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Stand-alone Micro Grid based on Artificially Intelligent Neural Network (AI-NN)

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Abstract

INTRODUCTION: Hybrid stand-alone Small Wind Solar Energy System offers a feasible solution in remote areas where grid connectivity is either financially or physically unavailable. A small wind turbine (SWT) and a solar photovoltaic system are part of the hybrid energy system, which is effectively employed to meet the energy needs of rural household loads.
OBJECTIVE: This research suggests an effective analysis of wind solar hybrid system controllers taking energy demands into account. The controller should be designed in such a way as to intelligently monitor the availability of wind energy and solar energy and store the energy without spilling it out.
METHODS: In order to cope with the challenging factors involved in designing the controller, intelligent power tracking with an artificially intelligent neural network (AI-NN) is designed. Added to that, the whole process has been designed and analysed with the MATLAB SIMULINK tool.
RESUSTS: The results of the simulation, infer that AI-NN achieved the regression value of 0.99 when compared with the Perturb & Observe algorithm (P&O), and the Fuzzy Logic Control (FLC) algorithm, and has a higher tracking speed. Also, the AI-NN attained 2.62kW whereas the P&O has attained 2.52kW and Fuzzy logic has attained 2.43W of power which is 3.89% higher than P&O algorithm and 7.52% higher than fuzzy MPPT algorithm.
CONCLUSION: The designed controller module enhances the system by artificially intelligent algorithm. The AI-NN attains the better power performance with lesser tracking time and higher efficiency. Thus, it is evident that AI-NN MPPT suits well for the hybrid system.

Keywords: Neural Networks (NN), Maximum power point tracking (MPPT), Small Wind Turbine (SWT), Solar Photovoltaic (SPV), P&O (Perturb and Observe), FLC (Fuzzy logic controller).

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1. Introduction

An alternative energy source is needed in the increasing population to satisfy the need for energy. The Wind and Solar hybrid systems have been deployed at the farm to meet the energy needs of the farm by developing efficient controllers [1]. Rezkallah et al. (2018) introduced and simulated PI controllers as an alternative approach to track power. Added to the present methods [2] say the new concept of adaptive Honey Bee Optimization (HBO) method has been developed and simulated for the hybrid wind turbine and solar model control system. Under developing the MPPT controller, the tracking algorithm is developed to control the converter to optimize power transfer to load [3]. Another method of modelling a stand-alone hybrid generator system [4] uses an intelligent controller which is the DC bus that allows the renewable resources to maintain the DC level at a stable rate without any deterioration at the output Various intelligent controls were developed to control stand by hybrid wind-solar power generation systems [5]. This method demonstrates the fusion of the tracking method with Neural Networks which are connected individually to and solar photovoltaic (SPV) model [6] in shading conditions. Whereas the other method has been introduced [7] which developed a hybrid perturb and observe algorithm and learning automata algorithm achieves maximum power point tracking. The same is designed and developed with higher efficiency. Another controller is designed with RBFN which is designed and analysed as a single controller for wind and solar MPPT.

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It is further trained with a neural networking tool in MATLAB [8]. In [9] another MPPT algorithm utilizes a fuzzy logic controller with an Elephant herding optimization method. At the same time [10] designs the micro power system with a hybrid battery and solar photovoltaic for standalone applications. The results are being obtained in comparison with the P-I-D controller for maintaining the direct current bus voltage stable. In [11], a combination of fuzzy and neural network algorithms was designed using MATLAB for its control strategy of hybrid wind solar hybrid system [12], and the steady state has been achieved at 0.01 seconds. Amidst all the MPPT techniques, the controller is specifically designed for battery power management is also an essential thing for any stand-alone system. In considering the pros and cons of various MPPT algorithms, the authors [13] and [14] designed a neuro-fuzzy system battery charge controller with corresponding charge state of battery.

On the other side, instead of simply designing the system it is designed for any particular application as well. The load characteristics are also the main factor to consider. In [15], [16] a controller is designed with ANFIS and GA for battery management as well as load management. In considering the literature various MPPT techniques, power management strategies, and load-balancing techniques were analysed. So, this paper concentrated on an Artificially Intelligent Neural Network (AI-NN) developed on MATLAB / Simulink environment with real-time wind speed, solar irradiation, and temperature profile. The main contribution in this article is the hybrid implementation of wind and solar energy systems for stand-alone applications with a single AI-NN based control algorithm for power management. It has to achieve maximum power from wind and solar energy systems and manages the battery and load simultaneously.

2. Description of Hybrid Small Wind Solar Energy System

The SWT along with the solar photovoltaic system with the developed artificially intelligent controller design has been developed. The general layout of the overall design has been shown in figure 1. The main renewable energy resources such as SWT and SPV are at first developed with the available mathematical model on the Simulink platform with real-time data such as wind flow characteristics and solar irradiation on the panels. In the case of the SWT design, the permanent magnet synchronous generator (PMSG) has been chosen. Since the power generated at the PMSG is AC, it needs to be converted to DC using rectifier circuit.

Now the DC power will be maintained uniformly throughout the bus. The master controller is designed intelligently to harvest wind and solar energy without spilling off with the help of the ANN algorithm. Among various ANN algorithms feed forward-back propagation algorithm is trained with the real-time power characteristics with 1kW capacity SWT and 1.65kW capacity SPV respectively. The simulation has been carried out to validate the MPPT-ANN controller with a classical MPPT controller.

2.1 Small Wind Turbine System Model

Small wind turbines are miniature models of large wind turbines which can be utilized for household applications. IEC 61400-2 standard says the rotor area of a small wind turbine is < 200m 2 and rated power should be below 50kW. The power output of the generator model is expressed in the following equations as shown below [17].

$$P_w = \frac{1}{2}\rho\pi R^2 V_w^3 C_p \quad - (1)$$

$$T_t = \frac{1}{2}\rho A R C_p \, {V_w^2}/{\lambda} \quad - (2)$$

The power coefficient C_{pw} is dimensionless which depends on the wind speed and constructional characteristics of the turbine.

$$\lambda = R\,\omega_t / V_w \quad - (3)$$

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_1} - 0.4*\beta - 5\right) e^{\frac{-16.5}{\lambda_1}} \quad -(4)$$

$$\lambda_1 = \frac{1}{\frac{1}{(\lambda+0.089)} - \frac{0.035}{(\beta^3+1)}} \quad - (5)$$

where, $\beta(w)$ - the blade pitch angle in degree and ω_t is the angular speed of the turbine rotor in rad/sec. The Whisper 200 1 kW SWT model is considered for the design with the following technical specifications listed below. The wind speed characteristics of said wind turbine have been fed to the PMSG model through the look up table with time stamp in order to generate the aerodynamic torque to operate the PMSG which in turn produce the respective power for the corresponding wind speed.

Table 1. Specification of 1kw Small Wind Turbine

System Description	Specifications
Power (P) at rated wind speed	1kW
Cut-in Wind speed	2.5 m/s
Rated Wind speed	16 m/s
Rotor Diameter	3.12 m
RPM operation range	180 – 775 RPM
Tip speed ratio	6.9
Voltage	24V – 350 VDC

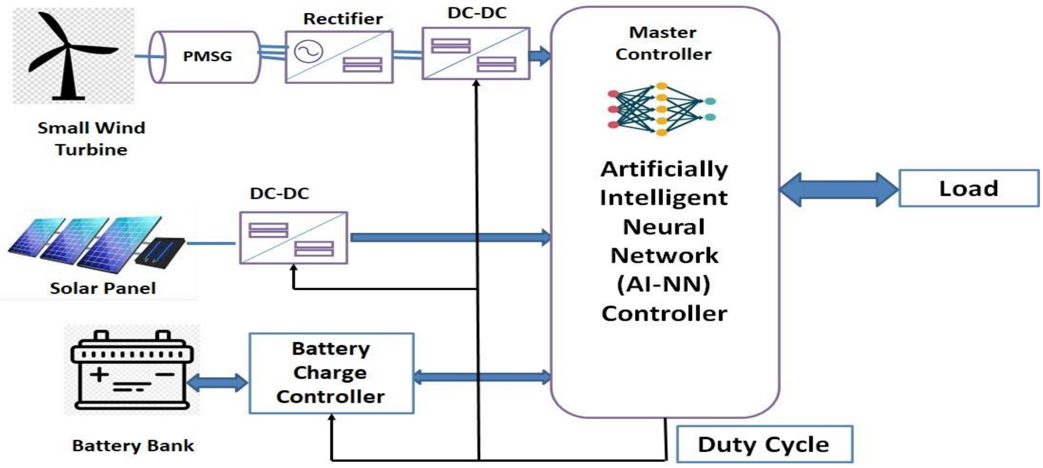


Figure 1. Block diagram of MPPT based AI-NN controller with wind solar hybrid system

2.2 Solar Photovoltaic System Model

A PV Array is a set of solar PV modules. The PV array is made up of parallel strings of PV modules, each string consists of PV modules linked in sequence. The Photovoltaic Array block consists of five parameters that represent the irradiance of light generated current source (IL) and series resistance (Rs). The equations below [mathworks] describe the diode current(I) and voltage (V) characteristics for a single solar module.

$$I_d = I_0 \left[exp\left(\frac{V_d}{V_T}\right) - 1 \right] \quad -(6)$$

$$V_T = \frac{kT}{q} \times nI \times Ncell \quad -(7)$$

Where Io is the Diode saturation current in A, k is the Boltzman constant, nI means Diode ideality factor, Idpv is Diode Current (A), Vd is Diode Voltage (V), q is Electron charge (1.6022e−19) C, T the Cell Temperature (K) and Ncell are No. of cells that are connected in series in a module.

Table 2. Specification Of 1.65kw Solar Photovoltaic Module

System Description	Specifications
Maximum Power (P)	1.65 kW
Open circuit voltage (Voc)	46.1 V
Short-circuit current (Isc)	9.5 A
Voltage at maximum power point (Vmp)	37.2 V
Current at maximum power point (Imp)	8.87 A
Number of Panels	5 (Parallel connection)
Maximum power per panel	330 W
Module efficiency	16.5

Two inputs need to be fed for the system design in which the first input is solar irradiance in W/m2and the other input is Cell temperature (0C). Both of these inputs are arrayed with the look-up table with time series.

2.3 Boost Converter Model

The Boost converter results in a specified DC output voltage according to the duty cycle at each switching frequency (fs). The device design consists of a switch which may be an Ideal switch, a thyristor, IGBT or MOSFET, a diode, an inductor, and a capacitor for storage purposes. In the boost converter output voltage obtained is higher than the given input voltage. The characteristics of the model are expressed as follows [18].

$$V_0 = \left(\frac{1}{1-D}\right) V_{pv} \quad -(8)$$

$$I_0 = \left(\frac{1}{1-D}\right) I_{pv} \qquad -(9)$$

$$M = \frac{V_0}{V_{pv}} = \frac{1}{1-D} \qquad -(10)$$

where, I_0 is the output current, V_0 is the output voltage, V_{ws} is the wind solar output voltage, D is the duty cycle, I_{ws} is wind solar output current and M is the voltage transfer gain.

3. Design of Artificially Intelligent Neural Network

Artificially intelligent MPPT techniques are a more advanced and efficient way of the control strategy. The AI is further subdivided into a Fuzzy logic controller algorithm, Artificial Neural Network algorithm, swarm algorithm, Machine learning algorithm, and a combination of two or more algorithms as a hybrid algorithm. Each algorithm has specific characteristics in terms of accuracy, tracking speed, settling time, efficiency, and cost. Since the system we considered is having varying wind and solar, real-time profiles with Perturb and observe optimization and Fuzzy logic controller, are used for better analysis with ANN controller. Since the Fuzzy Logic Control and Perturb & Observe algorithms are the efficient noncomplex algorithm for comparison purposes.

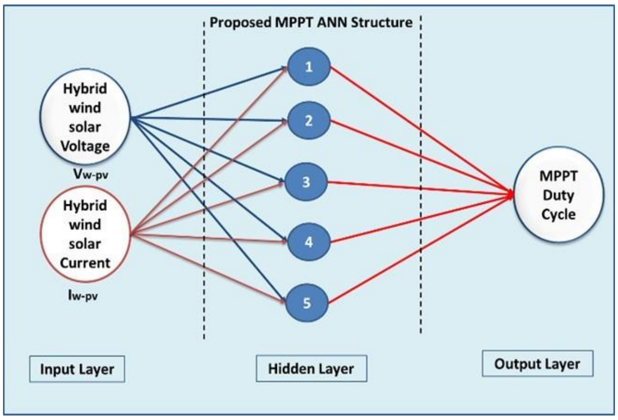


Figure 2. Proposed AI-NN controller algorithm

Neural networks, like the human brain, are made up of connections of neurons that process a machine's or system's learning law. To produce the most reliable and best performance, neural networks train a data set of inputs with a set of targets. In order to achieve the maximum power, the hybrid wind-solar DC output voltage and output current are fed as inputs for the neural network fitting, and the duty cycle for the boost converter is obtained as the output. The best maximum power is obtained by training the network with any of the classical MPPT algorithms. The current and average voltage is attained with the real-time data of small wind and solar panels under various environmental conditions. The artificially intelligent neural network is trained for various real-time conditions of wind speed, voltage, current, solar irradiance (G), and temperature profiles. During the training process, the weights were adjusted with the training data to attain the target data. The controller is fit to use only when it is trained with multiple iterations and minimum error. The error is computed with Mean square error (MSE) with equation 13.

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(t_i - a_i)^2 \qquad -(13)$$

4. Simulated Results and Discussion

The model is designed in MATLAB / Simulink platform to find the suitability of the proposed system. Each module is designed individually by the mathematical modelling and integrated to check the accuracy and feasibility of proposed master controller.

4.1 Small wind energy system (SWES)

From the prescribed power curve of a 1kW small wind turbine, the data has been taken in such a way that the cut-in wind speed is 2.5m/s and the cut-off wind speed is 24m/s are met during the entire day. The power curve of a small wind turbine is shown in figure 3.

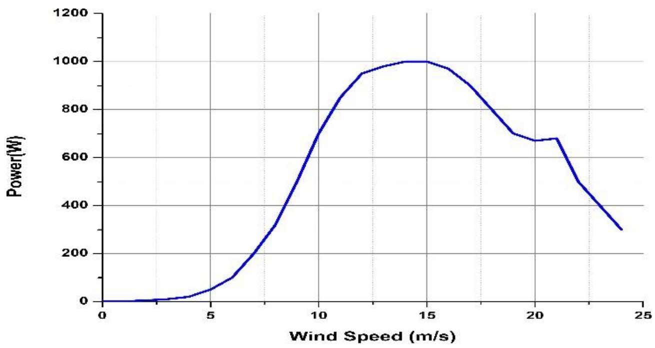


Figure 3. Power curve of small wind turbine

The rectified output power obtained at the small wind turbine is shown in figure 4. From the figure it is inferred that as the w i n d speed raises the power raises and the maximum power P_{max} of 750W is achieved at 14 m/s which is the rated wind speed.

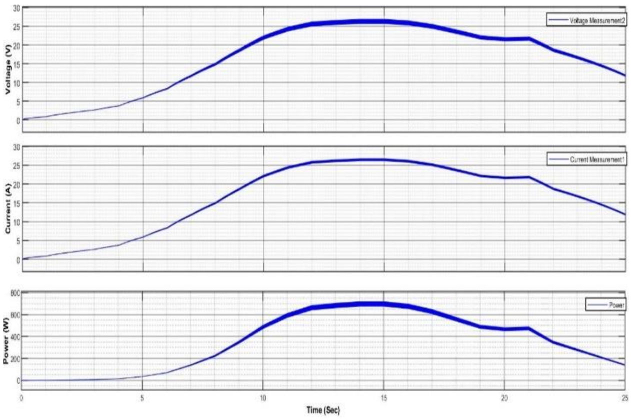
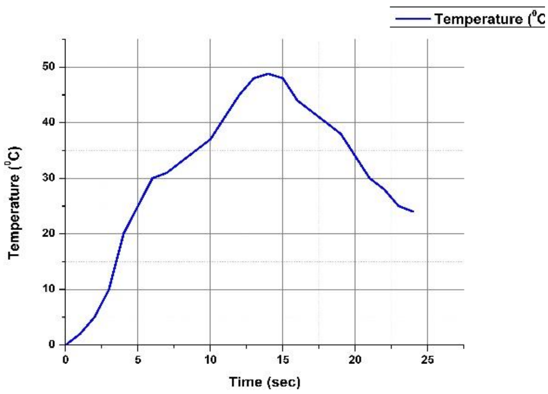


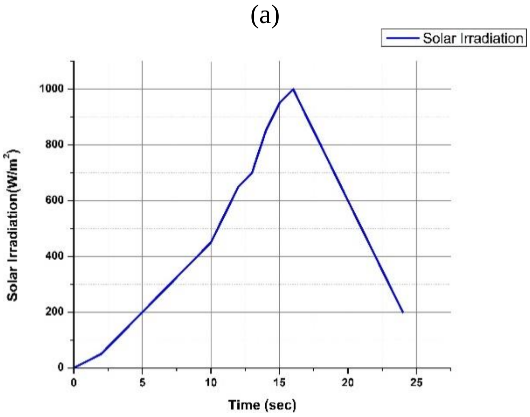
Figure 4. Small wind turbine voltage, current and power output for the given wind speed

4.2 Solar Photovoltaic System

The input parameter for the solar panel is irradiation (G) ranges from 0 to 1000 W/m^2 and the temperature values ranges from 0 to 25 ^{0}C (T). The irradiation (G) and temperature (T) characteristics is shown in figure 5a and 5b. The solar panel output is shown in figure 6.



(a)



(b)

Figure 5. a) Solar Irradiation profile; b) Temperature profile

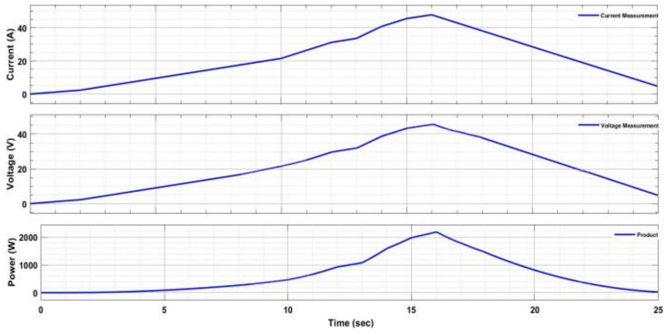


Figure 6. Solar panel output current, voltage and power for given irradiation and temperature profile

4.3 Boost Characteristics

The power outputs of both small wind and solar power systems are combined at the DC link which acts as a DC bus. The stable voltages of wind and solar power systems are boosted with the boost converter and the results are shown in figure 7.

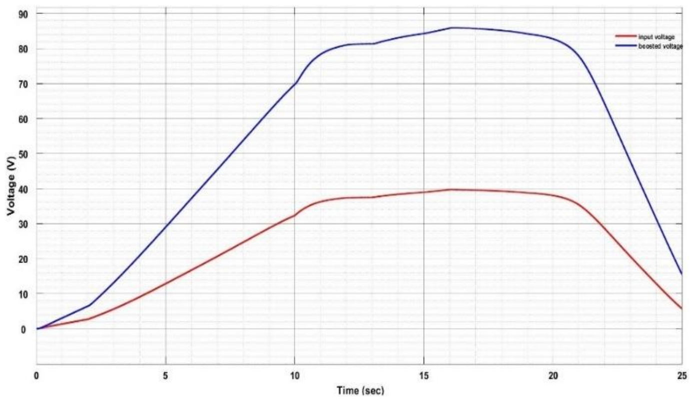


Figure 7. DC link characteristics

4.4 Artificially Intelligent Neural Network Controller

Initially, the artificially intelligent neural network controller is trained with the P & O algorithm with its various inputs and outputs. The input of the neural network is hybrid small wind and solar output DC bus voltage Vws and current Iws. The input voltage Vws and Iws corresponds to the wind speed, solar irradiation and temperature profiles that occur during the entire day of the wind and solar has been measured at the Chennai location which is shown in figure 8. It is fed to MATLAB using nftool. The nftool is trained by using Levenberg - Marquardt algorithm with the activation functions such as purelin and tansig respectively. The data considered for training the neural network is shown in figure

9. Where the training data is used to assess network generalization and to interrupt training when generalization begins to deteriorate.

Table 3. Input Data of Neural Network

Input data	Combined voltage V_{ws} and current I_{ws}
output	Duty cycle
Number of samples	5567318 samples
Number of hidden neurons	10
Number of iterations	1000
Training algorithm	Levenberg – Marquardt
Training data	70% (3897122 samples)
Validation data	15% (835098 samples)
Testing data	15% (835098 samples)


(a)


(b)

Figure 8. (a) 1.65kW Solar Panel and; (b) Whisper 1kW SWT

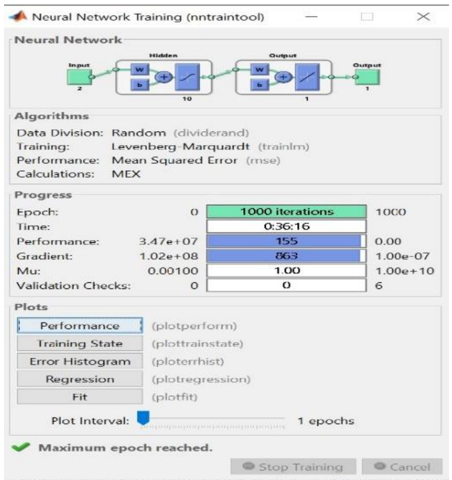


Figure 9. ANN Training using Matlab nftool

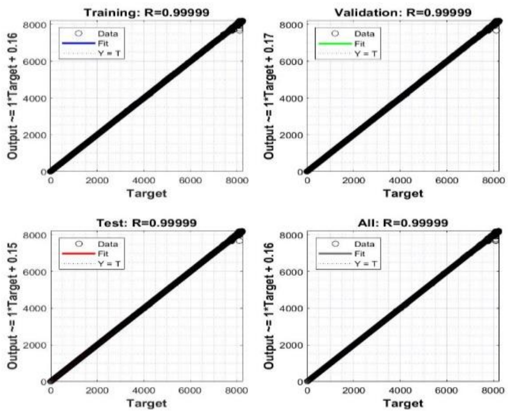


Figure 10. ANN Regression Output

On completion of the training process, the training, validation, and target testing outputs are obtained through a regression curve. For the data to fit perfectly, it should fall on a 45-degree line fit which means the output meets the target. The regression value for the system under consideration is 0.9999. After the successful training process, the tool provides the Simulink block set of the neural network controller. The toolbox is now trained and fit to act as an MPPT controller for the design as shown in figure 11. Now when any voltage and current arrives at this controller, it by itself adjusts and fit to the maximum power out of it.

With the designed hybrid small wind-solar AI-NN controller, it is analyzed with two other MPPT algorithms such as classical perturb and observe algorithm controller and fuzzy logic controller algorithm. The resultant power of FLC, P & O, and NN were analyzed as shown in figure 12.

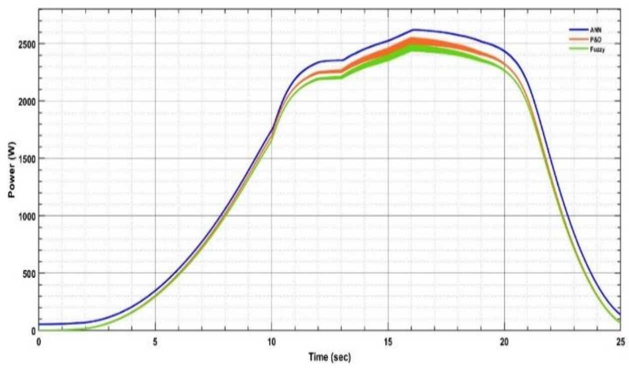


Figure 12. DC output power of AI-NN, P&O and Fuzzy controllers

From the above comparison, it is clear that an artificially intelligent controller achieves the maximum power in comparison with P & O and FLC controller outputs. The resultant parameters are compared in table 4.

Table 4. Comparison of Various MPPT Algorithm

MPPT Algorithm	Maximum power tracked (W)	Tracking time (s)	Efficiency (%)
FLC Algorithm	2444	0.0072	97.78
P&O Algorithm	2534	0.0068	98.02
AI-NN Algorithm	2626	0.0052	99.99

Based on the results obtained it is inferred that the Artificially Intelligent Neural Network (AI-NN) controller algorithm is efficient when compared with other conventional algorithms in the case of hybrid renewable energy resources. It also retains the period even though the wind speed, solar irradiation, and temperature are varying in nature. From the power curve, the maximum power point for the wind system is at different time duration and solar maximum power point is at a different time duration but the controller copes up to maintain the maximum power at a maximum level.

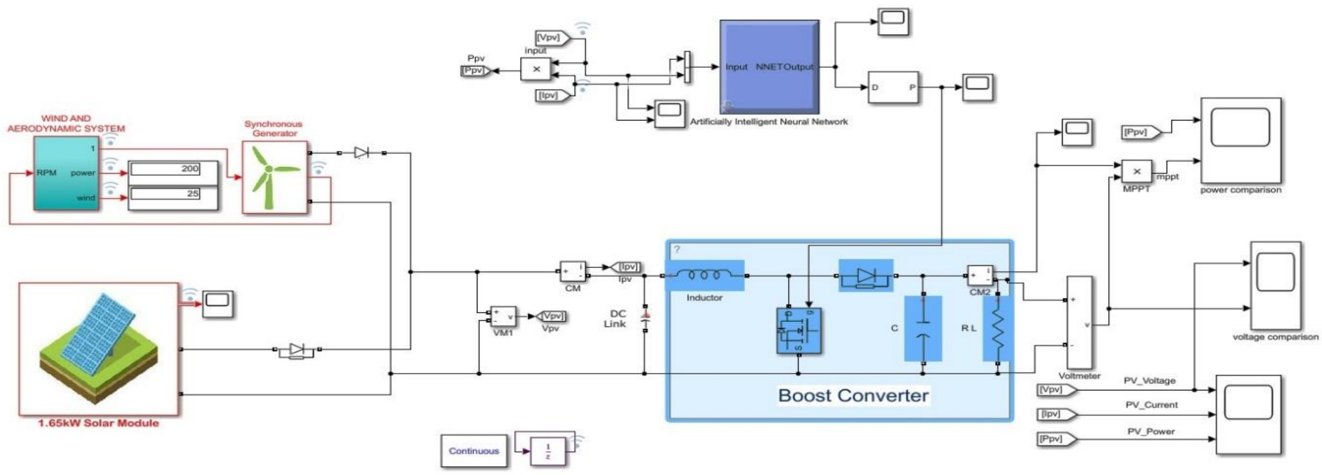


Figure 11. Simulink model of designed small wind and solar with AI-NN

5. Conclusion and Outlook

This paper presents the Artificially Intelligent Neural Network (AI-NN) controller for SWT and SPV hybrid stand- alone energy system. Various MPPT technology has been reviewed in the literature and the ANN MPPT fits best for the hybrid huge data managing system. The proposed system is designed with 1 kW SWT system model and 1.65 kW SPV system model with boost converter. The power performance of the hybrid system is analyzed in stand-alone condition with the real time wind speed, solar irradiance and temperature inputs for the entire power curve analysis. The entire module when compared with FLC and P & O MPPT algorithm, the AI-NN attains the better power performance with lesser tracking time and higher efficiency. Thus, it is evident that AI-NN MPPT suits well for the hybrid system. This works is further extended to real time implementation of the power efficient AI-NN controller which can be utilized at the agricultural farms for powering the irrigation motor pumps at the electricity unreachable area.

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