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Maximum Power Point Tracking for Wind Power Generation System at Variable Wind Speed using a Hybrid Technique

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Abstract

This paper presents the Wind Energy Conversion System (WECS) combining Permanent Magnet Synchronous Generator (PMSG) with PSO-RNN controller. The proposed hybrid technique uses Particle Swarm Optimization (PSO) algorithm along with Recurrent Neural Network (RNN) which generates the optimal dc reference current. The proposed Maximum Power Point Tracking (MPPT) algorithm finds the maximum operating point from the power curve which is based on the dc link voltage and current. The proposed hybrid technique is simulated using Matlab / simulink and the performance of the WECS is evaluated and compared with Proportional Integral (PI) and RNN methods. The errors in Power Coefficient, Tip Speed Ratio, DC link voltages and Average Power are evaluated.

Keywords: *RNN, PSO, MPPT, Wind turbine generation system, Dc link voltage and current*

1. Introduction

The wind energy is a pollution-free resource. Based on the application, the wind power generators can be classified into two main classes, constant-speed and variable speed generators. The power extraction from the wind energy should be maximized. The WECS uses the full scale converter with a PMSG. The advantages of PMSG are its high efficiency and reliability as it does not requires an external excitation. The Wind Generation System (WGS) can primarily be categorized into two types: (i) a constant-speed wind turbine whichis based on fine-tuning the pitch angle of wind turbine blades so as to control the output power of a wind turbine. (ii) a variable-speed wind turbine with optimum Tip Speed Ratio (TSR) [14, 15]. The variable-speed wind turbines are more striking, as they can extract maximum power at various wind velocities, and therefore, decrease the mechanical stress on wind energy conversion systems (WECS) [8,13]. A pitch control strategy was assigned in [16] based on the non-linear model. The inverse system method can control the output power over a wide speed range. But it is difficult to work for non-parametric uncertainties. The electromechanical analysis is introduced for reducing the torque ripple of the PMSG [13]. This increases the machine efficiency. However analysis does not reveal about optimal power extraction.

With the conventional method, the energy is extracted from the constant speed wind energy conversion system. Using Squirrel-cage Induction Generator or DoublyFed Induction generator, energy is supplied to the load and the main drawback is that it does not track the maximum power point [7]. Maximum Power Point Tracking (MPPT) control approach is commonly implemented in order to change the wind energy into electrical energy at the maximum levels in wind power generation systems [6, 12]. The competence of power regulation is reliant on the chosen control method [11]. Different control technologies have been developed andused to control the variable speed-variable-pitch wind turbine, together with generator torque, PID and adaptive controls [10]. Tip speed ratio control, power signal feedback and hill climbing search method are the three common types of MPPT control techniques. But traditional MPPT control approaches have limitations such as estimation fault and high frequency jitter, which leads to low precision [20]. The active techniques of extracting maximum wind energy are still under development by exploiting the wind energy generation system and raising the competence of the power system to a particular level [17].

At present several algorithms have been developed for maximum power point tracking (MPPT). A few problems of MPPT control approach are dealt with by adapting to the improvement of the intelligent optimization algorithm and combining with MPPT control approach [3]. Three general MPPT algorithms are: a) hill climbing search (HCS) or perturbation and observation (P&O), b) wind speed measurement (WSM) and c) power signal feedback (PSK) [7, 10]. Dissimilar computational intelligence (CI) methods, together with particle swarm optimization (PSO), mean-variance optimization (MVO), fuzzy logic, neural network, *etc.*, have been used to deal with challenging control issues (both transient, dynamic and steady-state controls) in WTG systems. PSO implementation is easy and also it leads to rapid convergence and hence PSO has become popular for many applications [5]. The proposed strategy launched in this paper, is the combination of PSO and RNN techniques. In Section 3, the PSO-RNN techniques are described. The performance results are analyzed in Section 4. Section 5 contains the concluding part of the paper.

2. Overview of WTGS

2.1. Model of Wind Turbine

The power extracted from the wind turbine is expressed as

$$P = \frac{1}{2}\rho\pi r^2 C_p(\lambda)V_w^3 \tag{1}$$

where ρ is the density of the air, r is the radius of wind turbine, V_w wind velocity and Cp (λ) is the power coefficient. The power coefficient depends on the tip-speed ratio

$$\lambda = \frac{r_w}{V_w} \tag{2}$$

The mechanical torque developed from the turbine is given by

$$\boldsymbol{T} = \frac{\frac{1}{2}\boldsymbol{\rho\pi r^2 C_p(\lambda)V_w^3}}{\boldsymbol{\omega}} \tag{3}$$

The electro-mechanical equations of the system torque can be expressed as

$$\boldsymbol{J\,\frac{dw}{dt} = T_l - T_e - B_w} \tag{4}$$

where J is the inertia of the system and T_e is the electromagnetic torque.

2.2. Modeling of PMSG:

Using Park’s transformation, based on stator voltage and current, PMSG is modeled by the equations given below:

$$V_d = Ri_d + \frac{d\lambda_d}{d_t} - \omega_e\lambda_q \tag{5}$$

$$V_q = Ri_q + \frac{d\lambda_q}{d_t} - \omega_e\lambda_d \tag{6}$$

where V_d and V_q are stator voltages, i_d and i_q are stator currents in d-q reference frame. R is the resistance of stator winding.

The electrical torque produced by the PMSG is given by the following equation.

$$T_e = \frac{3}{2}\,p\left(\lambda_m i_q - \left(L_q - L_d\right)i_q i_d\right) \tag{7}$$

Where λ_m is magnetic flux of the core, L_q, and L_d are the inductances of the stator winding, and p the number of pole pairs.

The active and reactive powers can be calculated using d-q transformation, which is expressed as.

$$P = \frac{3(v_d i_d + v_q i_q)}{2} \tag{8}$$

$$Q = \frac{3(v_d i_q + v_q i_d)}{2} \tag{9}$$

where, P and Q are the active and reactive powers of the wind generation system. Using the above equations, the proposed hybrid method is used for tracking the maximum power in wind turbine generation system (WTGS). The detailed explanation of the proposed controller is described in the following section.

3. Proposed Controller for Optimizing MPPT Control Technique in WTGS

3.1. Organization of Proposed System Structure

The block diagram of the proposed hybrid system is illustrated in Figure 1. From the Figure, it is seen that the power generator is connected through a PWM converter. The DC link capacitor is placed in between the converter and inverter. The PWM converter is used to control the torque and the speed. The PWM inverter is used to control the transit power in order to keep the DC-link voltage constant. Here, the inputs of the converter and inverter are received from their respective controller circuits.

3.2. Optimizing dc Voltage in the Wind Generation System using PSO Algorithm

PSO is a robust optimization technique based on swarm intelligence, which implements the simulation of social behavior. In this algorithm, each member is seen as a particle and each particle is a potential solution to the problem. In this paper, PSO algorithm is used to evaluate the dc link reference voltage (V_{dc}^{ref}) for getting maximum power from the wind generation system. The inputs of the PSO algorithm are dc link voltage and current. From the inputs, the maximized power is calculated which is the output and is optimized by the dc link voltage.

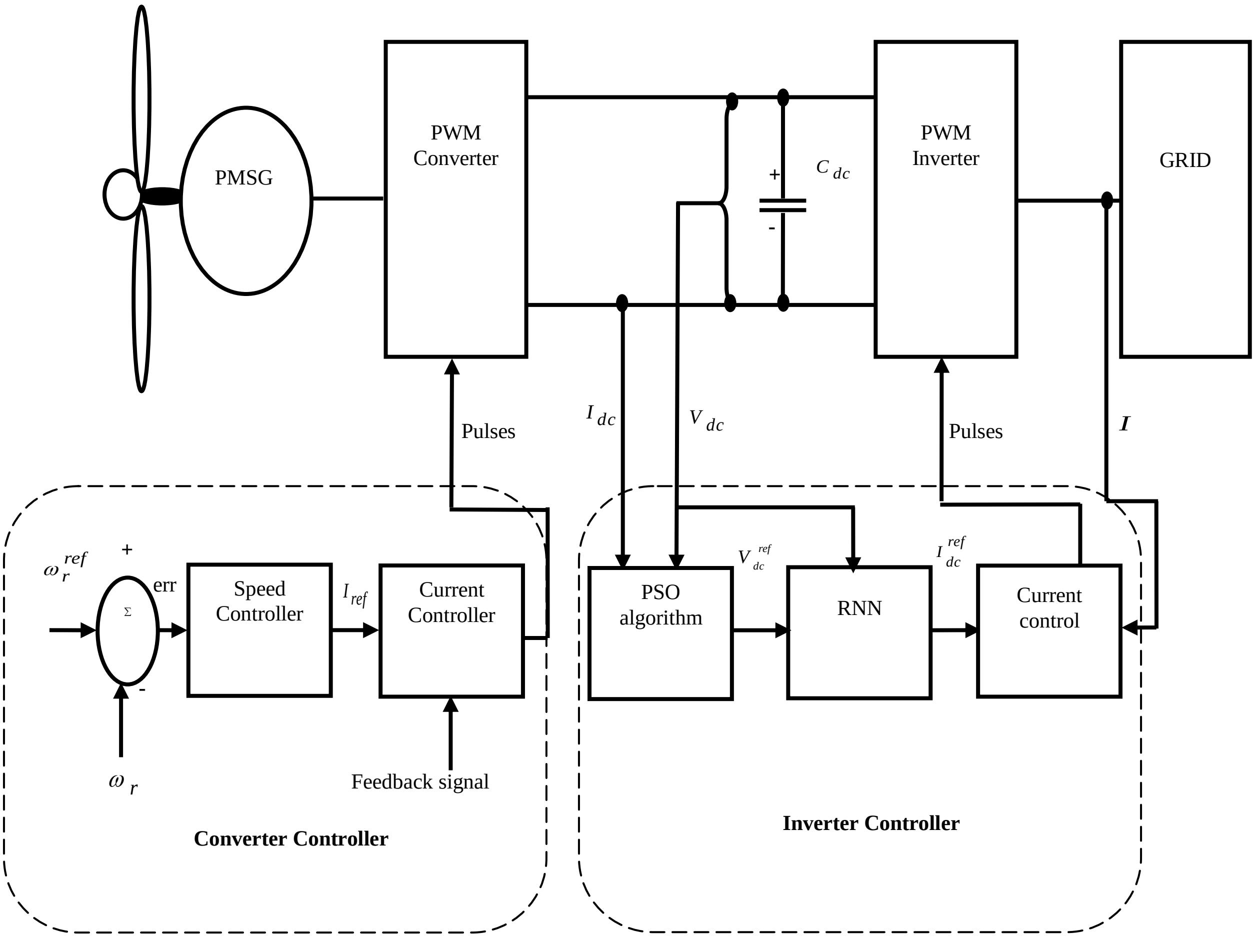

Figure 1. Block Diagram of Proposed Controller in Wind Turbine Generation System

The procedure of PSO algorithm is explained in the following section.

3.2.1. PSO Algorithm

Initialization

Step 1: The input parameters of PSO algorithm is V_{dc} and I_{dc}. Here, the positions and velocity vectors of the input parameters are initialized randomly. Each parameter is considered as a particle, whose position vector is $x_i^k = (x_{i1}^k, x_{i2}^k, \dots\dots, x_{in}^k)$in iteration k, and velocity vector is $v_i^k = (v_{i1}^k, v_{i2}^k, \dots\dots, v_{in}^k)$. Here, V_{dc} and $I_{dc}$are the dc link voltage and current.

Fitness Calculation

Step 2: Evaluate the fitness function of each input parameters. Here, the maximum value of power is taken as a fitness function.

$$fitness\ function = \max(P_d) \tag{10}$$

From the above equation, dc power (P_d) is calculated from the formula $P_d = (V_{dc} * I_{dc})$. Based on the fitness function, the optimal voltage is stored and compared with the personal best P_{best}^k of every parameter with its current fitness value. If the current fitness value is better than the previous P_{best}^k, then assign the current fitness value toP_{best}^k. The best solution achieved by ith particle in iteration k, is defined as $P_{best,i}^k = (P_{best,1}^k, P_{best,2}^k, \dots\dots, P_{best,n}^k)$. Here, i=1,2,…,n and k=1,2,…,n, which represent the dimensions in the specified range.

Step 3: Establish the current best fitness value in the whole of inputs. If the current best fitness value is better than global best g(best), then assign the current best fitness value to g(best) and assign the current coordinates to g(best) coordinates.

Update the Position and Velocity of Input Parameters

Step 4: Update the velocity and position of the particles using the equations (11) and (12).

$$ {}_i^{k+1} = w * v_i^k + \emptyset_1 * rand_1 * \left(pbest_i^k - x_i^k\right) * pbest_i^k + \emptyset_2 * rand_2\left(g\left(best_i^k\right) \right. \\ \left. - x_i^k\right) \tag{11}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{12}$$

where, i and ω denote the particle at ith position and inertia weight respectively. $\Phi_1$and Φ_2 are the learning rates governing the particle towards its best position and learning rates governing the social components. The rand$_1$ and rand$_2$ are represented as the random numbers that are uniformly distributed in the range [0, 1]. The V_i^k must be specified in the maximum and minimum range of [v_{max}, v_{min}] velocity. Next the dc link voltage positions are updated.

Termination

Step 5: When the maximum iteration is reached, the process is terminated; otherwise steps 2-4 are repeated. Here, the optimal voltage is calculated based on the fitness function and stored as the optimal dc link reference voltage (V_{dc}^{ref}).This voltage $V_{dc}^{ref}$is updated for every iteration. The working procedure of RNN is discussed in the following section.

3.3. Process for Recurrent Neural Network Training

RNN has two phases- training phase and testing phase and four layers-input layer, hidden layer, context layer and output layer, where 'n' neurons are considered in the unseen context layer [29]. There is a one-step time delay in the feedback path so that earlier outputs of the context layer, also called the states of the network, are employed to compute novel output values. The topology is the same as that of a feed forward network; apart from that the outputs of the unseen layer are applied as the feedback signals. The proposed RNN with voltages as input and one current as output is shown in Figure 2.

The RNN has two inputs namely, error voltage (E) and change of error voltage (ΔE). The output of RNN is termed as the control law (I_{dc}^{ref}), which is generated for regulating the load reference current. The RNN output is given to the inverter current controller. Here, the input layer to the hidden layer weights are specified as (w_{11},w_{22},…,w_{1n} and w_{21},w_{22},…,w_{2n}). The arbitrary weights of recurrent layer and the output layer neurons are generated at the specified interval [w_{min}, w_{max}]. For every neuron of the input layer, weight is assigned to be equal to one.

The RNN is trained by using back propagation through time delay (BPTT) algorithm with Bayesian regulation. The RNN process is based on the forward and backward passes. The procedure of Bayesian regulation BPTT algorithm is explained below.

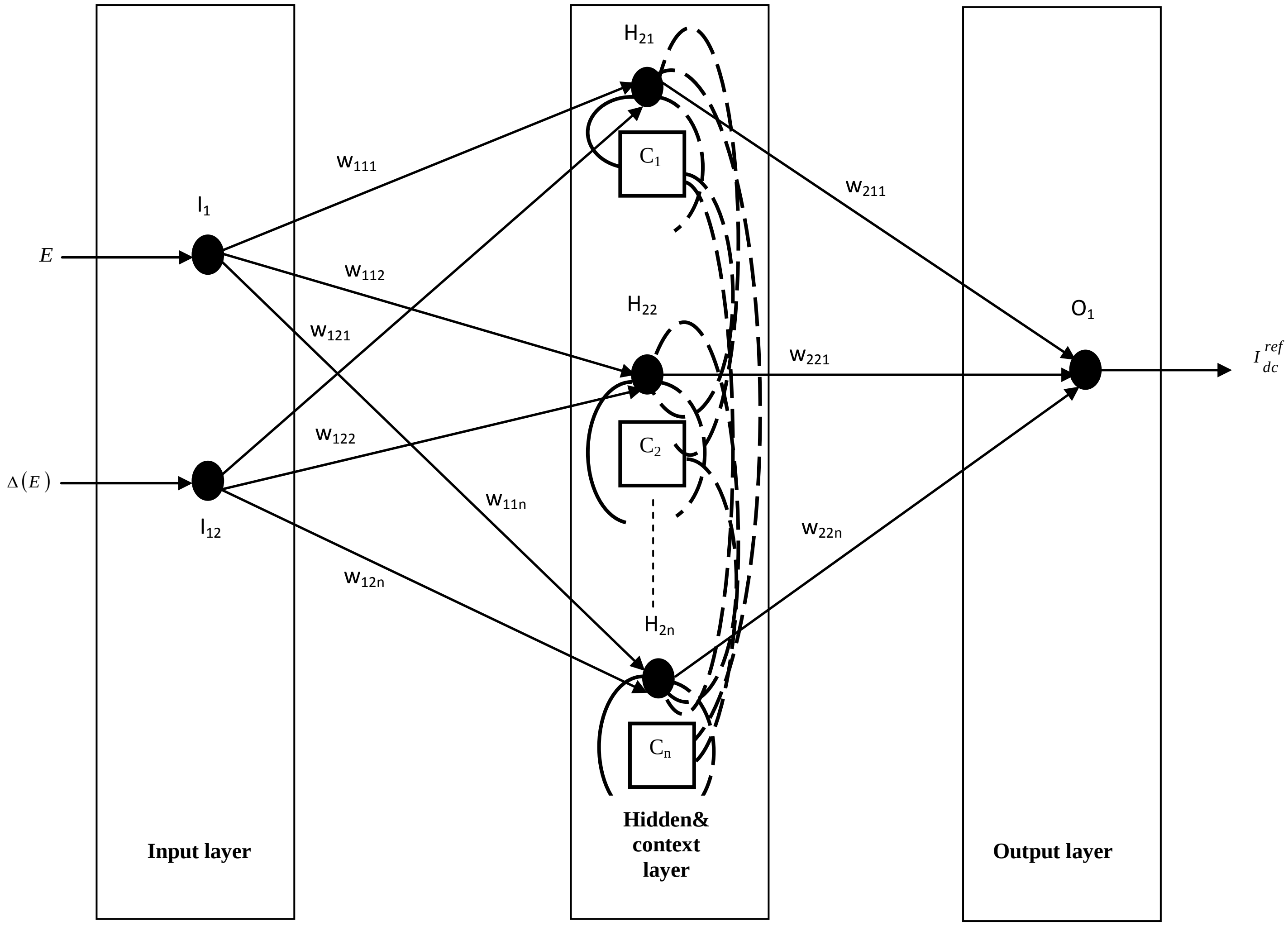

Figure 2. Training Structure of Proposed Recurrent Layer Neural Network

Procedure of BPTT Algorithm with Bayesian Regulation

Step 1: Initialize the inputs of the input layer and assign their weights. The inputs of the network is error voltage (E) and change in error voltage (ΔE) and they are calculated from $E = V_{dc} - V_{dc}^{ref}$ and $\Delta E = \grave{E}$ respectively.

Step 2: Forward Pass

In general, an RNN can be expressed with the following equations,

$$x_i(t) = \sum_j y_j(t) + w_{ij}(t) \tag{13}$$

$$y_i(t) = f_i(x_i(t)) \tag{14}$$

where, y_i and w_{ij} specify the activation state of neuron i at a time t and optimized values of weights respectively. The activation function f_i depends on the network inputs and context layer inputs.

Step 3: The hidden node activation function is passed through the sigmoid function f_i, to determine the decision vector.

$$f_i = \frac{1}{1+e^{(-x_i)}} \tag{15}$$

The RNN output is$\hat{y} = w_{2i} f_i$ for a single output weight matrix with i=1,2.

Step 4: Backward Pass

In the forward pass of back propagation, the output of each neuron is calculated using the following function.

$$y_i(t) = f_i(x_i(t), C_i(t)) \tag{16}$$

$$x_i(t) = \sum_{j \in H} y_j(t) w_{ij} + \sum_{j \in I} x_j(t) w_{ij} + \sum_{j \in C} y_j(t - \tau_{ij}) w_{ij} \tag{17}$$

where,f, H, I, Cdenote the activation function of neuron, hidden layer values, input values and the values of the context neuron, which store the information about the previous network stage. Then x_j is the j^th input to the neuron and τ_{ij} is an integer indicating the displacement in recurrent connection.

Step 5: Back Propagation Error

The back propagation error is calculated from the following equation.

$$E_m = Y^t - \hat{y} \tag{18}$$

The error can be minimized using the Bayesian Regularization approach which is described below.

Step 6: Network Training using Bayesian Regularization Approach

In this Bayesian Regularization technique, the objective function is modified by combining the mean sum of squared network errors E_d of the network weights and making a better working network by suitable selection of weight matrix and activation function of the neural network. The above processes are involved in the Bayesian Regularization technique, which are based on Levenberg-Marquardt training function, and then the weight and bias values are updated in this function.

The mean sum of squared network error E_d is given by

$$E_d = \frac{1}{N} \sum_{i=1}^{N} ((E_m)^2) \tag{19}$$

Step 7: The updated weights B_r are calculated using (20) as shown below.

$$B_r = \beta E_d + \alpha E_w \tag{20}$$

where, $E_w$is the sum of squares of the network weights, α and β are the parameters to be optimized in Bayesian framework. The training is continued until the Back Propagation error gets reduced to a small predetermined value. The well trained network object is obtained from the above. The current control law is generated from this network. The results obtained and the analysis of the proposed hybrid method is described in the following section.

4. Results and Discussion

In this paper, a hybrid control technique is proposed for tracking the maximum power generation system. The proposed hybrid controller is implemented in MATLAB/Simulink working platform. Here, the proposed controller is placed within the PWM inverter controller. The PSO algorithm is used for calculating the dc link reference voltage. The controlled signals are generated from the RNN technique. These signals are given to the inputs of the current controller which generates the controlling pulses. By using the current control law, the load current reference is adjusted. The proposed hybrid method is tested using the parameters given in Table 1, and its performances are analyzed and are given in Figures 3-8.

Table 1. Implementation Parameters of the Proposed Method

No	Description	Value
1	Number of hidden layers	30
2	$W = (w_{\min}, w_{\max})$	(0,1)
3	Number of inputs	50
4	Maximum number of iterations	100

4.1. Performance Analysis and Evaluation Metric

The performances of the proposed hybrid controller are analyzed. Here, the power coefficient, tip speed ratio, torque, speed, DC link voltage and the real power are evaluated separately using PI controller, ANN technique and the proposed hybrid model PSO-ANN and the performances are compared which are shown in Figure 3-8. The ANN employed here is Recurrent neural network.

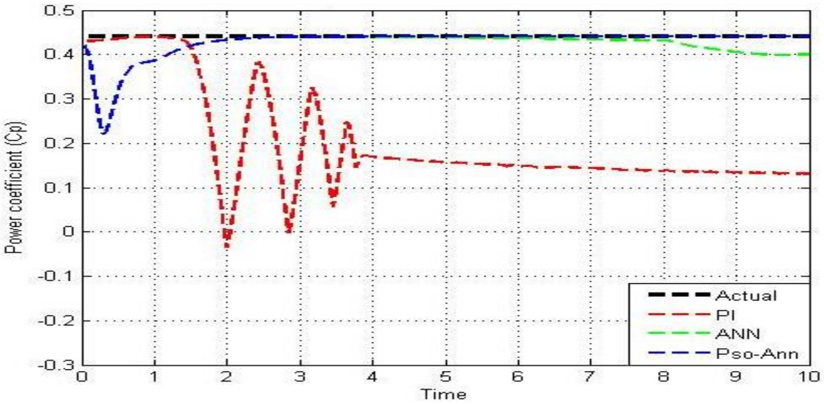

Figure 3. Power Coefficient in Various Methods

The power coefficient outcomes are illustrated in Figure 3. The power coefficient values are assessed from the wind speed and the maximum power can be extracted as a function of power coefficient from the wind. 70% of the Betz Limit is converted into electrical energy by the wind turbine and thus the C_p of this wind turbine is calculated as 0.7 x 0.59 = 0.41. The practical values of the power coefficient lie between 0.2 and 0.5. Here, the maximum power coefficient value C_p= 0.44. By using PI controller technique, it is observed that the C_p value is found to increase from time t = 0.01sec. From t=2sec, the power coefficient value decreases slowly and reaches a C_p value of (0.13) till t=4 sec.

Beyond t=4 sec, the C_p value starts decreasing. While using the ANN technique, initially the curve starts with a C_p value of 0.41and remains at the same level until t=8 sec. Then the curve starts to decrease slightly and remains at 0.4. In the proposed hybrid technique, the power coefficient is evaluated and it is very close to the maximum power coefficient value throughout the time period. Here, the curve increases gradually from the time t=2sec and reaches a maximum power coefficient value of 0.44 at t=3sec, after which it remains constant at a value of 0.44. Similarly, the torque, speed, power coefficients and tip speed ratios are analyzed using the PI, ANN and PSO-ANN methods.

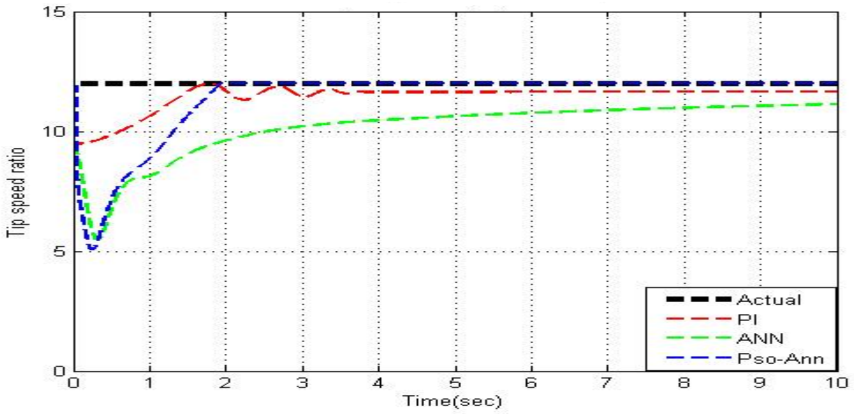

Figure 4. Tip Speed Ratio in Various Methods

It is observed from Figure 4 that the tip speed ratio with PI controller reaches the steady state condition after a lapse of 3.8 sec, whereas the tip speed ratio in the controller using the ANN reaches the steady state value after 8.5 sec. With the proposed hybrid technique the tip speed ratio reaches the desired value at t=2 sec.

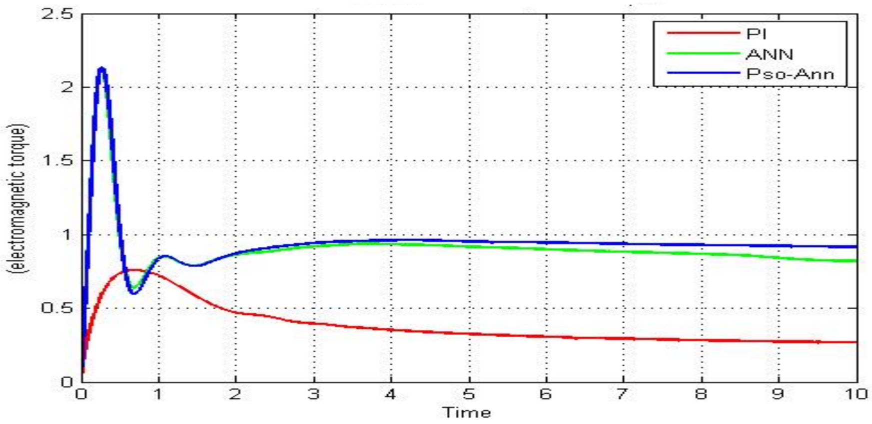

Figure 5. Torque Comparison in Various Methods

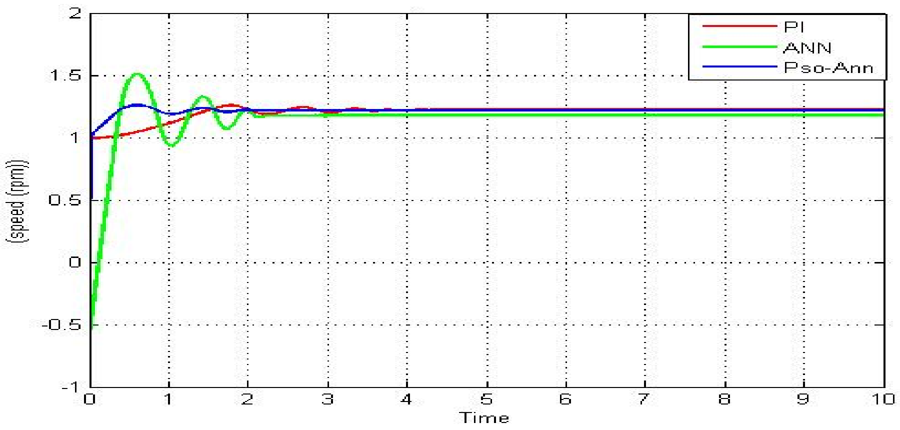

Figure 6. Speed Comparison in Various Methods

The response of the electromagnetic torque and the rotor speed of the generator are shown in Figures 5 and 6. The simulation results of the response and recovery times of the torque and speed for PI, ANN and PSO-ANN methods are given in the Table 2 below.

Table 2. Simulation Results - Torque and Rotor Speed

	Method					
	PI		RNN		PSO-RNN	
	Torque (Nm)	Speed (rpm)	Torque (Nm)	Speed (rpm)	Torque (Nm)	Speed (rpm)
Transient Response Time (sec)	0-2.5	0-4	0-2	0-2.1	0-1.3	0-1
Steady State Response Time (sec)	2.5-9	4-4.2	2-9.1	Below nominal value	1.3-4	1-2

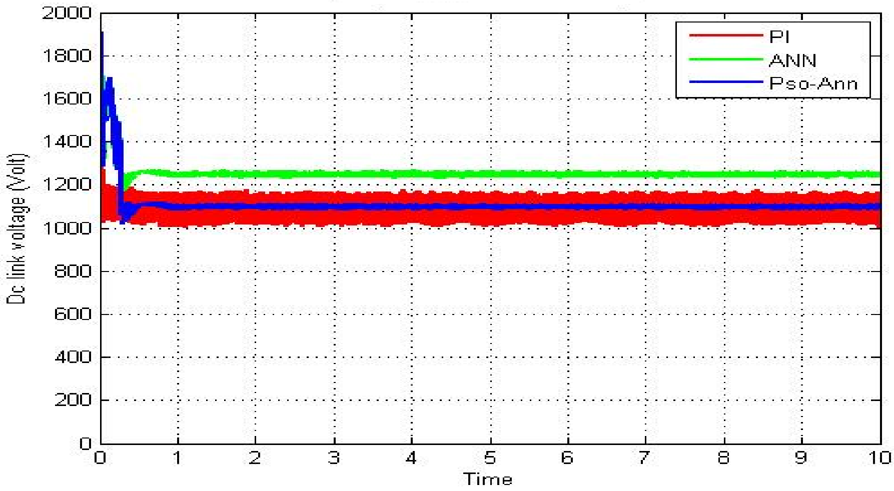

Figure 7. DC Link Voltage in Various Methods

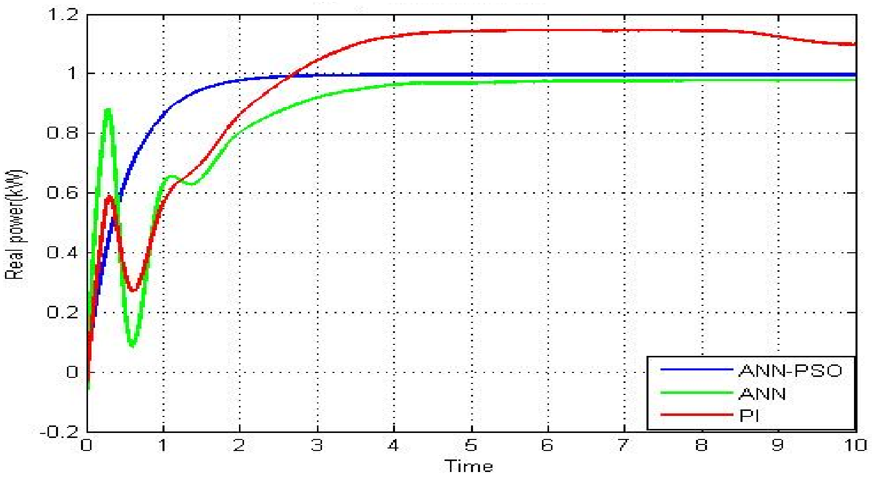

Figure 8. Power Comparison in Various Methods

Figure 7 shows the DC link voltage waveform with various controllers. In Figure 8 the real power obtained in all the three methods is analyzed. In the PI controller technique, the power curve swings between 0.0 and 1.1 in the time range between 0 and 0.3sec. From t=0.3sec the power curve starts to increase slowly and reaches the maximum power of 1.12MW at t = 4sec. After t=4sec, the maximum power remains constant at a value of 1.75 MW and at t = 8.6 sec it stars decreasing slowly. While using the ANN technique, initially the curve swings during the period between 0 and 4 sec and remains constant at a value of 0.98. In the proposed technique, the power starts to increase gradually from t = 0 sec and reaches its maximum power value of 1Mw at t=3sec. After reaching the maximum power, the curve remains steady after t=3 sec. As compared to the power obtained using the other techniques, the proposed method only attained the rated power of 1MW. In the proposed method the real power remains constant over a time period whereas power fluctuations occur in the ANN and PI controller techniques as it is evident from Figure 8. The superiority of the proposed method over the existing methods in terms of real power is clearly identified.

With the proposed hybrid method, the wind turbine system achieves high torque and high speed and the rated power as compared to the other existing methods.

The Percentage Error value is evaluated as given below:

$$Error\ percentage(\%) = \frac{Actual\ value - Estimated\ value}{Actual\ value} * 100 \tag{21}$$

Table 3 shows the performance of the proposed PSO-RNN method in terms of Average Power (W), maximum error of power coefficient, increased power error of dc link voltage, maximum error of tip speed ratio. The Average Power (W) of the proposed method is 962.9. The existing methods such as PI and RNN offer only 892.1(W) and 899.9(W) of Average Power respectively. When compared to the existing systems, the proposed PSO-RNN Method gives higher Average Power (W).It shows that the proposed method is more accurate than the other methods. Also the proposed method has given 7.936% higher power than that of the existing PI and RNN techniques.

Table 3. Performances Characteristics of the Methods

Controller type Control	PI	RNN	Proposed Method (PSO-RNN)

Characteristics			
Average Power (W)	892.1	899.9	962.9
Max.error of power coefficient	27.2273	4.5454	1.3636
Increased power (%)	-	0.8743	7.936
Max.error of dc link voltage (%)	6.9818	9.8181	0.1818
Max.error of tip speed ratio (%)	2.1170	14.4239	1.8781

In the same way maximum errors of power coefficient, dc link voltage and the tip speed ratio of the proposed method are considerably low when compared to the existing techniques. The error percentage is calculated using the equation (21). Low error and high average power imply that the proposed (PSO-RNN) method gives better performance and found to be more efficient than the PI and ANN techniques.

5. Conclusion

In this paper, a hybrid technique is proposed for the improvement of maximum wind power extraction for variable-speed Wind Power Generation System (WPGS). The hybrid technique consists of a combination of PSO and ANN techniques. The hybrid method is simulated using MATLAB/SIMULINK. In the proposed hybrid method average power, power coefficient, dc link voltage and tip speed ratio are evaluated and compared with the respective values obtained using PI controller and the ANN techniques. The dc link voltage and the real power remain constant and an increased value of the average power is obtained in the proposed method. Hence it is established that the PSO-RNN method gives low errors of power coefficient, dc link voltage and tip speed ratio with a high percentage of average power.

Parameters of Turbine-Generator System

Wind Turbine

Base wind speed	12 m/s
Nominal Mechanical Power	8.5 kW
Air Density	1.225kg/m^2

PMSG

Stator Resistance	0.425 Ω
No of Poles	10
Magnetic Flux Linkage	0.433 Wb
Stator d-axis inductance	0.835mH
Stator q-axis inductance	0.835 mH
Moment of Inertia	0.01197 kg.m^2

References

[1] G. Mishra and R. Mishra, "Control Strategy for Wind Energy and Hybrid Generating Systems Based on the Concept of Power Electronics", International Journal of Engineering and Computer Science, vol. 1, no. 3, **(2012)**, pp. 114-120.

[2] A. A. Estmin, G. L Torres and G. S. Souzai, "A hybrid particle swarm optimization applied to loss power minimization", IEEE transaction on Power systems, vol. 20, no. 2, **(2005)**, pp. 859-866.

[3] X.-P. Li, W.-L. Fu, Q.-J. Shi, J.-B. Xu and Q.-Y. Jiang, "A Fuzzy Logical MPPT Control Strategy for PMSG Wind Generation Systems", Journal of Electronic Science and Technology, vol. 11, no. 1, **(2013)**, pp. 72-77.

[4] K. Tan and S. Islam, "Optimum Control Strategies for Grid-Connected Wind Energy Conversion System without Mechanical Sensors", IEEE Transactions on Energy Conversion, vol. 19, no. 2, **(2004)**, pp. 392-399.

[5] Rajih data and V. T. Ranganathan, "A method of tracking peak power points for a variable speed wind energy conversion systems", IEEE transaction on Energy Conversion, vol. 18, no. 1, **(2013)** March.

[6] D. Jose and S. B. Jeyaprabha, "Design and Simulation of Wind Turbine System to Power RO Desalination Plant", International Journal of Recent Technology and Engineering, vol. 2, no. 1, **(2013)**, pp. 102-105.

[7] M. G. Simues, B. K. Bose and R. J. Spigel, "Fuzzy logic based intelligent control for a variable speed cage Machine wind energy conversion system", IEEE transaction on Power Electronics, vol. 12, no. 1, **(1997)**, pp. 85-87.

[8] J. Sopanan, V. Rweskanen, J. Nerg and J. Pyrhonen, "Dynamic Torque analysis of a wind turbine drive train including a direct-drive permanent magnet generator", IEEE transaction on Industrial Electronics, vol. 58. no. 9, **(2011)**.

[9] M. Sarvi and S. Azarbara, "A Novel Maximum Power Point Tracking Method Based on Extension Theory forWind Energy Conversion System", International Journal of Computer Science & Engineering Technology, vol. 3,no. 8, **(2012)**, pp. 294-303.

[10] H. Geng and G. Yang, "Output Power control of variable speed – variable pitch wind generation systems", IEEE transaction on Energy Conversion, vol. 125, no. 2, **(2010)**.

[11] W. Guo-qing, N. Hong-jun, W. Guo-xiang, Z. Jing-ling, Z. Wei-nan, M. Jing-feng and C. Yang, "Maximum power point tracking control strategy for variable speed constant frequency wind power generation", Journal of Chongqing University (English Edition), vol. 9, no. 1, **(2010)**, pp. 21-28.

[12] Q. Wang and L. Chang, "An Intelligent maximum power extraction algorithm for inverter based variable speed wind turbine system", IEEE transaction on Power Electronics, vol. 19, no. 5, **(2004)**.

[13] M. Narayana, G. A. Putrus, M. Jovanovic, P. S. Leung, S. Mc Donald, "Generic maximum power point tracking controller for small-scale wind turbines", International Journal of Renewable Energy, vol. 44, **(2012)**, pp. 72-79.

[14] Q. Wang, and L. Chang, "An Intelligent Maximum Power Extraction Algorithm for Inverter-Based Variable Speed Wind Turbine Systems", IEEE Transactions on Power Electronics, vol. 19, no. 5, **(2004)**, pp. 1242-1249.

[15] L. G. González, E. Figueres, G. Garcera and O. Carranza, "Maximum-power-point tracking with reduced mechanical stress applied to wind-energy-conversion-systems", International Journal of Applied Energy, vol. 87, **(2010)**, pp. 2304–2312.

[16] C.-Y. Lee, P.-H. Chen and Y.-X. Shen, "Maximum power point tracking (MPPT) system of small wind power generator using RBFNN approach", International Journal of Expert Systems with Applications, vol. 38, **(2011)**, pp. 12058-12065.

[17] A. Meharrar, M. Tioursi, M. Hatti and A. Boudghene Stambouli, "A variable speed wind generator maximum power tracking based on adaptive neuro-fuzzy inference system", International Journal of Expert Systems with Applications, vol. 38, **(2011)**, pp. 7659-7664.

[18] N. Mendis, K. M. Muttaqi, S. Sayeef and S. Perera, "Standalone Operation of Wind Turbine-Based Variable Speed Generators with Maximum Power Extraction Capability", IEEE Transactions on Energy Conversion, vol. 27, no. 4, **(2012)**, pp. 822-834.

[19] C.-M. Hong, C.-H. Chen and C.-S. Tu, "Maximum power point tracking-based control algorithm for PMSG wind generation system without mechanical sensors", International Journal of Energy Conversion and Management, vol. 69, **(2013)**, pp. 58-67.

[20] S. Abdeddaim and A. Betka, "Optimal tracking and robust power control of the DFIG Wind turbine", International Journal of Electrical Power and Energy Systems", vol. 49, **(2013)**, pp. 234-242.

[21] J. Chen, J. Chen, and C. Gong, "Constant-Bandwidth Maximum Power Point Tracking Strategy for Variable-Speed Wind Turbines and Its Design Details", IEEE Transactions on Industrial Electronics, vol. 60, no. 11, **(2013)**, pp. 5050-5058.

[22] S. Sreedharan, W. Ongsaku, J. G. Singh, "Maximization of instantaneous wind penetration using particle swarm optimization", International Journal of Engineering, Science and Technology, vol. 2, no. 5, **(2010)**, pp. 39-50.

[23] J. H. Laks, L. Y. Pao and A. D. Wright, "Control of Wind Turbines: Past, Present, and Future",

Proceedings of American Control Conference, **(2009)**.

[24] S.Belakehal, H. Benalla and A. Bentounsi, "Power maximization Control of small wind system using permanent magnet synchronous generator", Revue des energies Renouvelables, vol. 12, no. 2, **(2009)**, pp. 307-319.

[25] W. Qiao, J. Liang, G. K. Venayagamoorthy and R. Harley, "Computational Intelligence for Control of Wind Turbine Generators", Proceedings of IEEE conference on Power and Energy Society General Meeting, **(2011)**, pp. 1-6.

[26] S. M. Barakati, M. Kazerani and X. Chen, "A New Wind Turbine Generation System Based on Matrix Converter", IEEE Proceedings of International Conference on Power Engineering Society General Meeting, vol. 3, **(2005)**, pp. 2083-2089.

[27] A. J. Mahdi, W. H. Tang, L. Jiang and Q. H. Wu, "A Comparative Study on Variable-Speed Operations of a Wind Generation System Using Vector Control", International conference on renewable energies and power quality, Spain, **(2010)**.

[28] P. Xiao, G. K. Venayagamoorthy and K. A. Corzine, Impedance "Identification of Integrated Power System Components using Recurrent Neural Networks", Proceedings of IEEE Electric Ship Technologies Symposium, **(2007)**.

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