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GRID CONNECTED WIND TURBINE SYSTEM USING RECURRENT NEURAL NETWORK FOR OPTIMAL ESS PROTECTION

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Abstract: This paper proposes an optimal Energy Storage System (ESS) protection for grid-integrated wind turbines using a Recurrent Neural Network (RNN). Traditional methods struggle with predicting power fluctuations, reducing efficiency and grid stability. By leveraging RNN, prediction accuracy improves, optimizing ESS management. The wind farm, consisting of multiple turbines, generates electricity under varying wind conditions. A transformer adjusts the voltage to align with grid requirements, ensuring seamless integration. The ESS plays a crucial role in balancing supply and demand by storing excess energy during high wind periods and releasing it when generation is low. A centralized controller continuously monitors the wind farm and ESS, sending control signals to optimize performance. It directs the ESS to store surplus energy when generation exceeds demand and discharge energy into the grid when needed. This system enhances grid stability and renewable energy reliability. The paper is implemented using MATLAB Simulation 2021a.

***Index Terms* - Energy Storage System (ESS); Recurrent Neural Network (RNN); Doubly Fed Induction Generator (DGIG); Wind Energy Conversion System (WECS); Electric Vehicles (EVs)**

I. INTRODUCTION

Wind energy is one of the fastest-growing renewable sources, converting wind's kinetic energy into electricity to provide a sustainable alternative to fossil fuels. It helps reduce greenhouse gas emissions, combat climate change, and conserve natural resources. Wind turbines, categorized as horizontal-axis (HAWT) and vertical-axis (VAWT), capture wind energy and transform it into mechanical power, which is then converted into electricity by a generator. Key components include rotor blades, gearboxes, and generators, with advanced control systems ensuring efficiency and protection [1].

Seamless integration of wind energy into the electrical grid is essential for stability and reliability. Challenges such as intermittency, voltage fluctuations, and grid instability necessitate solutions like energy storage systems for balancing supply and demand, smart grids for enhanced control, and forecasting models for efficient grid operations. Power electronics, including transformers and inverters, support maximum power point tracking (MPPT) to optimize energy capture. SCADA systems further enhance performance through real-time monitoring and fault detection.

The reduction of traditional energy sources and environmental pollution are two important problems to be solved in today's world. In the past, different types of energy (such as electricity, heating and cooling) often existed independently of each other. In recent years, researchers have turned their attention to the best combination of energy sources because of the benefits they provide. In an energy network, different forms of energy can transform and reinforce each other. When it comes to energy bills, families can choose from a variety of low-energy options to meet their energy needs. Generally speaking, the power grid aims to meet the energy demand of both business and consumer [1,13].

These models increase reliability, reduce environmental pollution, promote energy efficiency improvement, increase safety, and achieve the goal of energy saving and good energy use. The concept of energy center (EC) has attracted the attention of researchers. EEC is considered as a multifunctional machine that combines electrical and load components through a transformer. Previous studies have addressed the issues related to EEC and the relationships between different types of efforts through the EEC model.

Several studies have been conducted on the ESS, focusing on its design, performance, and application in various power electronics systems. Here's a summary of key areas explored in the literature:

Krishneel A. Singh et al [2022] proposed a Studies are currently underway to assess the wind energy characteristics of two islands in the Cook Islands. Daily, monthly and summer average wind speed, changes in wind coefficient, temperature and temperature are estimated using wind data collected over a period of one year from Mauk and Rarotonga in the Cook Islands [2].

Pranoy Roy et al [2022] described Renewable energy sources (RES) are used together by two or more renewable energy sources (such as wind turbines and photovoltaic systems) to increase the efficiency and stability of electronic devices for some reasons. Electricity production from wind and photovoltaic devices can vary seasonally or daily depending on weather and climate. Hybrid systems have many advantages over solar or wind energy due to the combined use of wind and solar energy. Due to the differences in wind forces, the rotation speed of the generator that produces the most power in wind energy conversion needs to be determined [3].

Yinping Yang et al [2022] developed Wind and solar energy are the main reliable renewable energy sources used by the grid. The variability and unpredictability of this renewable energy requires the use of additional services, which in turn results in additional costs. This difference is due to two reasons. First, the specific capacity in the WGC model is assumed to be seasonally adjusted, while the storage capacity in the WSPC model is allowed to vary hourly according to the day-ahead forecast for wind and solar energy [4].

Chiyori T. Urabe et al [2022] it has been revealed that the rapid growth in the integration of renewable energy sources (VRE) can complicate the energy production of these renewable sources due to the change in their output. Both profile types have the same resolution time for each BA. If WPP data is found to be missing, we will not use other personal data at the same time. STF operation often results in power loss [5].

Iram Akhtar et al [2023] presented Measuring the reliability of wind energy has been incorporated into microgrid systems to increase grid security. The share of wind energy in electricity generation is increasing due to environmental concerns and reducing carbon footprint. Create efficient wind turbines for smart devices designed to reduce the load on the grid. Integrating wind turbines into home networks can increase the reliability of microgrid systems in smart designs. These wind turbines do not need to be purchased from fossil power plants, making the process reliable, and all eight cases are environmentally friendly and reduce carbon emissions [6].

Florian Stadtmann et al [2023] described a Digital twin technology and its potential focus on its applications in the wind energy industry. Challenges from the company's perspective were identified and recommendations were made to various stakeholders to facilitate the adoption of the technology. This means that the power output of wind energy and photovoltaic energy is lower than expected and the PHS station cannot meet the deficit. Therefore, TES systems need to release heat to generate electricity [7].

Marc Principato et al [2023] demonstrated Potential of machine learning-based methods to detect and prevent bird-wind turbine collisions. A comprehensive review of existing systems is conducted and important gaps in the literature are identified, providing the basis for future research and development in this area. They are particularly vulnerable to environmental degradation due to their small population size and low cost [8].

Samandar Khan Afridi et al [2024] brief Extensive research on onshore, offshore and floating offshore wind turbines, which are important components of sustainable energy production. An in-depth study to show the unique features, benefits and limitations of various wind turbines. This caution stems from factors not fully considered, such as lifespan, operational expenses, and financial costs. Onshore wind farms not only contribute significantly to the global shift towards clean energy but also bring about crucial environmental benefits [9].

Bingrong Shang et al [2024] suggested an integration of renewable energy into the grid is becoming increasingly common, but its randomness can make energy stable. The high-voltage direct current (HVDC) connection model, based on modular multi-level converters with on-board energy storage (MMC-EES), is intended to use the massively parallel computing capacity of graphics processing units (GPUs). For change. However, for multi-terminal complicated systems, FPGA is deficient in terms of digital hardware resources to accommodate practical large-scale circuits and systems [10].

Mourad Yessef et al [2024] demonstrated Experimental study of a proportional input (PI) controller using control strategies to control a generator using multiple wind turbines. This control scheme uses pulse width modulation (PWM) to control the power of a two-ratio induction motor controlled by direct power control (DPC) to control and control the inverter. MRWT turbines can overcome the negative winds generated by the turbines in wind farms because the turbines are not affected by these winds, which makes their energy production large and irreversible [11].

Objectives:

- To implement optimal ESS protection in grid integrated wind turbine system using recurrent neural network.
- To develop a bidirectional DC-DC converter to manage energy flow between the battery and the DC bus.
- To implement PWM rectifiers and generators for effective voltage regulation.
- To design PI controllers for stable operation and quick response to system demands

II. CONFIGURATION OF GRID CONNECTED WIND ENERGY SYSTEM

This paper develops a Recurrent Neural Network (RNN)-based Energy Storage System (ESS) protection for a grid-integrated wind turbine system. It combines a doubly-fed induction generator (DFIG)-based Wind Energy Conversion System (WECS) with an ESS to enhance grid stability and efficiency. The DFIG captures wind energy and converts it into electrical power, which is processed through a PWM rectifier to generate a stable DC voltage. This voltage is transferred via a DC bus for efficient energy distribution. A PWM generator and a Proportional-Integral (PI) controller regulate voltage and current outputs, ensuring optimal performance. The ESS, equipped with a bidirectional DC-DC converter and battery, enables energy storage and retrieval, maintaining power reliability under fluctuating wind conditions. An RNN controller monitors battery state of charge (SOC), manages energy flow, and detects faults for system protection. Additionally, an LC filter and a Voltage Source Inverter (VSI) improve power quality at the grid connection. The paper is implemented using MATLAB Simulation 2021a.

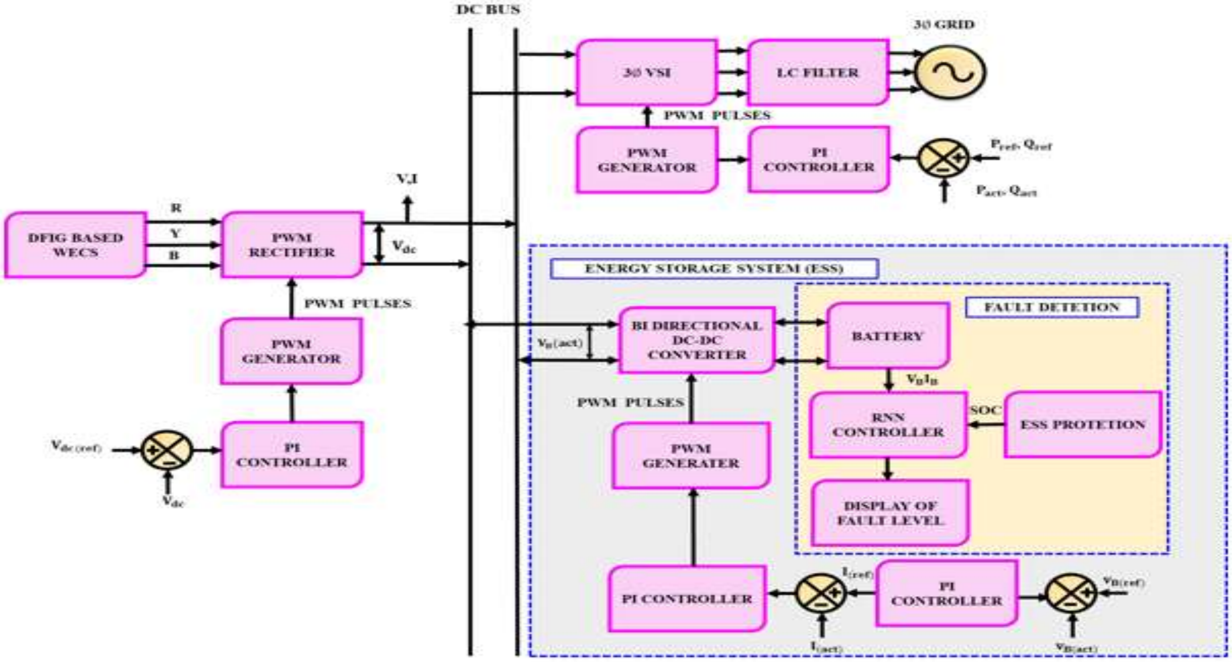


Figure 1 Block Diagram of Proposed System

A. DFIG Based WECS System

Doubly-fed induction generators (DFIGs) are widely used in wind energy conversion systems (WECS) due to their ability to operate across varying wind speeds while ensuring power control and grid stability. In a DFIG-based WECS, wind turbines convert wind energy into mechanical energy, which is transferred to the rotor shaft and then to the DFIG for electrical conversion [12].

The DFIG has two winding groups: the stator, directly connected to the grid, and the rotor, controlled by back-to-back converters. These converters regulate frequency, voltage, and current while enabling bidirectional power flow between the rotor and the grid, enhancing efficiency. The control system optimizes power generation using rotor-side control to adjust generator speed for maximum power extraction and grid-side control to regulate voltage and ensure stable power supply. This configuration enhances grid compatibility, improves reliability, and increases overall efficiency in wind power integration.

A DFIG-based WECS effectively converts wind energy into electricity while enhancing grid stability through reactive power control. Its variable-speed operation and advanced control mechanisms ensure high efficiency and adaptability, making it well-suited for modern renewable energy grids. This system maximizes wind energy utilization while maintaining a stable and reliable power supply to the grid [13,14].

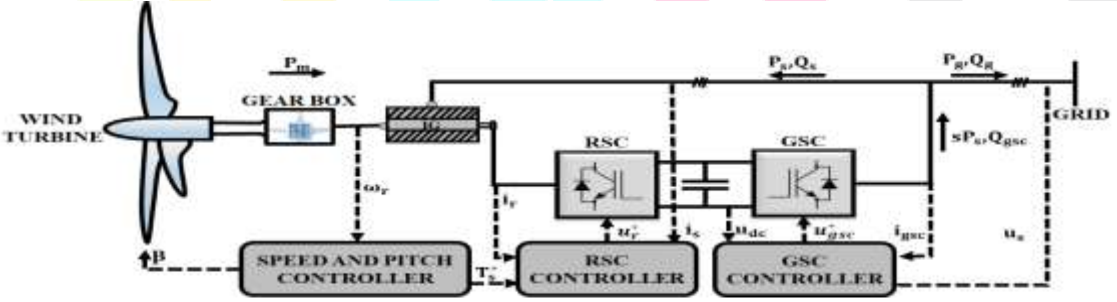


Figure 2 Schematic Diagram of DFIG

III. RESULTS AND DISCUSSIONS

The simulation results were analysed using the program called MATLAB/SIMULINK. MATLAB is a language that can be used to calculate, visualize and compute in the user environment, where the problem and its solution are expressed using the information method. MATLAB is the best tool for signal analysis. The overall simulation diagram is shown in figure 3 and the obtained results were explained below.

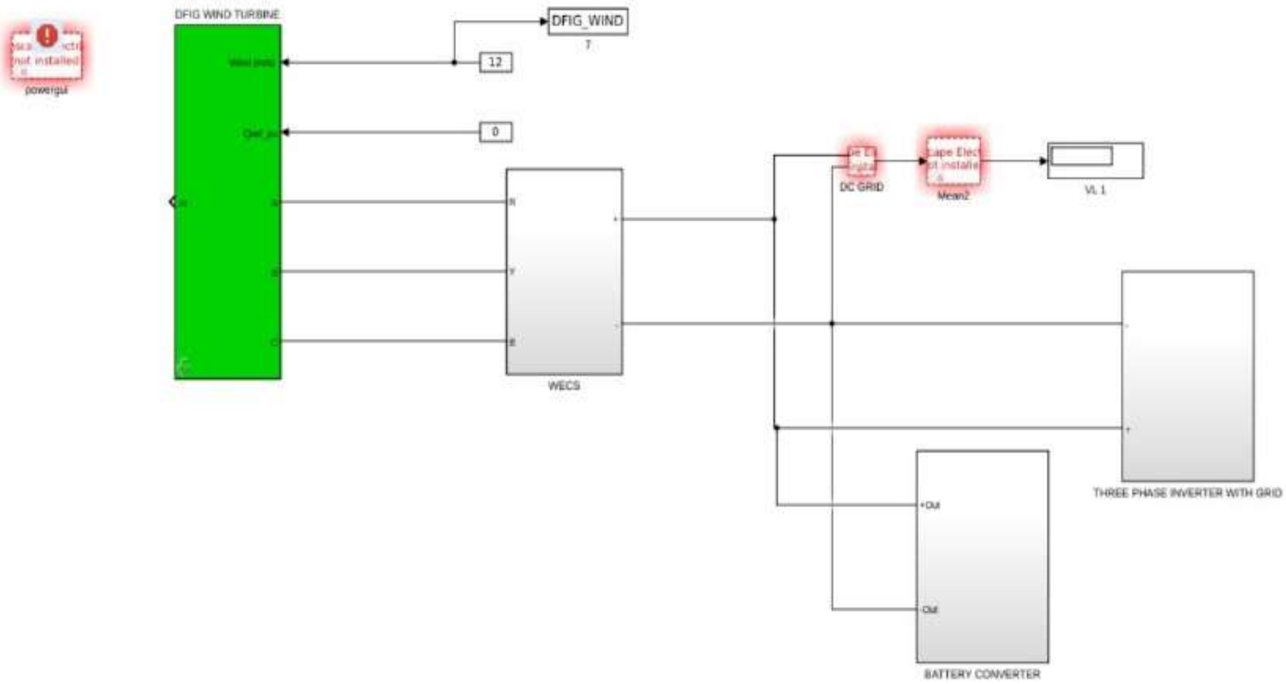
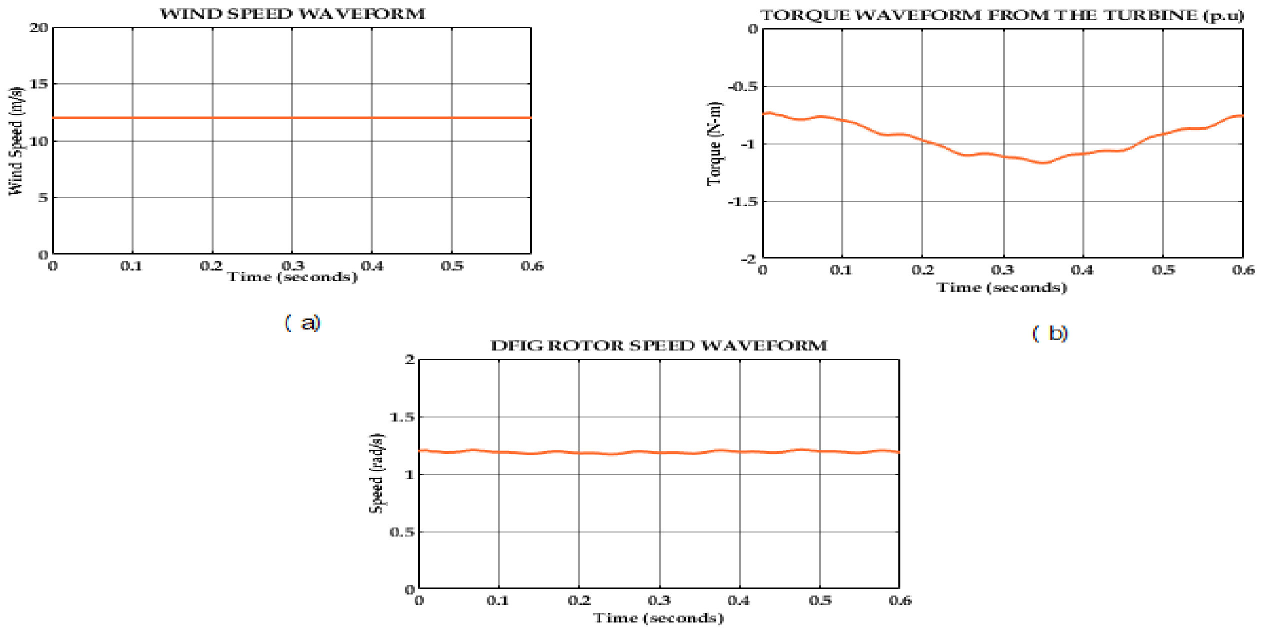


Figure 3 Overall Simulation Diagram



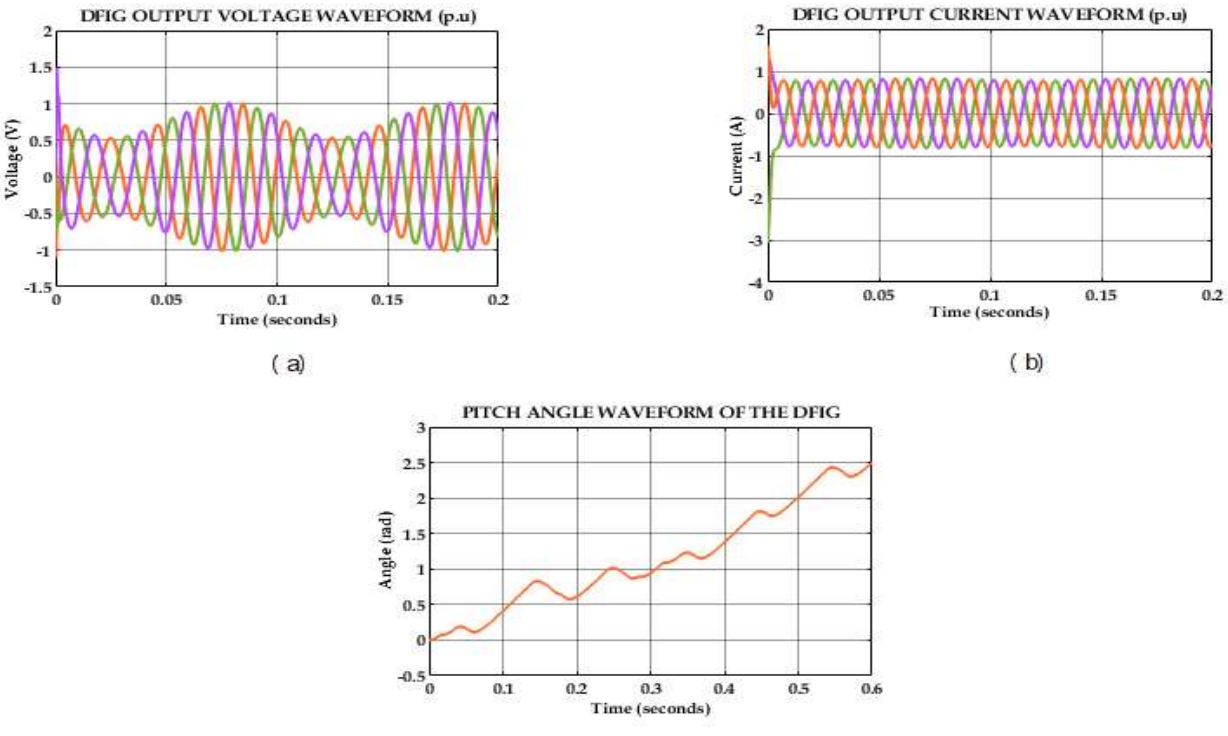
(a)

(b)

(c)

Figure 4 (a) Waveform for wind speed and (b) Torque from wind turbine (c) DFIG rotor speed

Figure 4(a) shows constant wind speed at 12 m/s over 0.6 seconds. Figure 4(b) illustrates wind turbine torque, initially decreasing to -1 before gradually increasing. Figure 4(c) depicts the DFIG rotor speed, maintaining a steady 1.2 rad/s throughout the duration.



(a)

(b)

(c)

Figure 5 (a) Waveform of DFIG output voltage and (b) output current and (c) Pitch angle

Figure 5 (a) shows the DFIG output voltage, which fluctuates initially before stabilizing after 0.15 seconds. Similarly, Figure 5(b) illustrates the output current of the DFIG, which deviates at first and then remains constant. Figure 5(c) depicts the pitch angle of the DFIG, gradually increasing over time.

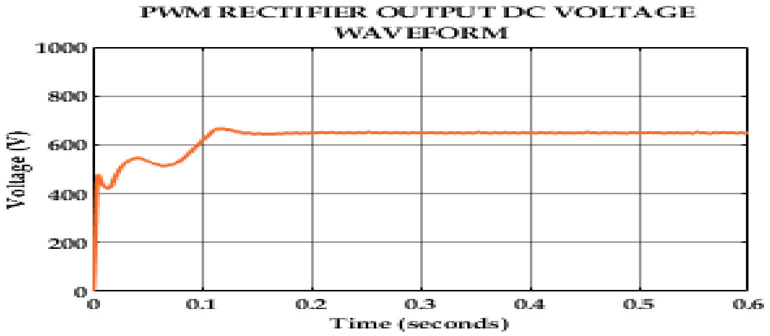


Figure 6 Waveform of output DC voltage of PWM rectifier

Figure 6 shows the DC output voltage waveform of the PWM rectifier, which rapidly rises to 470V at the beginning, then gradually fluctuates and increases to 630V before stabilizing.

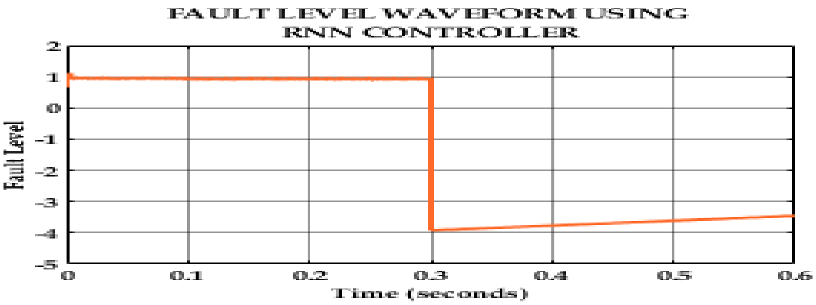
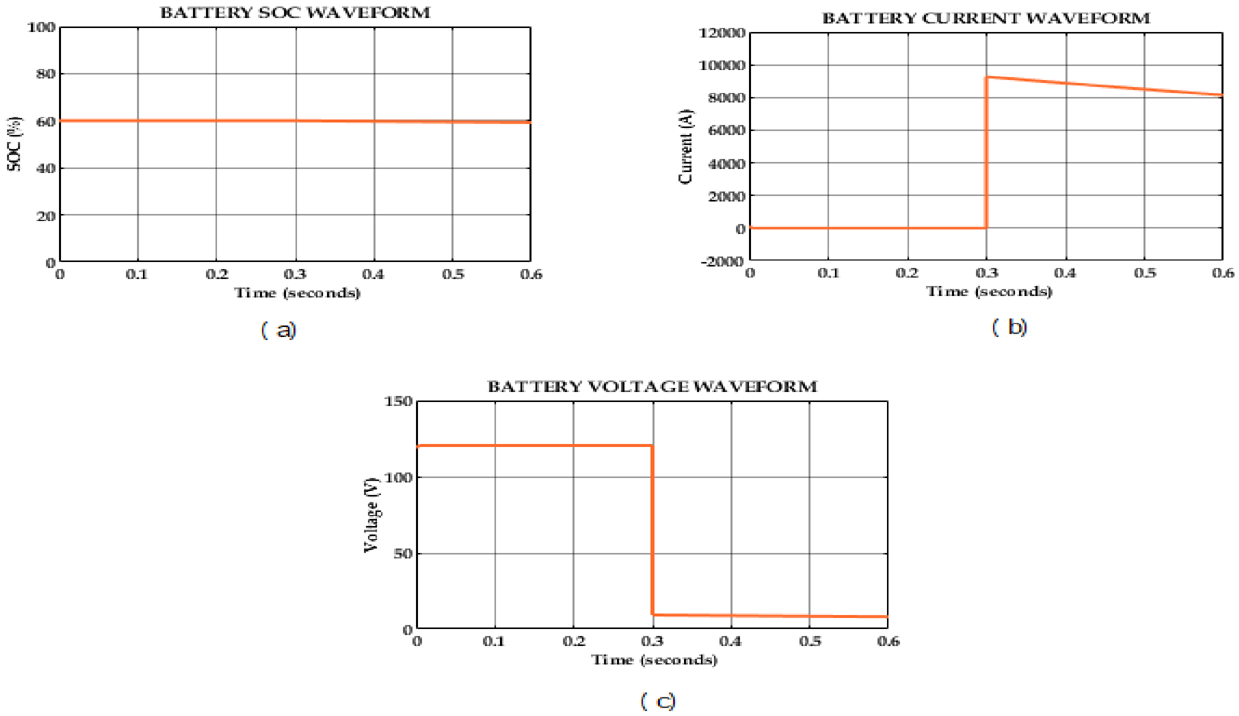


Figure 7 Waveform of fault level for RNN controller

Figure 7 illustrates the waveform of the RNN controller fault level. Initially, the fault level is 1 and remains stable until 0.3 seconds, at which point it sharply drops to -4, then gradually increases to -3.5.



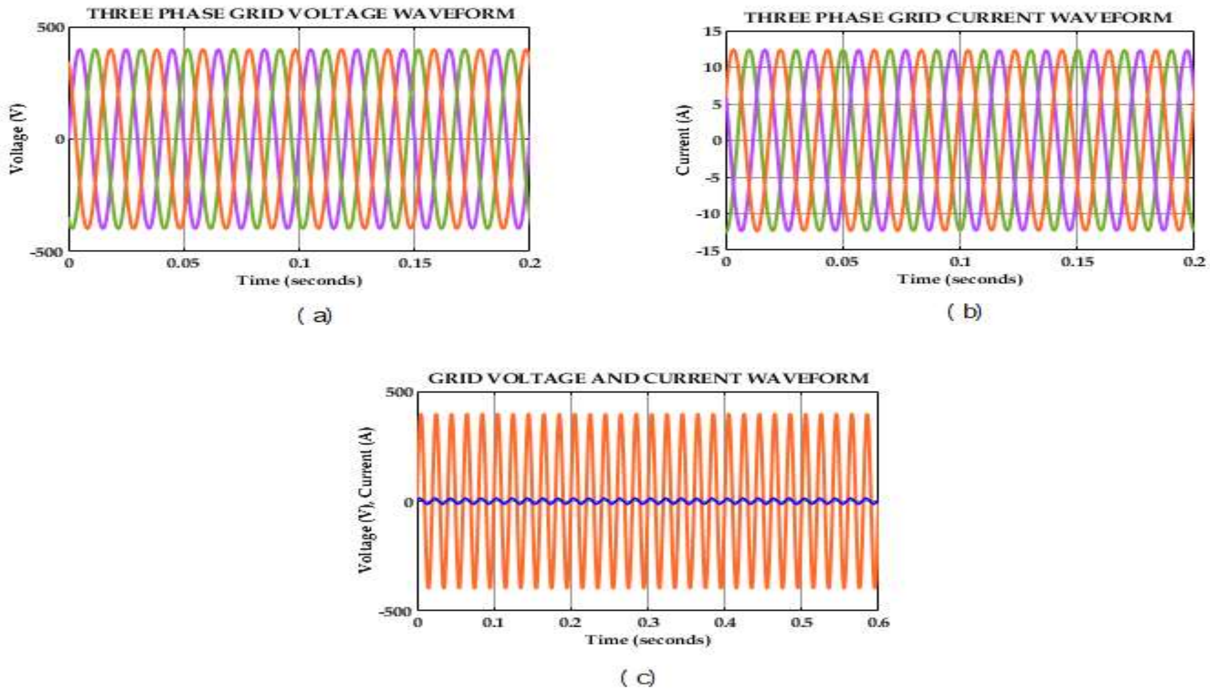
(a)

(b)

(c)

Figure 8 (a) Waveform of battery SOC (b) current and (c) voltage

Figure 8(a) shows the battery's state of charge (SOC), which remains stable at 60% throughout the time period. Figure 8(b) and (c) depict the battery current and voltage waveforms, where the current spikes above 8000 at 0.3 seconds before decreasing, and the voltage drops below 50V at 0.3 seconds, then stabilizes.



(a)

(b)

(c)

Figure 9 (a) Waveform of Three-phase grid voltage and (b) current (c) grid current and voltage

Figure 9(a) and (b) show the three-phase grid voltage and current waveforms, where both voltage and current remain stable without deviations. Figure 9(c) depicts the grid voltage and current waveforms, with both current and voltage staying consistent throughout the 0.6-second time interval.

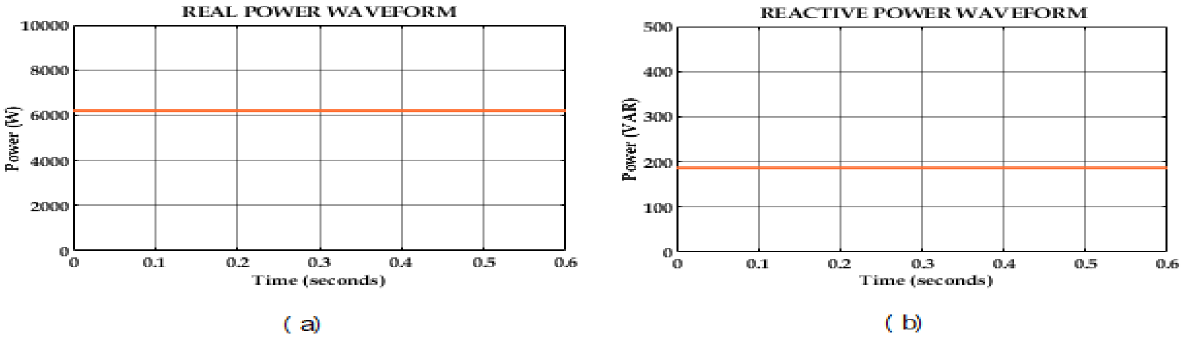


Figure 10 (a) Waveform of Real power (b) Reactive power

Figure 10(a) and (b) show the real and reactive power waveforms, with both remaining stable at 6110 W and 190 VAR, respectively, resulting in enhanced power output and reduced losses.

IV. CONCLUSION

In conclusion, this paper demonstrates the effectiveness of using Recurrent Neural Networks (RNNs) for the optimal protection and management of an Energy Storage System (ESS) in a grid-integrated wind turbine setup. By integrating wind energy with the electrical grid, this approach enhances renewable energy stability and reliability, addressing wind power intermittency. The centralized control system, combined with the RNN-based predictive model, ensures optimal performance by efficiently managing supply and demand. Through MATLAB Simulation 2021a, the paper validates the RNN-driven ESS control's ability to improve grid stability, reduce energy waste, and support a more sustainable, reliable renewable energy infrastructure.

REFERENCES:

1. S. Vendoti, M. A. Inayathullaah, M. Chiranjivi, C. Fabbina, K. S. Kavin and P. Malathi, "A WECS fed Grid Tied DC-DC LUO Converter for Energy Management in Electric Vehicle System," 2024 2nd International Conference on Computer, Communication and Control (IC4), Indore, India, 2024, pp. 1-7, doi: 10.1109/IC457434.2024.10486647.
2. K. A. Singh, M. G. M. Khan and M. R. Ahmed, "Wind Energy Resource Assessment for Cook Islands With Accurate Estimation of Weibull Parameters Using Frequentist and Bayesian Methods," in IEEE Access, vol. 10, pp. 25935-25953, 2022.
3. P. Roy, J. He, T. Zhao and Y. V. Singh, "Recent Advances of Wind-Solar Hybrid Renewable Energy Systems for Power Generation: A Review," in IEEE Open Journal of the Industrial Electronics Society, vol. 3, pp. 81-104, 2022.
4. Y. Yang, C. Qin, Y. Zeng and C. Wang, "Optimal Coordinated Bidding Strategy of Wind and Solar System with Energy Storage in Day-ahead Market," in Journal of Modern Power Systems and Clean Energy, vol. 10, no. 1, pp. 192-203, January 2022.
5. C. T. Urabe, T. Ikegami and K. Ogimoto, "Mitigation of Short-Term Fluctuations in Wind Power Output in a Balancing Area on the Road Toward 100% Renewable Energy," in IEEE Access, vol. 10, pp. 111210-111220, 2022.
6. I. Akhtar, A. Altamimi, Z. A. Khan, B. Alojaiman, M. Alghassab and S. Kirmani, "Reliability Analysis and Economic Prospect of Wind Energy Sources Incorporated Microgrid System for Smart Buildings Environment," in IEEE Access, vol. 11, pp. 62013-62027, 2023.
7. F. Stadtmann et al., "Digital Twins in Wind Energy: Emerging Technologies and Industry-Informed Future Directions," in IEEE Access, vol. 11, pp. 110762-110795, 2023.
8. M. Principato, L. Hasselwander, M. Stangner and R. Buettner, "Unlocking the Potential of Wind Energy with Machine Learning-Based Avian Detection: A Call to Action," in IEEE Access, vol. 11, pp. 64026-64048, 2023.
9. S. Khan Afridi et al., "Winds of Progress: An In-Depth Exploration of Offshore, Floating, and Onshore Wind Turbines as Cornerstones for Sustainable Energy Generation and Environmental Stewardship," in IEEE Access, vol. 12, pp. 66147-66166, 2024.
10. B. Shang, N. Lin and V. Dinavahi, "Detailed Nonlinear Modeling and High-Fidelity Parallel Simulation of MMC With Embedded Energy Storage for Wind Farm Grid Integration," in IEEE Open Access Journal of Power and Energy, vol. 11, pp. 196-206, 2024.
11. M. Yessef et al., "Experimental Validation of Feedback PI Controllers for Multi-Rotor Wind Energy Conversion Systems," in IEEE Access, vol. 12, pp. 7071-7088, 2024.
12. S. Vendoti, K. Ravi Shankar, P. Chinni Gopal and K. R. S. Akhil Kumar, "Implementation of four-phase interleaved DC–DC boost converter for electric vehicle power system," 2023 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE), Bengaluru, India, 2023, pp. 587-590, doi: 10.1109/IITCEE57236.2023.10090980.
13. Vendoti Suresh, Muralidhar M., R. Kiranmayi, "Modelling and optimization of an off-grid hybrid renewable energy system for electrification in a rural areas", Energy Reports, Volume 6, 2020, Pages 594-604, ISSN 2352-4847. (SCI & SCOPUS) https://doi.org/10.1016/j.egyr.2020.01.013.
14. Vendoti, S., Muralidhar, M. & Kiranmayi, R. "Techno-economic analysis of off-grid solar/wind/biogas/biomass/fuel cell/battery system for electrification in a cluster of villages by HOMER software". Environ. Dev. Sustain., 23, 351–372 (2021). https://doi.org/10.1007/s10668-019-00583-2.