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Study and Analysis of RBFN based MPPT controller for wind energy integrated with Traction Power Supply System

Abstract: -The need of energy for railway is rising due to the increased speed at which trains must operate to maintain safety and dependability. This situation implies more electricity consumption and more challenges to railway operation stability. Therefore, this research suggests configuring wind energy integration with the current railway traction substations built on the current traction substation. The suggested setup consists of a converter that converts DC to DC with RBFN-based MPPT regulator wind energy source linked to a permanent magnet synchronous generator (PMSG), a rectifier, and a conventional traction system. The proposed system is modelled and analyzed by utilizing a radial basis function network (RBFN) in this study. Three traction substations: Aysha, Adegla and Dewanle:-are the subject of the case study, which integrates wind energy with the railway electric power system working at 25 kV AC. For the Aysha wind farm, a MATLAB/Simulink simulation is run in order to confirm the suggested technology. The setup with or without MPPT was used in order to evaluate the results. The proposed system produces an average output of 260.3kW without MPPT and 289.3kW with MPPT controller at wind speed of 20m/sec. The simulation findings suggest that the RBFN-based control method performs better under diverse wind conditions and is more suited for wind energy integration with traction system.

Keywords: MPPT, PMSG, RBFN, Traction power, Wind Energy

I. INTRODUCTION

One of the primary sources of green, sustainable energy and energy efficient methods of generating electricity from renewable sources for the modern electric system is wind energy. Due to its abundant wind resources, among the most significant and rapidly growing sources of green energy in the globe.The unique characteristics of wind power systems such as its inconsistent environment, wind turbine technological advances, and security concerns provide further challenges to the economic and effective incorporation of the systems. Reliability and accuracy in wind power forecasting are critical for the effective operation of wind farms and their integration into the electrical grid. Because wind is unpredictable, it is challenging to forecast, which makes integrating wind power into electrical system is challenging.[1]-[4] It also offers a clean energy source, making it a viable short-term alternative in Ethiopia. Ethiopia has access to an extensive array of green power resources such as hydropower, geothermal energy turbines, biomass, and solar power. Hydropower has an estimated 45GW of exploitable potential, Energy from geothermal sources has five GW, winds provide ten GW, and solar energy varies between 4.5 KWH/m2 to 7.5 KWH/M2/day. [5]

This research work is done based on the "Aysha II wind farm'', which is in Somali Region, Ethiopia, about 170 kilometers to Dire Dawa, about 150 km from Djibouti, and the Ethio-Djibouti Railway line through the west of wind farm. Ethio-Djibouti 230kV transmission line crosses the wind farm and the local 33kV distribution grid is laid along the all-weather road. Aysha wind farm is located in north latitude 10° 29'～ 10° 49', east longitude 42° 30'～ 42° 47', which belongs to the semi-desert and semi-gobi area, and the transition zone of plateau in the face of the ocean as shown in the Figure 1.Aysha area is in the northern Somali region and at the end terminal of the national grid, away from the power source center, situated in the tropical desert climate zone without power resources, and is subject to serious shortage of electricity supply due to heavy power loss supplied by the national grid and aging distribution network.

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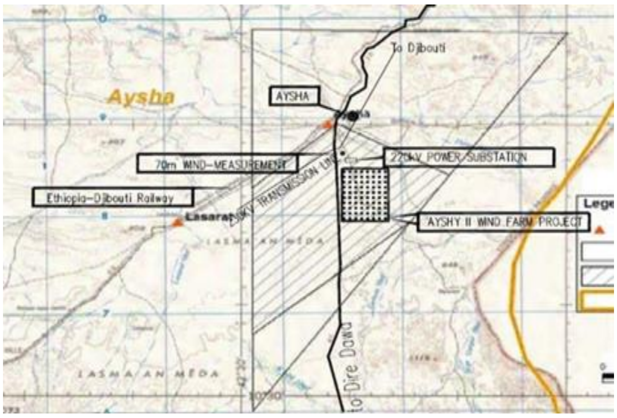

Fig.1. Layout of Aysha Wind Farm

The installed capacity of Aysha II wind farm is 120 MW, the proposed WTGs are 48 sets DEC DF103-2500. The outlet voltage is 0.69 kV, the step-up transformers is 48 sets of box-type transformer with a capacity of 2750 kVA. The connection of WTG and step-up transformer is by unit connection with one WTG with one box-type transformer. The box-type transformer is located about 15~20m beside WTG. There are 6 circuit 33kV collector lines, and each circuit collector line connects 8 WTGs. The HV side of a 33kV box-type transformer connects to collector line by XLPE insulated cable. The technical characteristics of related turbines are specified in Table 1.

Table 1: Technical parameters of Aysha Wind Farm

Name	**DF-103-2500**
Rated power	300kW
Blade Quantity	3
Rotor Diameter	103m
Cut in wind speed	3m/sec
Rated wind speed	10.8m/sec
Cut out wind speed	25m/sec
Hub height	80m
Generator type	Permanent magnet synchronous Generator
Out voltage	690v
frequency	50Hz

Ethio-Djibouti Railway is the first modern cross-border railway in Eastern Africa, which adopt traction power system of 25kV and 50Hz.But there is frequently power cut in railway line due different reasons which affects the railway transportation. The data from the local SCADA system of the Ethio Djibouti railway traction substations shows that on average there is a power cut of more than 29 hours per month. The frequently power cut affects the voice and data communication. The most critical data is signal data used to communicate wayside equipment's with train and control center. To have safe and efficient railway operation there should be continuous data transfer between stations and train, between way side equipment’s etc. It's critical to increase efficiency and dependability by utilizing renewable power sources.

Thus, developing the railway's digital tiny generation network is crucial to accomplishing a decrease in pollutants, power saving, and increased electricity stability for the station. [6–7] It is crucial for tracking the highest point in the grid-connected turbine architecture to optimize the productivity of solar power. Trains are one of the greatest energy-intensive forms of transportation. Due to the rapid and swift growth of the lighted railroads, tremendous quantities of electricity are required. Because solar power is variable and uncertain and train load fluctuates quickly, railroad power is vulnerable to unexpected reductions in strength as well as additional reliability issues. These issues affect how the train system operates. To fulfill this country's major electrical requires, the goal in this study is to find a solution for the challenge of acquiring the optimum amount of electricity from intermittent sources of electricity with electrical assets creating low output of emission.

This work primarily concerned with the investigation of the optimal power tracking controller approach that uses a direct-current (DC) to direct-current (DC) for wind electricity conversion systems (WECS). A computerized neural web is required for this technique.

This approach relies on artificial neural networks. The proposed approach abstracts the selected voltage from wind speed using an artificially intelligent control method based on a Radial Basis Function network. The capability of the suggested MPPT in the absence of wind vitality linked with a mechanical electricity supply system is evaluated by taking into consideration the shifts in information on wind speeds over time.[8]– [10]A single MPPT controller, which is designed around the radial basis features network is used in an aerodynamic system with a 250kW wind component rating and a traditional boosting converter topology. The findings from simulations are shown to validate the combination of voltage measuring capability of the proposed MPPT control technique. The article is structured as follows for the remainder of it. The planned RBFN and its integration with the electrical and propulsion systems of power are shown in Section 2. The MPPT algorithm built on the radial basis function of the radial basis system is explained and its efficiency in relation to different atmospheric conditions is examined in Section 3. Section 4 reports the modeling findings, while Section 5 enumerates the outcomes. are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. Literature Review

One of the biggest and most energy-intensive end users is the electric railway system.[11] One potential approach to support the partial independence of energy producers in the traffic rail sector is to hybridize railway substations using energy sources derived from renewable sources. Using renewable energy can help reduce the amount of energy used by railway and the depletion of nonrenewable energy sources. Renewable energy sources (RES), such as turbines that spin and solar PV sections, are used as an alternative to the conventional electric grid to either entirely or in part provide the required capacity. One potential tactic to encourage the energy producers' partial independence in the traffic rail sector is to hybridize the energy used in railway substations with renewable energy. Using renewable energy can help reduce the amount of energy used by railroads and the depletion of nonrenewable energy sources,besides providing electricity to the primary electricity grid, renewable energy sources (RES) like solar cells and turbines that produce electricity are employed to supply the required capacity partly or completely.[12]– [13] Through single-phase 132kV/25kV transformers, the electrical supply system of a railway line supplies the trains with the appropriate characteristics of electric power from the high-voltage network. The power transmission system's two phases are connected to these transformers. The system of transmission power sources is divided into isolated portions by the intermediate portion, which receives electricity from multiple traffic substations as well. [14-15]

Wind-powered electricity gathering mechanisms, which generate environmentally friendly electricity that powers independently. The motion energy created by the rotor's strength is converted into electricity and motion by an alternator in a turbine that produces electricity. The PMSG varies in its reaction to variations in the pace of the wind. Utilizing an optimal power point tracking (MPPT) system, the solar energy collection system is operated at a rate that corresponds to the greatest power at any wind direction. Numerous methods are developed in order monitor the biggest power point efficiently.

The majority of current MPPT algorithms have the flaw of being slow tracking, which lowers utilization efficiency. The following are examples of artificial neural networks (ANNs) using back propagation techniques: fuzzy logic controller for intelligent control with DC-DC converter, incremental conductance computation (INC), hill climbing or perturbation and observation (P&O), and particle swarm optimization are some examples of MPPT control techniques that can be used to increase wind energy efficiency. A review of the literature on several maximum point tracking system techniques has been conducted and reported in this study.

A straight MPPT method, similar Perturb & Perceive, was proposed by V. T. Vasantha Kumar and B. Ashok Kumar [16] besides is intended for use in solar energy systems. In addition to designing the RBFN procedure, that is utilized in MPPT for renewable energy plants, the utilization of wind power systems in grid-tied applications is investigated once it is linked to a hybrid structure. Using a DC/DC converter, a suggested maximum power point tracking, or MPPT, control scheme for wind energy conversion systems (WECS) depends on artificial neural networks (ANNs) in [17]. To excerpt the most conceivable control beginning the wind velocity, suggested topology makes use of a neural network control technique based on radial basis function networks (RBFNs). The outcomes are contrasted using the Back Propagation Network (BPN) method and the conventional P&O (Perturb and Observe) technique. For maximal power extraction, the bidirectional backstepping termination sliding type is a presented in [18]. This is confirmed whether the structure is finite-time stability using the Lyapunov coefficient. PV power is supplied to the load via a DC-DC buck-boost converter. A radial basis function neural network produces reference voltages for the suggested controller (RBF NN).

Tiwari R, and Babu NR [19] proposed the greatest amount of tracking from solar and wind energy is achieved with a controller based on fuzzy logic. However, to create fuzzy rules and maximize power generated from sources of renewable energy, previous information on the weather at the moment is necessary. A differential step size in this work, an Advanced Fuzzy Logic Controller constructed around Peripheral Basis Functions Networks (VSSDE-AFLC) is proposed [20] to track the fuel cell system's peak power point. The benefits of suggested Maximum Power Point Tracking (MPPT) regulator include a fast swiftness of tracking the petroleum chamber's operating point, extra elasticity, a great abundance of allowable fluctuations over MPP, besides a reduced reliance taking place fuel stack modelling.

This paper [21] uses a variety of MPPT techniques, including Neural network technology built a radial basis-function network (RBFN), gradual conductance, and disruption and observation to determine proper responsibility sequence for gaining the optimal control beginning the solar PV tree. In comparison to the other two methods, the RBFN-based NN offers superior pursuing competence besides reduced fluctuation, according to simulation and real-time findings. A controller that uses fuzzy logic to monitor solar and wind electricity or energy's maximum power was proposed by Tiwari R and Babu NR [22]. It is necessary to have prior information about current weather conditions to create fuzzy rules that increase the amount of power produced by sources of sustainable energy. Power supply for the Ethiopia-Djibouti Railway is a single-phase, 25 kV, 50 Hz system. The three-phase, 132kV power supply that powers the railway system and is sourced from the national grid via a V/V transformer serves as the main power source in this study. The catenary system is then powered by this 25 kV two-phase voltage, which is created from the 132 kV three-phase voltage. [23] Figure 2 illustrates the basic structure of the suggested arrangement. Three main components make up the suggested system. These include the control system, train locomotive, renewable energy source, and railway traction substation. Wind energy source and the main grid power supply system are integrated into the strategy of a mixture or hybrid scheme. Following its receipt by after being regulated by a rectifier using diode bridges and supplied again to the DC-DC boost conversion, the energy input from the solar power generator is received by the DC-DC converter. By using the suggested MPPT control strategy, the AC train electrical power method incorporates wind turbines. AC railway power supply system integrates wind energy through the recommended MPPT control approach. The tracing approach is applied to cutting the greatest control from wind or turbine energy, and it is simulated as a case study. To maximize the electricity generated by the winds, we propose an ANN-based MPPT algorithm to increase the amount of power produced using green energy across a range of weather conditions.[24]– [26] This subsection provides an explanation of each of the wind generator, PMSG, and electric power conversion simulators that make up the entire WECS system. This part is the various wind generator, PMSG, and electricity conversion simulators that make up the entire WECS technology.

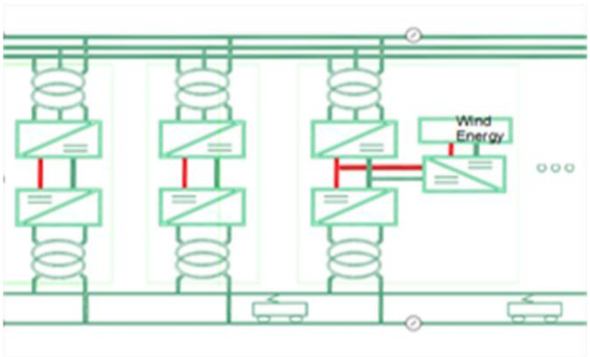

Fig.2. Wind energy system integrated with traction power supply

III. RBFN BASED MPPT CONTROL ALGORITHM OF WIND ENERGY SYSTEM

Trains are one of the most energy-intensive forms of transportation. It is obvious that energy use and carbon emissions are related to the global climate. Because of how quickly the electrical railway developed, enormous amounts of electric energy are consumed. Because wind energy is variable and unpredictable and train load fluctuates quickly, traction power is vulnerable to unexpected dips in voltage and other power quality issues. These issues affect how the railway operation.

A stable electricity supply and the achievement of the net zero carbon emission target are the driving forces behind this research project. Additionally, experts and researchers regarding wind power can ascertain the present status of ANN application in wind energy integration with railway traction power supply system. This study may also be helpful in identifying new research directions that could enhance the railway power supply system and produce renewable energy for the railway.

As seen in Figure 3, the RBFN created MPPT controller comprises an input layer, a hidden layer, and an output layer, making it a three-layer networks. Multilayer perceptron's are trained using this supervised learning algorithm (MLP). Levenberg-Marquardt (LM) training was used to assess the model in an array of transmitting layers. [27]-[31] Time-tuning the weights to produce the expected output (duty cycle) when a set of inputs is applied is the training objective of RBFN based on MPPT approaches, as shown in Figure 4. To do this, the RBFN must be trained with wind and current values as input variables. The maximum voltage is then provided as output data. The following is a summary of the RBFN implementation methodology.

Step 1. Input layer to receive voltage and current input data from wind energy sources.

Step 2. Prepare the training set of data.

Step 3. Figure a RBFN with hidden layer.

Step 4 Modify the parameters of RBFN.

Step 5. Productivity can be improved by adjusting the weights of the hidden neuron layer by changing the weights of the network.

Step 6. Complete the RBFN training, validation, and testing.

Step 7. Create PWM to regulate the switch's duty or work cycle.

Input layer   Hidden layer.

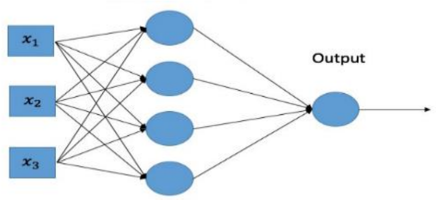

Fig. 3. RBFN Architecture

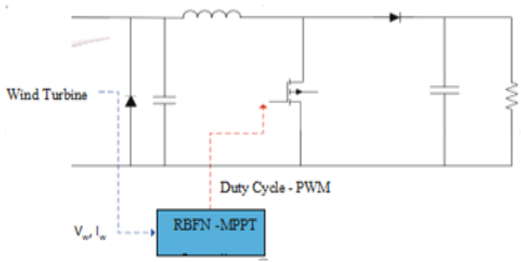

Fig. 4: RBFN -based MPPT algorithm

The ANN framework for this study was created using MATLAB version R2021, as seen in Figure 5. For ANNs to be used for prediction and classification, the statistical features of the test, validation, and training data are crucial. The data set is divided into three subsets: 15% is put aside for testing, 15% for validation, and 70% is used for training. As the training progressed, Levenberg-Marquardt (LM) training algorithms were employed.

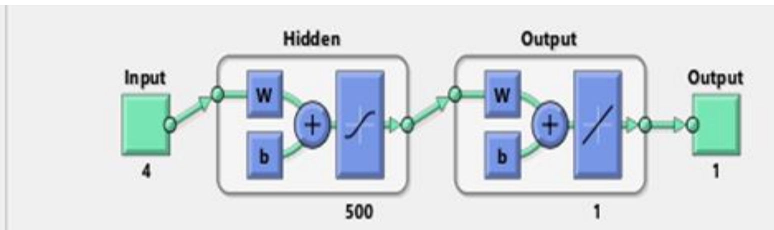

Fig.5: RBFN based single MPPT architecture for wind energy system.

IV. Simulation and Result Discussion

As seen in Figure 6, In the MATLAB, the MPPT-based wind turbine was modeled. A boost converter and 300kW of wind energy were employed in the proposed model's simulation [31-32] to increase the voltage step. The RBFN learning algorithm uses 2000 data items to create an output neuron, 500 hidden-layer neurons, and the

MPPT algorithm. This study tests the suggested system for wind energy integration with a railway power supply both with and without an MPPT controller. Figure 7 shows the best validating results of the RBFN administrator, which was developed using the Levenberg-Marquardt method. Figure 8 presents a validation check and the recommended RBFN trained network gradients. In Figure 9, the optimal regression for training, test, validation, and overall efficacy data is displayed for the proposed and suggested RBFN-based MPPT method.

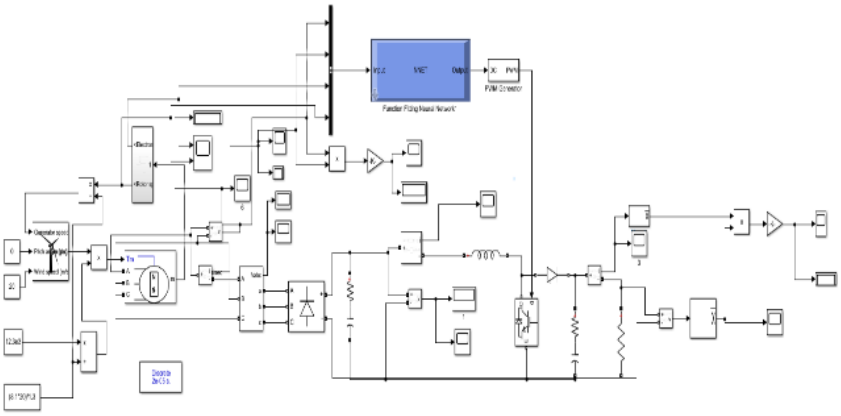

Fig. 6: Simulation of Wind Energy system integrated with Railway power supply with MPPT.

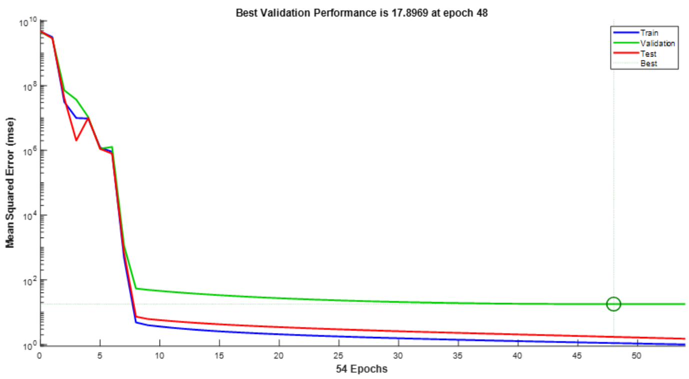

Fig.7: Validation Performance of RBFN wind with MPPT controller

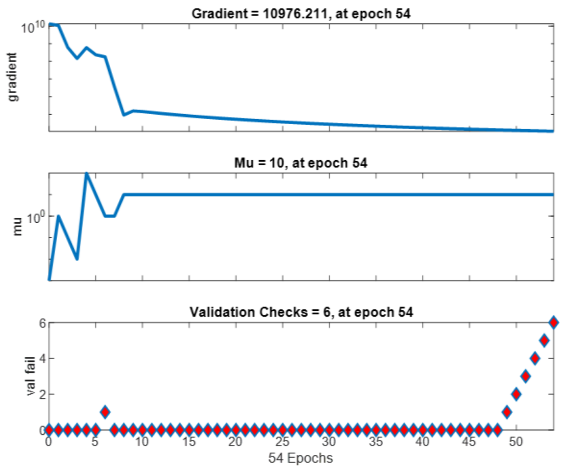

Fig. 8: Training data of RBFN with MPPT controller

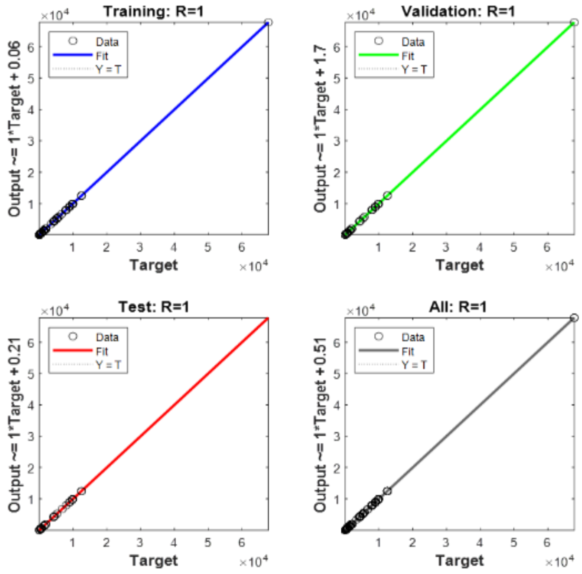

Fig. 9: Training and Validation of RBFN wind with MPPT controller

The suggested approach is assessed in this paper for wind energy integration with a railway power supply using an MPPT controller, and it is also implemented in a MATLAB/Simulink model without an MPPT controller, taking into account a 7200KW load and an AC grid rated at 132kV, 50 Hz. Figure 10 shows-controlled regulator of the three-phase inverter's flow which receives power from the common DC link. For the wind turbine to monitor its highest output more effectively based on PMSG that is integrated with a railway power supply system, this paper presents artificial neural network techniques based on the RBFN-MPPT controller. Table 2 summarizes the generated power, voltage, and current values both with and without MPPT. This segment gives the outcomes of the imitation done below MATLAB/Simulink.

Table 2: Output power in different wind speed

Wind speed(m/sec)	Power without MPPT (kW)	Power with MPPT (kW)
8	209.4	216.6
10	240.5	248.8
12	225.7	250.1
14	246,6	254.8
16	252.2	255.7
18	255.2	256.6
20	260.3	289.3

To examine the wind speed variation, a 300kW wind turbine was evaluated using MATLAB and Simulink models in turn. At a wind speed of 18 m/sec with MPPT control, figures 10, 11, and 12 illustrate the power extracted, the resulting wave forms for the voltage that is generated, output current. Extraction power, output current, and output voltage waveform are depicted in figures 13, 14, and 15, without MPPT control. According to the simulation results, there is a small oscillation present, and the average power extracted under MPPT control is 256.6 kW and without MPPT control is 255.2kW.

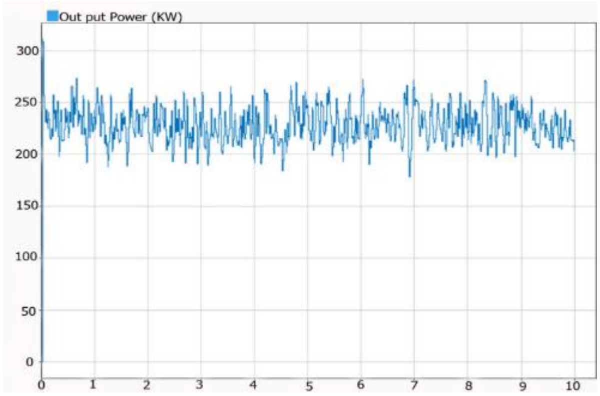

Fig. 10: Output power with MPPT at 18m/sec

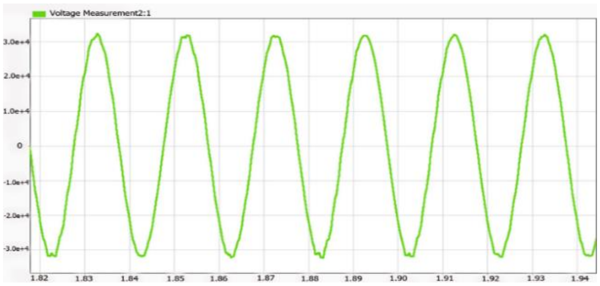

Fig.11: Output Voltage with MPPT at 18m/sec

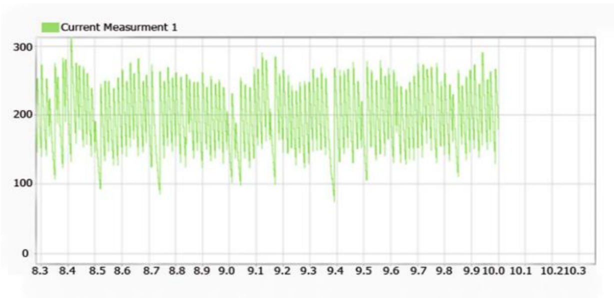

Fig. 12: Output current with MPPT at 18m/sec

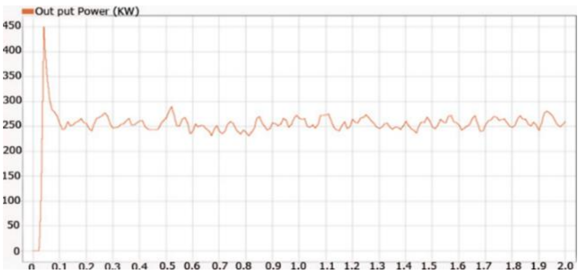

Fig. 13: Output Power without MPPT at 18m/sec

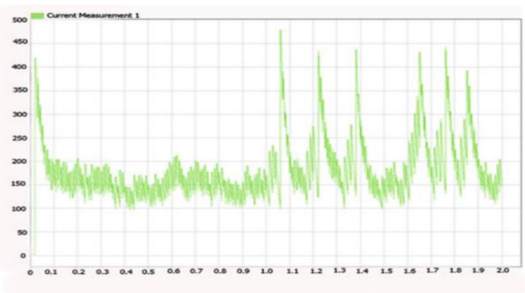

Fig.14: Output current without MPPT at 18m/sec

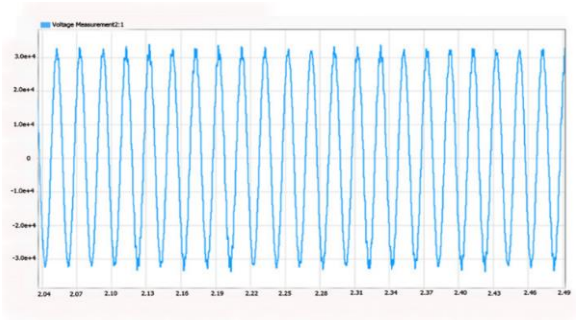

Fig.15: Output voltage without MPPT at 18m/sec

Figures 16, and 17 show the power extracted, and current flowing from the waveforms at a wind speed of 20 m/sec without MPPT control. Figures 18, 19, and 20 show the power extracted, the waveform forms for the output voltages and current with MPPT control. The simulation findings indicate that a considerable degree of oscillation is present; without MPPT control and the average power extracted is 260.3 kW, and the average power extracted under MPPT control is 289.3 kW with small number of oscillations.

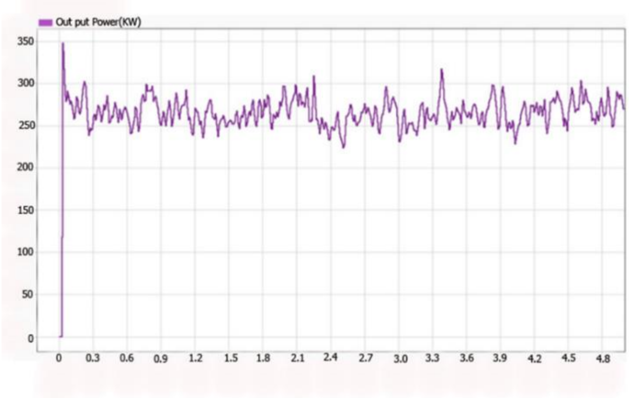

Fig.16: Output Power without MPPT at 20m/sec

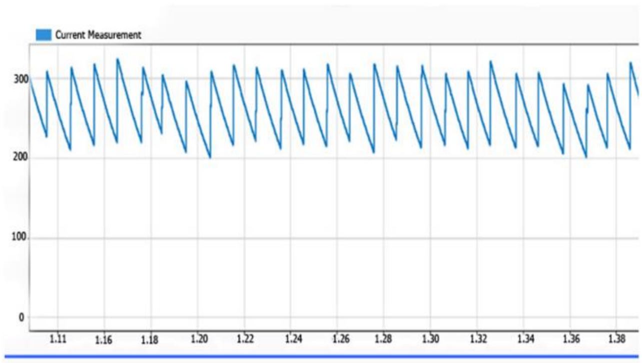

Fig.17: Output current wave form without MPPT at 20m/sec

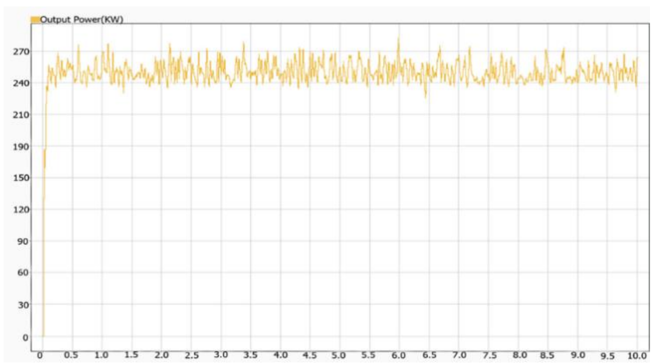

Fig.18: Output Power with MPPT at 20m/sec

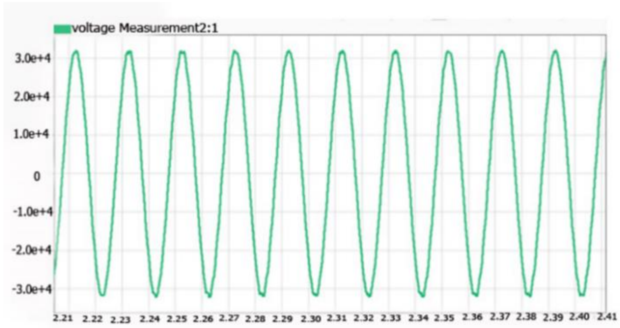

Fig. 19: Output voltage with MPPT at 20m/sec

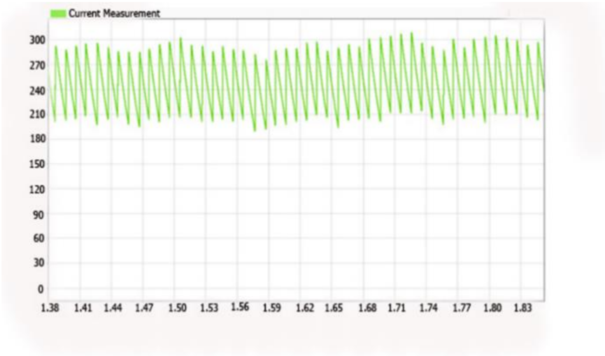

Fig.20: Output current with MPPT at 20m/sec

V. CONCLUSION AND FUTURE WORK

This work studies modeling besides simulating an RBFN based MPPT regulator for wind energy integrated with railway power supply system. An application of the suggested MPPT controller design is found in wind energy structures of 250kW wind system and has been applied to the conventional boost converter to track maximum power from wind energy and simulated in MATLAB and integrated with railway power supply system. The mean square error (MSE) from the MATLAB Simulink simulation results is used to validate the concert of the offered control. The proposed MPPT approach is tested beneath numerous wind hustles using MATLAB/Simulink. The output control graph is displayed in the results section so that the differences in output power with and without MPPT can be compared. At a wind speed of 20 meter per second, the developed system provides an average maximum power of 289.3 kW with MPPT. The MSE value of 0.012 is comparatively low, making it more appropriate for use in an MPPT controller. According to the simulation's outcomes, monitoring the highest power was effectively accomplished by the RBFN-based MPPT controllers.

Further research will be conducted to develop and verify the proposed approach. This will involve using more detailed models and validating the simulation model on a laboratory-scale experimental WECS setup. Additionally, power quality analysis should be conducted to ensure the constancy of the wind energy integrated with the railway power source scheme in the future work.

ACKNOWLEDGMENTS

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ACCESS TO INFORMATION

Upon request, the field investigation provides the data that was used to support the research findings.

CONFLICTS OF INTEREST

Considering the publicizing of the work at hand, the contributors affirm that they have no problems of duty.

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