NEURAL-NETWORK BASED CONTROL AND INTERFACING OF A GRID CONNECTED WIND TURBINE GENERATOR

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Abstract — An ac-dc-ac converter is an important device used to extract power from synchronous speed wind generators and feed it into the grid. This paper describes how these converters incorporate Maximum Power Point Tracking (MPPT) based on its power feed to the grid at different wind speeds. Using the synchronous machine’s generator voltage, grid current and grid voltage samples the dynamic behavior of the proposed system is achieved. A dump load circuit is employed to protect the turbine from high wind speed operation when disconnected from the grid. It also protects the inverter from high dc voltage input from the wind generator at high wind speed. To achieve a fast and stable response for real power control an Improved Elman Neural Network (ENN) is used, where the output signal is used to control the converters.

Keywords—Dumpload; ElmanNeuralNetwork(ENN); Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

In recent years, the development of Wind Energy Generation has been associated with wind farms located onshore and offshore. Variable-Speed Wind Turbines have more advantages compare to others. The wind farms are connected to strong Transmission Grids and their power ranges from some tens to a Hundred megawatts. The wind turbine can operate with Maximum Aerodynamic Efficiency, and the power fluctuations can be absorbed as an inertial energy in the blades. The wind turbines interfaced to an ac grid through grid connected inverters have wide applications in household and industrial level power generation. The main advantage of this arrangement is all the generated power can be fed to the power grid. The main issues with the existing grid connected inverter systems are as follows.

1) Limited speed range: The existing grid connected inverters have limited dc voltage which will limits the power extraction in both low and high wind speed range.

2) High cost: Grid connected inverters adapted from the common type photovoltaic inverters requires additional Front end ac-dc conversion and voltage limiting Power electronic circuits and control algorithms. This will increase the system cost.

Considering these issues a simple ac-dc-ac converter is used for the grid connected wind power generation systems with the advantage of inexpensive cost and easy control of the generator load.

In this project, a stand-alone system consisting of wind generator is proposed with the battery for energy storage. Wind is the primary power sources of the system to take full advantages of renewable energy. The dynamic modeling and control of the system is proposed. The concept and principle of the system with its supervisory control were delineated. The system consists of a synchronous machine wind turbine generator, a dump-load control circuit, a diode rectifier, and a grid-connected inverter. The output voltage of a synchronous generator is rectified to provide a dc voltage that will vary in magnitude to reflect the turbine speed and is controlled and given to the grid connected inverter. The system also consists of
a dump load circuit, which not only protects the inverter from over speeding but also protect the inverter from high dc voltage in grid-connected mode under high wind speed conditions. When compared to existing systems, the proposed circuit has advantages such as low cost, and it can also control “dump-load.”

The necessary conditions of MPPT are: simple, low cost, quick tracking when condition varies, and during slight output power fluctuation. The traditional methods are simple and low cost without good tracking performance, such as hill climbing, P&O, and incremental conductance, etc. Novel methods are developed with higher accuracy but complex process, such as the optimum gradient method, fuzzy logic control, and neural networks (NN). To achieve a fast and stable response for the real power control, the intelligent controller consists of an improved Elman neural network (ENN) for maximum power point tracking (MPPT) is used. The pitch angle of wind turbine is controlled by the ENN, where the output signal is used to control the dc/dc boost converters to achieve the MPPT.

In the proposed system a small wind generation system with NN for wind-speed estimation and PI control for maximum Wind-power extraction. The mechanical power of the wind turbine can be well tracked for both the dynamic and steady state, but the power deviation and speed tracking errors are large for transient response lasting for almost 20s. The Elman neural network (ENN) is a partial recurrent network model first proposed by Elman where the dynamic characteristics are provided by internal connections. The ENN does not need to use the state as input or training signal, which makes the ENN superior to static feed forward network and is used in dynamic system identifications widely. In order to improve the ability of identifying high order systems, some modified ENN have been proposed recently, which proved to have more advantages than the basic ENN, including a better performance, higher accuracy, dynamic robustness, and it has good transient performance.

II SYSTEM OVERVIEW AND MODEL DESCRIPTION

The proposed wind generation system is shown in the following Fig.2.1. The main components are modeled using MATLAB/Simulink.

![Fig 2.1 Wind Generator Grid Connected System](image)

The wind power generation system studied in this paper. It composed of a synchronous generator, In this system the synchronous machine is designed with the rating of 500KVA, 400V, a current control PWM ac/dc converter, a field orientation mechanism including the coordinate translator, a current controlled dc/ac inverter, and the MPPT controller, where the ENN are studied in this paper. The dc-bus voltage is regulated at a constant value so the real power from the wind turbine can pass to the grid. By using the reference frame theory and the linearization technique, the field-oriented synchronous generator system can be reasonably represented and used in this system. Grid is considered as the load to this system. Generally the voltage of the grid is not variable hence the output power is reflected by the grid connected current. According to the theory of power balance between the input and output power the power of the wind turbine can be characterized by the active current of grid connected. The frequency and phase of the current in grid side is decided by the voltage in the grid. The control of this system is separated into two categories: dc voltage control and grid side current control.

The controller used in this system is the ENN controller. It is one of the improved type neural network controller. The basis structure of ENN controller is shown in Fig.2.2. It consists of an input layer, hidden layer and a context layer and a output layer with two inputs and one output as shown. In order to make the neurons sensitive with respect to the input data self connections of the context nodes and output feedback nodes are added with it. So this proposed structure will have the capacity to deal with the nonlinear problems and it will improve the convergence property and reduce learning time. Once the ENN is initialized a supervised learning is used to train the system. It is same as that of the back propagation algorithm which is used to adjust the other parameters of ENN by using the
training patterns. The error term of each layer is calculated and updated by the recursive application of chain rule. The main aim of supervised learning is to minimize the error function which is expressed as E. A common supervised learning is used in this paper.

In supervised learning it defines the effect of one set of observations called as inputs, has another set of observations, called as outputs. In other words, the inputs are assumed to be at the starting and outputs at the end of the causal chain. The models will also have the mediating variables between the inputs and outputs.

The signal propagation and the basic function in each layer are given as follows.

a) In the input layer the node is defined by,
\[
\text{net}^{(1)}_i = e^{(1)}_i (k)
\]
\[
x_i^{(1)}(k) = f_i^{(1)}(\text{net}^{(1)}_i(k)) = \text{net}^{(1)}_i(2)
\]
where \(k\) represents the \(k\)th iteration, \(e^{(1)}_i(k)\) and \(x_i^{(1)}(k)\) are the input and the output of the layer.

b) In the hidden layer the node is defined by
\[
\text{net}^{(2)} = \sum_i W_{ij} * x_i^{(1)}(K) + \sum_r W_{rj} * x_r^{(3)}(K)
\]
\[
x_r^{(3)}(K) = 1/1 + \exp - \text{net}^{(2)}(4)
\]
Where \(X_i^{(1)}\) and \(X_r^{(3)}\) are input and \(X_i^{(2)}\) is output of the hidden layer. \(X_i^{(3)}(K)\) is also the output of the context layer, and \(W_{ij}\) and \(W_{rj}\) are the connecting weights.

c) In the context layer the input and output node is defined by
\[
X_i^{(3)}(K) = \alpha x_i^{(3)}(K-1) + x_j^{(2)}(K-1)
\]
Where \(0 \leq \alpha < 1\) is a self connecting feedback gain.

d) In output layer the node input and output layer are represented as
\[
\text{net}_i^{(4)}(k) = \sum_j W_{pj} * X_j^{(2)}(K)
\]
y_0^{(4)}(k)=f_i^{(4)}(net_0^{(4)}(k)) \quad \text{(7)}

Where W_0 is the connecting weight of hidden neurons to output neurons, and y_0^{(4)}(k) is the output of the improved ENN and also the control effort of the proposed controller. The error function E is expressed as

\[ E=\frac{1}{2}(P_{\text{out}}-P_{\text{ref}})^2=\frac{1}{2}e^2 \quad \text{(8)} \]

P_{\text{out}} and P_{\text{ref}} are the actual output power and reference output power of the generator.

### III POWER IN THE WIND

The wind systems that exist over the earth’s surface are due to the result of variations in air pressure which are in turn due to the changes in solar heating. Wind is merely the movement of air from one place to another. There are various wind patterns related to large scale solar heating of different regions of the earth’s surface. Localized wind patterns are also available due the effects of change in temperature between land and seas, or mountains and valleys.

Wind speed generally increases with height above the ground. This will happen because the roughness of ground features such as vegetation and houses cause the wind to be slowed. Wind speed data can also be obtained from the wind maps or from the record of meteorology office. The general availability and reliability of wind speed data is extremely poor in many regions of the world. Significant areas of the world have mean annual wind speeds of above 4-5 m/s (meters per second) which will make the small-scale wind powered electricity generation an attractive option. It is necessary to get accurate wind speed data for the site in mind before any decision can be made as to its suitability. The power in wind is proportional to the following factors:

- the area of windmill which is being swept by the wind
- the cube of the wind speed
- the air density - which varies with altitude

The energy can be extracted from the wind by two ways; these are through the creation of either lift or drag force (or through a combination of the two). The difference between drag and lift is explained by the difference between using a spinnaker sail, which fills like a parachute and pulls a sailing boat with the wind, and a Bermuda rig, the familiar triangular sail which deflects with wind and allows a sailing boat to travel across the wind or slightly into the wind. Drag forces provide the most easy means of propulsion, these being the forces felt by a person (or object) exposed to the wind. Lift forces are the most efficient means of propulsion but being more subtle than drag forces. The basic features that characterize lift and drag force are:

- Drag force in the direction of air flow
- Lift force is the force which is perpendicular to the direction of air flow
- Generation of lift always causes some amount of drag force to be developed

In order to achieve the maximum power point in the Wind Power Generation System, it is necessary to install the Power Electronic Converters between the Wind Turbine Generator (WTG) and the Grid. The function of the wind turbine is to convert kinetic energy in to mechanical energy which is given to the generator. The mechanical output power of the Generator is expressed as

\[ P_m = \frac{1}{2} \rho A V_w^2 C_p(\beta, \lambda) \quad \text{(9)} \]

where \( \rho \) is the air density, \( A \) is the area swept by blades, \( V_w \) is the velocity of wind in m/s, and \( C_p \) is power coefficient. It is the function of blade pitch angle \( \beta \) and tip speed ratio \( \lambda \). Tip speed ratio is defined by

\[ \lambda = \frac{\omega r}{V_w} \quad \text{(10)} \]

where \( r \) is the blade radius of wind turbine, and \( \omega \) is the turbine speed. A variable speed pitch-regulated wind turbine is considered in this research, where the pitch angle controller plays an important role. Fig. 3.1. shows the groups of \( C_p-\lambda \) curves of the wind turbine used in this research at different pitch angles. From the figure that \( C_p \) can be controlled by varying the pitch angle \( \beta \). So the output power of the wind turbine can be adjusted by pitch angle control.
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It is not easy to measure the wind speed in the rotor of turbine, so an indirect approach is implemented. According to the theory of power balance of the system, the maximum power point of the wind turbine can be tracked by judging the grid-connected power. This strategy has a simple structure and needs no additional measurements. The function of unit MPPT is to find the corresponding rectify voltage reference of wind turbine maximum power point. The compensator of the rectify voltage loop is proportional and integral for realizing zero difference. Therefore, MPPT tracking can be achieved by incorporating it with grid-connected power control without any information of wind speed.

IV SIMULATION AND RESULTS

The wind generator system shown in Fig. 1 is implemented in the MATLAB/SimPower environment. Parameters of the WECS are used in the simulation. Tests were conducted to show performance of the model under various conditions, with the MPPT scheme. It can be seen that the ENN controller provides a better control performance. The ENN oscillates only slightly in transient response at the starting point.

Fig.3.1. \( C_p - \lambda \) Characteristics of the WECS.

Fig.4.1 Simulation diagram

In this variable speed wind turbine is used and gate pulse for converter is generated by MENN controller.

Fig.4.2 MPPT Voltage of WECS

The MPPT voltage is obtained as shown in the Fig.4.2. The pitch angle of the wind energy conversion system is obtained using simulation and it is shown in the following Fig 4.3.
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V CONCLUSION

In this project, a Wind Generation System is proposed and implemented. This stand-alone wind Generation system can effectively extract the maximum power from the wind. By using this intelligent controller to kept the grid voltage constant under disturbances. From the case studies, it shows that voltage and power can be well controlled in the wind generation system under a changing environment. A better transient and more stability, even under disturbance is obtained. The simulation model of the hybrid system was developed using MATLAB/Simulink. The electrical torque of the WECS generator is controlled to drive the system to the rotational speed where maximum energy can be obtained. Based on the load size and the power supplied by the WECS generator, the control system regulates the rotational speed.

VI FUTURE WORK

In future, any other source of renewable energy may be utilized in Hybrid Power Generation System and also the performance may be improved by minimizing the THD by using any other controllers. The Simulations may also be carried out by using any other software such as Proteus software and Multisim etc...

REFERENCES


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