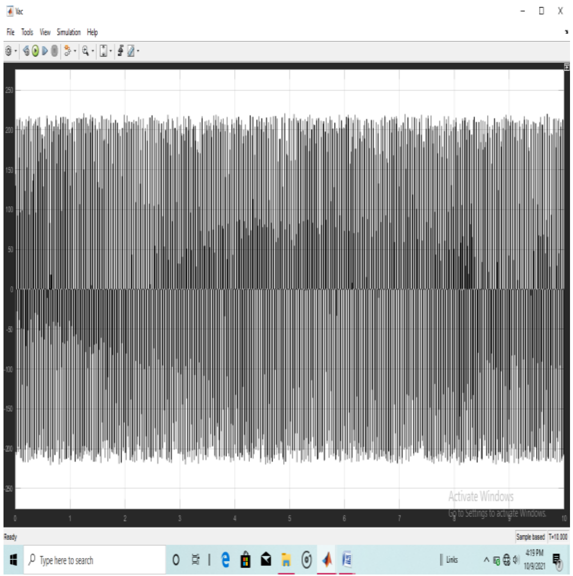

Figure. 11: AC voltage

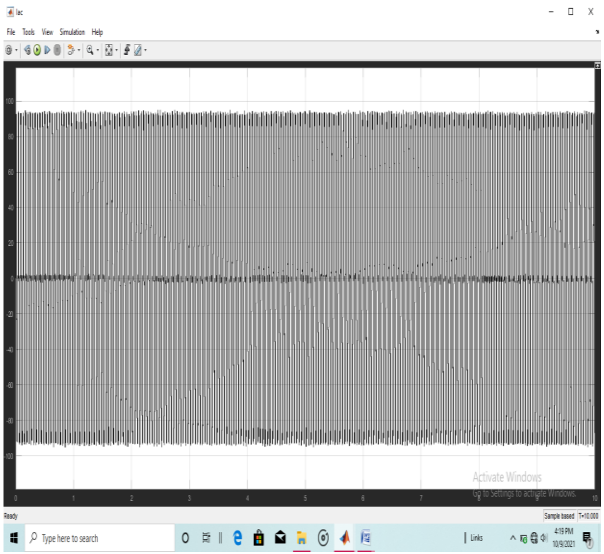

Figure 12: AC current

Figures 11 and 12 illustrate the AC voltage and current of the inverter and was measured to be 200 volts and 92 amperes with a consistent frequency of 50Hz as shown in Table IV and pure sine wave form, highlighting the successful conversion achieved by the system.

TABLE IV
ELECTRICAL OUTPUT PARAMETERS

Output parameter of the designed model	**Numerical values**
Voltage (volt)	200
Current (amps)	92
Frequency (Hz)	50
Power	18.3

These results demonstrate the effectiveness of the converter in producing stable and grid-compatible electrical output from the variable input provided by the wind turbine. The non-fluctuating frequency and pure sine wave characteristics signify the high-quality power generated, not only for farming activities, but also ensuring seamless integration with the grid and reliable operation of connected electrical devices.

C. Results Discussion

The analysis of the wind energy conversion system's fluctuating electrical parameters and the converter system's ability to stabilize and regulate the output for grid integration and efficient utilization is summarized in detail in Tables II, III, and IV.

Table II illustrates the intrinsic variability in electrical characteristics that arises from the intermittent nature of wind energy due to differences in wind speed. These parameters include voltage, current, frequency, and power fluctuations. These parameters are erratic, which emphasizes the necessity of a converter system to stabilize and rectify the electrical output in order to guarantee grid compatibility and effective use of wind power. For example, the wind speed fluctuated between 3.10 and 9.83 meters per second. This led to variations in the generated voltage, which ranged from 98 to 250 volts, the current, which varied from 51 to 103 amps, the frequency, which varied from 39 to 65 Hz, and the electrical power, which varied from 5.1 to 20.6 kW.

Turning to Table III, it is clear how the AC/DC converter helps to rectify the erratic electrical signals produced by the wind turbine system. Effectively converting the erratic AC voltage, current, and frequency into stable forms appropriate for grid integration is the converter's main function. For example, the varying AC voltage varied between 98 and 250 volts, the varying AC current varied between 51 and 103 amps, and the varying frequency varied between 39 and 65 Hz. With the frequency becoming constant at 0 Hz and the voltage stabilizing at 200 volts and the current at 93 amps, these inputs were transformed into a steady DC output.

Table IV demonstrates the effectiveness of the inverter circuit (DC/AC converter) in producing non-fluctuating AC output with consistent voltage, current, frequency, and power. This dual-stage conversion process, involving both rectification and inversion, ensures the delivery of stable and synchronized electrical energy suitable for farming activities and grid connection. For example, the output parameters presented in the table signify the successful transformation of variable wind energy into reliable electrical power, with a voltage output of 200 volts, current output of 92 amps, frequency output of 50 Hz, and power output of 18.3 kW.

These findings emphasize the practicality and viability of implementing such a model as a dependable source of electricity, particularly in remote regions. The potential applications extend to crucial sectors such as irrigation and grain preservation, offering substantial benefits to communities. Zaria local government, Kaduna state Nigeria, renowned for its agricultural activities, tackles with the challenge of unreliable electricity supply, which significantly impedes optimal production and results in substantial losses for farmers. The proposed model holds the promise of bridging this gap by providing a consistent and substantial electricity supply, thereby empowering farmers to enhance their agricultural endeavors. The ripple effects of such empowerment are far-reaching. Not only would it elevate the agricultural output and livelihoods of local farmers, but it would also contribute to bolstering the Gross Domestic Product (GDP) and accelerating economic growth, not only within Zaria local government but also across Nigeria as a whole.

IV. CONCLUSION

In conclusion, the simulation of a small-scale wind energy conversion system tailored for the irrigation needs of farmers in arid seasons has yielded promising results. Utilizing wind speed data from the Nigeria Meteorological Agency (NIMET) and employing Zaria Local Government as a case study, the modeling outcomes demonstrate the system's capability to generate an average power output of 18.3 kilowatt. Moreover, the generator produces 92A of AC current at 200V. These findings affirm the feasibility and practicality of implementing such a model as a reliable source of electricity for remote agricultural areas. By addressing the persistent challenge of electricity scarcity, particularly during dry seasons, this wind energy solution holds significant potential for

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Received 3 Maret 2024, Revised 17 April 2024, Accepted 24 April 2024.
DOI 10.26623/elektrika.v16i1.8999

enhancing agricultural productivity and contributing to economic prosperity in farming communities. Subsequent research ought to concentrate on verifying these findings via empirical experiments, evaluating the feasibility from an economic standpoint, investigating the integration of energy storage, refining control mechanisms, and carrying out life cycle evaluations to guarantee environmental sustainability.

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Jurnal Elektrika Vol. 16 No. 1 2024 P-ISSN 2085-0565 | E-ISSN 2580-8486
Received 3 Maret 2024, Revised 17 April 2024, Accepted 24 April 2024.
DOI 10.26623/elektrika.v16i1.8999