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Extracting Maximum Power from Wind Turbines using Tip Speed Ratio, Hill-Climbing and Neural Network controllers

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ABSTRACT: This paper proposes three maximum power point tracking (MPPT) controller employed in wind power system using permanent magnet synchronous generators. These controllers can be classified into three main control methods, namely tip speed ratio (TSR) control, hill-climb search (HCS) control and artificial neural network (ANN) control. Most control schemes use the Hill climbing (HCS) technique, because it's simple and easy to implement, but it's less efficient and present wrong directionality. To solve this problem, The ANN algorithm is proposed. The system proposed is developed by combining the models of established wind turbine with the algorithms of tip speed ratio (TSR), hill climbing (HC) and artificial neural network (ANN) when a wind speed is fixed. The Matlab/Simulink is used to establish the model of a wind turbine with the different MPPT controller.
The simulation results of the proposed system compare the performances of the algorithms proposed on the basis of speed responses and ability to achieve the maximum energy. It can be concluded that the wind turbine system with ANN MPPT algorithm is simpler, faster and can be the solution of many problems.

KEYWORDS: Renewable Energy, wind turbine system, MPPT, Tip Speed Ratio Technique, Hill Climbing Technique, Artificial Neural Network Technique.

I.INTRODUCTION

Like energy solar, wind energy source is becoming more and more used as a renewable source. It offers several advantages such as incurring no fuel, not being polluting and inexhaustible source [1]. A unique limitation of energy conversion systems such as wind and solar is their inability to track peak power production efficiently at varying wind speeds and solar insulation respectively [3]. To increase the efficiency of the wind turbine system, it is important to extract the maximum power point using different MPPT controllers at varying wind speeds. The purpose of this paper describes and compares advantages, shortcomings and execution efficiency for different MPPT techniques in wind conversion system, including tip speed ratio (TSR), hill climbing search (HCS) and artificial neural network (ANN) techniques. Matlab/Simulink is used to implement the proposed system, and to compare performance, efficiency and accuracy for the selected MPPT controllers.

This paper starts with an introduction which includes the background of wind energy, and the purpose of this paper. Then wind turbine model, tip speed ratio, hill climbing and artificial neural network MPPT controllers are presented. The simulation and the discussion of the MPPT controllers are described before the conclusions which are given in the last section of this paper.

II- WIND TURBINE CHARACTERISTICS

The power produced by a wind turbine is given by:

$$P = \frac{1}{2}\pi\rho C_p(\lambda,\beta)R^2V_v^3 \qquad (1)$$

Where V_v is the wind speed, R is the turbine radius, ρ is the air density, Cp is the power coefficient, λ is the tip speed ratio and β is the pitch angle.

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The power coefficient *Cp* varies with λ and it is maximal at the particular λ_{opt}. It is expressed by the following equation (2) and is shown in Fig.1.

$$C_p(\lambda) = -0.2121\lambda^3 + 0.0856\lambda^2 + 0.2539\lambda \qquad (2)$$

In this work, β is set to zero and The tip speed ratio λ is given by:

$$\lambda = \frac{\Omega R}{V_v} \qquad (3)$$

Where Ω is the turbine angular speed.

The power extracted from the wind turbine system is maximized when the power coefficient *Cp* is at its maximum at a defined value of the tip-speed ratio λ. Therefore, for each wind speed there is an optimum rotor speed where maximum power is extracted from the wind. For that reason, if the wind speed is assumed to be constant, the value of *Cp* depends on the wind turbine rotor speed. Thus by controlling the rotor speed, the power output of the turbine is controlled.

The variation of power captured by the wind turbine versus the rotational speed for different values of wind speed is shown in fig.2.

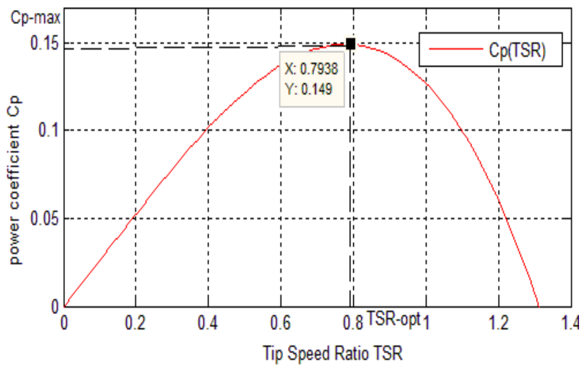

Fig. 1 The characteristic of the power coefficient as a function of tip speed ratio

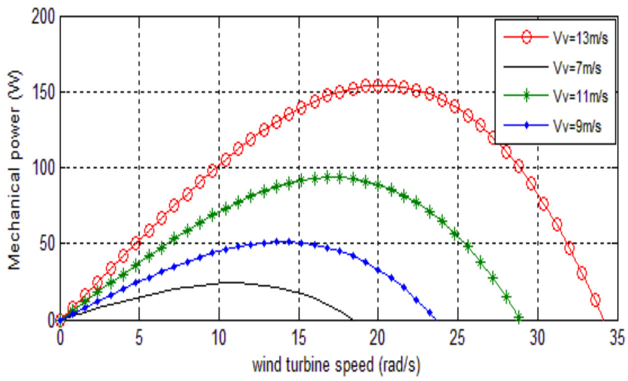

Fig. 2 Turbine mechanical power as a function of rotor speed for various wind speeds.

III. MAXIMUM POWER POINT TRACKING CONTROL

The schematic diagram of the wind energy conversion system studied is presented in Fig. 3. It consists of a horizontal wind turbine connected to a permanent magnet synchronous generator (PMSG), rectifier, a boost converter and batteries.

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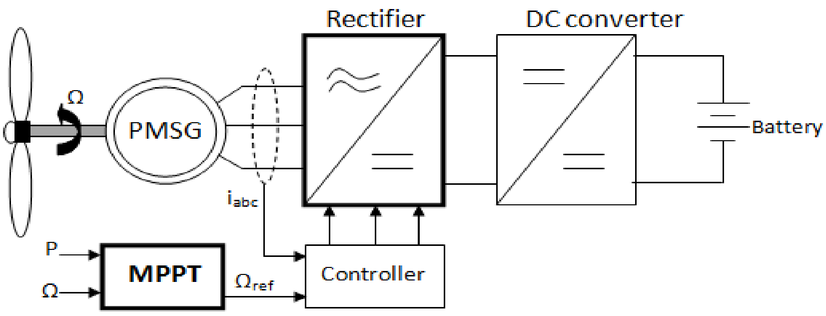

Fig. 3 Wind energy conversion system.

Amount of power output from a wind energy conversion system depends upon the accuracy with which the peak power points are tracked by the MPPT controller of the wind energy conversion system control system irrespective of the type of generator used [2].

Fig.4 shows the Matlab/Simulink model of the wind energy conversion system. It contains five main blocks: the wind turbine, the PMSG, rectifier, the DC/DC converter, and the MPPT controller.

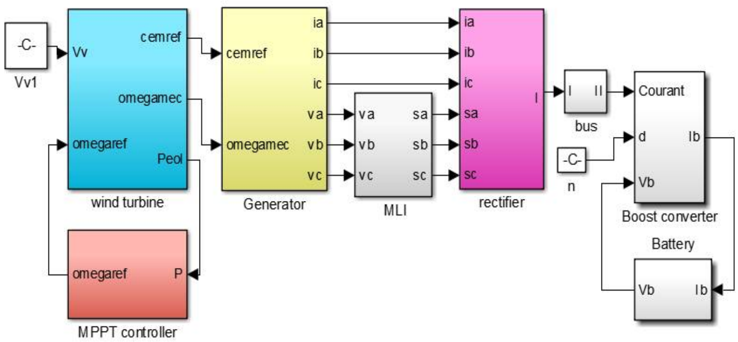

Fig. 4 Matlab/Simulink model of the wind energy conversion system

A. TIP SPEED RATIO CONTROL

The TSR control method uses sensors to track the MPP by the control of rotor speed and torque. It directly regulates the turbine speed in order to maintain the TSR to an optimum value at which power extracted is maximum. For a given wind turbine, the TSR remain constant and do not depends on wind speed. When TSR remains constant at the optimal value, the extracted energy will be maximized. Therefore in this method the energy conversions forced to remain at this point by making comparison with the actual value and feeding this difference to the controller. The optimal point of the TSR value can be determined experimentally or theoretically and reserved as a reference. This result is changing the speed of the generator to reduce the error. Fig.5 describes the block diagram of a wind energy conversion system with TSR control.

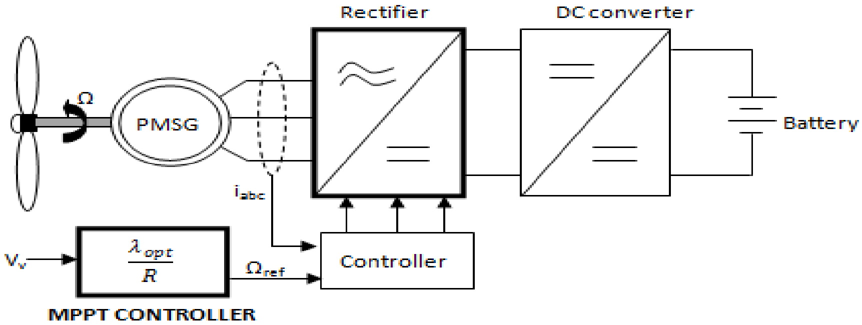

Fig. 5 Wind energy conversion system with tip speed ratio control.

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The limitation of this method is that wind speed needs to be known along with the turbine rotational speed measurements. This adds to the system cost, especially when considered for use with small scale wind turbines [3].
The Matlab/Simulink model of the wind turbine with MPPT "Tip Speed Ratio" control algorithm is presented in fig.6.

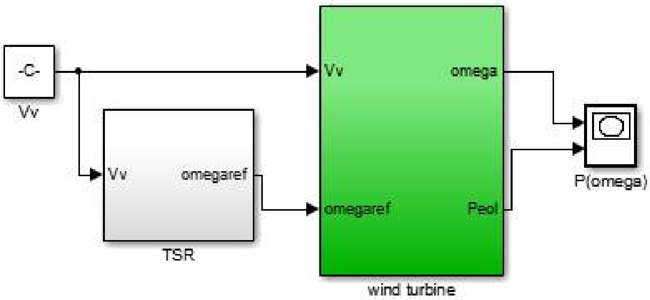

Fig. 6 Tip speed Ratio control.

B. HILL CLIMBING SEARCH CONTROL

Frequently, Hill climbing Search is used in wind energy systems to extract the optimal operating point that will maximize the extracted power. This method is based on perturbing a control variable in small step-size and observing the resulting changes in the target function, the power previously delivered is compared with the one after disturbance. This method associate the present power at some instant to the power attained at the previous step. This method is simple and independent from wind turbine characteristics. Fig. 7 describe the principle of hill climbing search control and fig. 8 presents the block diagram of a wind energy conversion system with hill climbing search control.

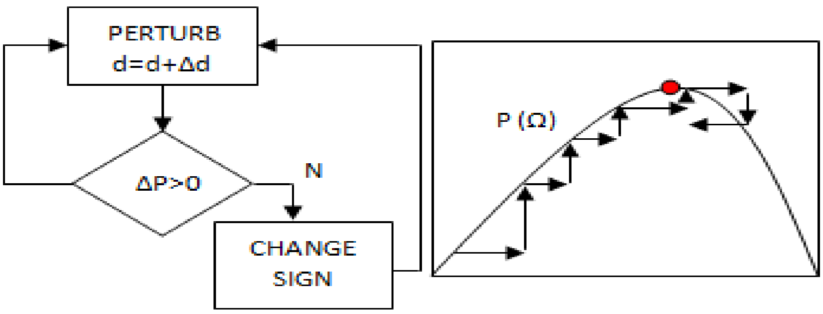

Fig. 7 Hill climbing search control principle.

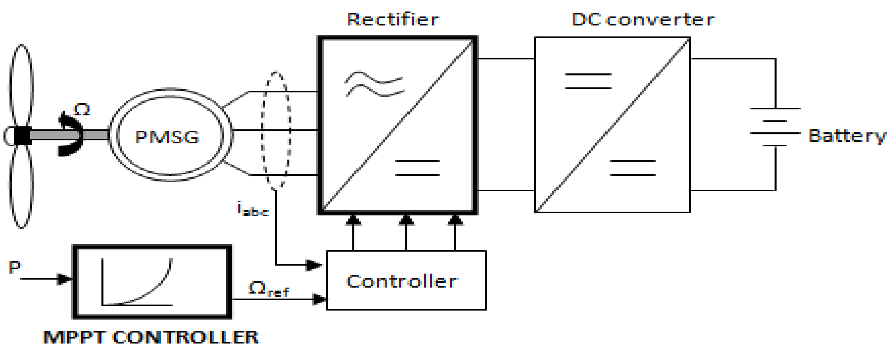

Fig. 8 Wind energy conversion system with hill climbing search control.

Limitation of the Hill Climbing Search method is its inability to track the maximum power point in cases of suddenly varying wind speed [5].

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C. NEURAL NETWORK CONTROL

An ANN can be defined as a complex network composed of interconnected elementary processing units (neurons). Neurons are organized into layers and can be connected in different ways. The topology of connections between neurons determines the network architecture and is related to the problem to be solved (non linear regression, classification, optimization, etc.). The network comprises parameters which are determined through a learning process. There are many types of ANN. Multi Layer Perceptron (MLP) are feedforward neural networks commonly used in problems of nonlinear regression. An MLP network comprises an input layer, one or more hidden layers and an output layer. The neurons of a hidden layer receive information from the neurons of the previous hidden layer or from the inputs, and are connected to the neurons of the next layer or to neurons of the output layer. There is no connection between the neurons of the same layer. Each neuron of the output layer performs a nonlinear function of the inputs of the network [4].

In fig. 9 is shown the architecture of a simple neural network. The artificial neuron consists of input, activation function and output with respected weight. In this simple feed-forward neural network, which consists of a single layer of output nodes, the inputs are fed directly to the outputs via a series of weights. The weights of the artificial neuron are adjusted to obtain the outputs for the specific inputs. The sum of the products of the weights and the inputs is calculated in each hidden node, and if the value is above some threshold (typically 0) the neuron fires and takes the activated value of (typically 1); otherwise it takes the deactivated value (typically -1).

The algorithm used for training of the neural network is back-propagation. The back-propagation training algorithm needs only inputs and the desired output to adapt the weight. Back-propagation training is referred to as supervised training. The neural network was trained using MATLAB software.

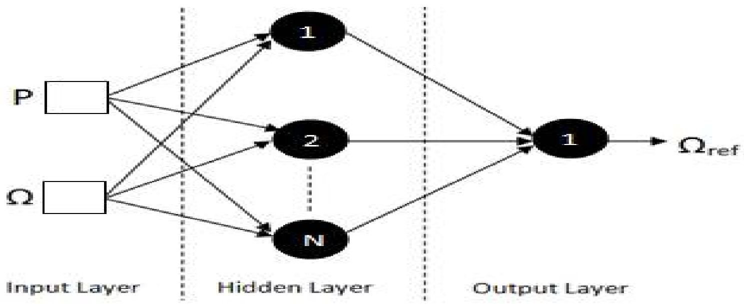

Fig. 9 The neural network architecture.

The Matlab/Simulink model of the wind turbine with MPPT "Neural Network" control algorithm is presented in fig.10.

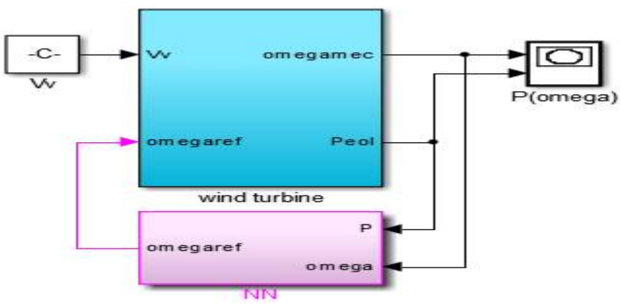

Fig. 10 The neural network control

IV. SIMULATION RESULTS

To compare the different results of the MPPT controllers architectures, we have analyzed several artificial neural networks with two hidden layers and different neuron numbers and activation function in these layers. The artificial neural networks ANN structures are given in table I.

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TABLE I. THE STURCTURES OF ANALYZED ANN CONTROLLERS

Controller Type	ANN structure	1st layer	2nd layer	3rd layer
1	Neuron numbers	1	1	-
	Activation function	sigmoidal	sigmoidal	-
2	Neuron numbers	2	1	-
	Activation function	sigmoidal	linear	-
3	Neuron numbers	10	1	-
	Activation function	sigmoidal	sigmoidal	-
4	Neuron numbers	10	1	-
	Activation function	sigmoidal	linear	-
5	Neuron numbers	1	1	1
	Activation function	sigmoidal	sigmoidal	sigmoidal
6	Neuron numbers	1	1	1
	Activation function	sigmoidal	linear	linear

In Fig. 11 is shown the comparison between power versus time evolution obtained with MPPT control with the first ANN, Hill-Climbing and TSR controllers. As one can see, the maximum power value is obtained more quickly with the ANN control.

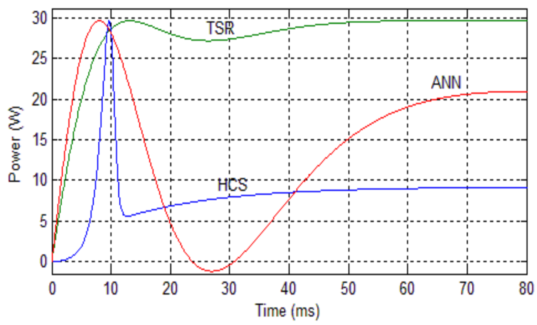

Fig. 11 Comparison between power-time dependence obtained with structure 1 of ANN, HCS and TSR controllers.

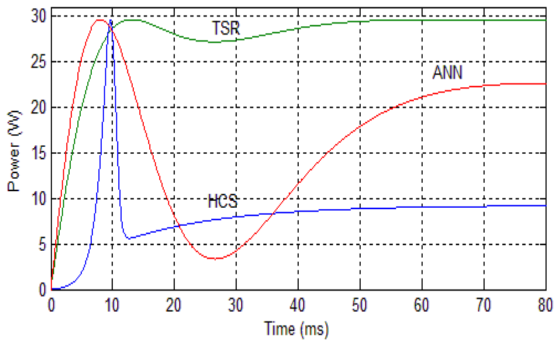

Fig. 12 Comparison between power-time dependence obtained with structure 2 of ANN, HCS and TSR controllers.

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The second analyzed ANN structure has the first hidden layer with two neurons and a sigmoid activation function, and the second hidden layer with a single neuron and linear activation function. The comparison of power-time dependence realized with the dependence obtained with Hill-Climbing and TSR algorithms is shown in Fig. 12. The maximum value of power is obtained more quickly with the ANN control.

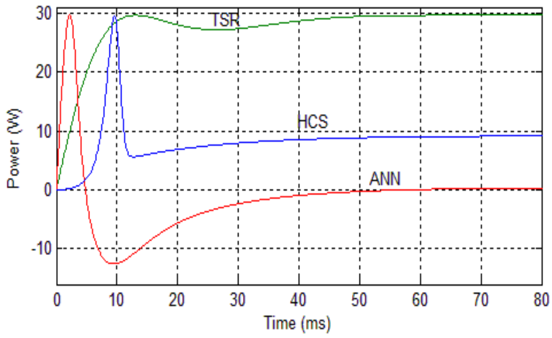

Fig. 13 Comparison between power-time dependence obtained with structure 3 of ANN, HCS and TSR controllers.

In Fig. 13 is shown the comparison between power versus time evolution obtained with MPPT control with the third ANN, Hill-Climbing and TSR controllers. The third analyzed ANN structure has 10 neurons in the first hidden layer and sigmoid activation functions. In this case, the maximum value of power is obtained more quickly as in the case of the first and the second ANN structures.

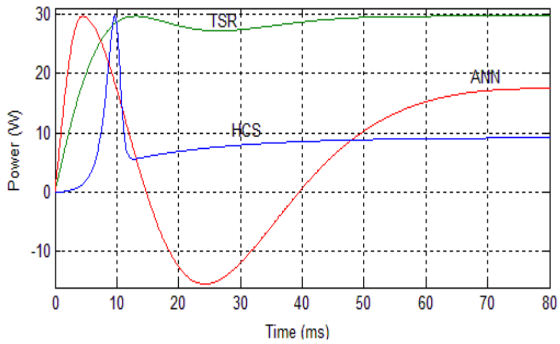

Fig. 14 Comparison between power-time dependence obtained with structure 4 of ANN, HCS and TSR controllers.

The fourth analyzed ANN structure has the first hidden layer with 10 neurons and a sigmoid activation function, and the second hidden layer with a single neuron and linear activation function. The comparison of power-time dependence realized with the dependence obtained with Hill-Climbing and TSR algorithms is shown in Fig. 14.In this case, the maximum value of power is obtained more quickly as in the case of the Hill-Climbing and TSR algorithms.

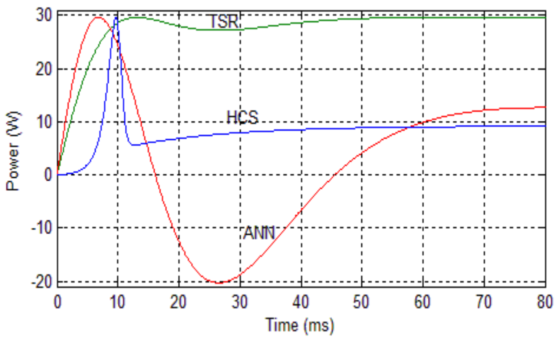

Fig. 15 Comparison between power-time dependence obtained with structure 5 of ANN, HCS and TSR controllers.

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The fifth analyzed structure has three hidden layers and sigmoid activation functions. The comparison of power-time dependence realized in this case with the dependence obtained with Hill-Climbing and TSR algorithms is shown in Fig. 15. In this case, the maximum value of power is obtained more quickly as in the case of the others algorithms.

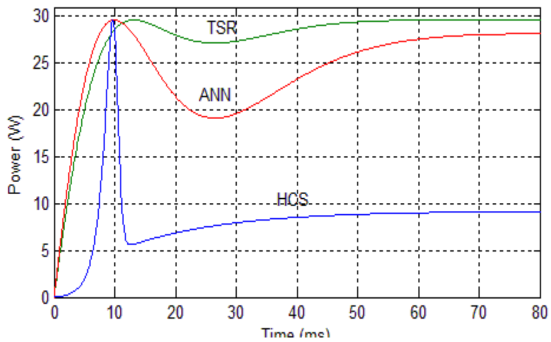

Fig. 16 Comparison between power-time dependence obtained with structure 6 of ANN, HCS and TSR controllers.

In Fig. 16 is shown the comparison between power versus time evolution obtained with MPPT control with the last ANN, Hill-Climbing and TSR controllers. As one can see, the maximum power value is obtained more quickly with the ANN and Hill-Climbing controls.

V.CONCLUSION

The wind conversion system with artificial neuron network MPPT algorithm achieved the maximum power point before the others algorithms. It is more efficient in comparison with wind conversion system using Tip Speed Ratio and Hill-Climbing MPPT algorithm. It does not require knowledge of internal system parameter values, needs less calculation, and allow a faster attend of the maximum value of the delivered power at fixed speed value.

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