NEURO FUZZY BASED MAXIMUM POWER TRACKING CONTROL ALGORITHM IN WIND ENERGY CONVERSION SYSTEMS

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ABSTRACT

In this paper, a method of extracting the maximum power in a wind energy conversion system (WECS) is proposed, which adjusts the pitch angle of the wind turbine as well as control the grid side converter to attain maximum efficiency. The proposed neuro-fuzzy algorithm searches for the maximum power by varying the blade pitch angle in the desired direction and enhancement control of the system. The generator is operated in the speed control mode with the speed reference being dynamically modified in accordance with the magnitude and direction of change of active power. Wind turbines with double output induction generators can operate at variable speed permitting conversion efficiency maximization over a wide range of wind velocities. In order to maximize energy extraction from the wind, wind energy conversion systems (WECS) should be able to operate at variable rotational speed. The paper describes a variable speed wind generation system where neuro-fuzzy logic principles are used for efficiency optimization and performance enhancement control. A neuro-fuzzy controller tracks the generator speed with the wind velocity and adjust the pitch angle to extract the maximum power. A second neuro-fuzzy controller gives robust speed control against wind gust and turbine oscillatory torque. The complete control system has been developed, analyzed, and validated by simulation study using MATLAB/SIMULINK software.

KEYWORDS: Neuro-fuzzy algorithm, Wind energy conversion systems, MATLAB/SIMULINK

INTRODUCTION

Wind energy has steadily established itself as one of the most reliable and affordable renewable energy resources. The aim is to ensure that by 2030, wind energy will be the most cost-efficient energy source on the market. However, with the growing demand for green electricity worldwide, rising turbine costs and increased competition to supply green electricity to the grid, wind farm operators must improve their existing power output. In India, the total installed capacity of wind power generation is 8754 MW in the year 2008. By the end of 2012, the total installed capacity is going to be reached to 12000 MW according to ministry of new and renewable energy, India and total installed capacity of wind energy is estimated to be more than 160 GW [WWEA] all around the world [1].
Wind energy has been the subject of much recent research and development. In-order to overcome the problems associated with fixed speed wind turbine system and to maximize the wind energy capture, many new wind farms will employ variable speed wind turbine. Double Fed Induction Generator (DFIG) is one of the components of Variable speed wind turbine system. A DFIG is a special type of induction generator with a wound rotor. DFIG offers several advantages when compared with fixed speed generators including speed control. This analysis highlights two of the DFIG’s main advantages. First, a small amount of reactive power from the rotor becomes a large amount of reactive power in the stator. Second, the rotor power rating is required to be only a fraction of the entire generator rating. DFIG’s can achieve reactive power control and a wider speed range than for a cage-type induction generator. Variable speed operation allows the DFIG to capture a greater amount of power in the wind for a given wind speed.

The mechanical output power at a given wind speed is affected by the turbine’s speed. At a given wind speed, the maximum turbine energy conversion efficiency occurs at an optimal pitch angle of the blade. Therefore, as wind speed changes, the turbine’s rotor speed needs to change accordingly in order to extract the maximum power from the available wind resources.

Recently, maximum power point tracking (MPPT) controls have been reported in [2]–[4], in which the wind speed is estimated for MPPT or the maximum power point is determined without the need of the wind speed information. Quincy Wang [5], proposes a paper which focuses on the development of maximum wind power extraction using hill climbing algorithms for inverter-based variable speed wind power generation systems. This algorithm has the capability of providing initial power demand based on error driven control, searching for the maximum wind turbine power at variable wind speeds, constructing an intelligent memory, and applying the intelligent memory data to control the inverter for maximum wind power extraction, without the need for either knowledge of wind turbine characteristics or the measurements of mechanical quantities such as wind speed and turbine rotor speed. Whei-Min Lin [6], proposes a paper in which a solar and diesel–wind hybrid generation system was proposed and implemented. An efficient maximum power sharing and extraction technique among energy sources using neural network are successfully demonstrated with more efficiency, a better transient and more stability, even under disturbance.

Yu-Lin Juan [7], proposed an interface mainly composed of a dynamic maximum power point tracking (MPPT) control of wind conversion system and a half-controlled single-stage rectifier with an integrated control. In [8], the MPPT is achieved by a fuzzy-logic-based control. For a particular wind speed, the fuzzy control adaptively performs an incremental/decremental search for the WTG shaft speed along the direct to increase the output wind power, until the system settles down at the maximum output power condition. However, if the wind speed changes significantly from moment to moment, this method may requires a long searching time to locate the maximum power point.

Artificial neural networks (ANNs) are well known as a tool to implement nonlinear time-varying input-output mapping. To overcome the drawbacks of the methods in [3]–[4], Li et al. [2]
propose a multilayer perceptron neural network (MLPNN) based wind speed estimation method for a direct-drive small WTG system. This method provides a fast and smooth wind speed estimation from the measured generator electrical power but suffers from the drawback of being black box property of ANN.

This paper proposes a new wind speed estimation based output maximization control based on Neuro-Fuzzy Logic for variable-speed DFIG based wind generation system. The wind speed is estimated from the measured generator electrical power while taking into account the power losses in the Wind Turbine Generator (WTG) and the dynamics of the WTG shaft system. The optimal pitch angle of the blade is found out using the control logic and the DFIG rotor speed command is then determined from the estimated wind speed. Other control issues, such as the reactive power and voltage control over the grid are also investigated in the entire control system design. The resulting WTG system delivers maximum electrical power to the grid with high efficiency and high reliability.

WIND TURBINE MODEL

The basic configuration of a DFIG driven by a wind turbine is shown in Fig. 1. The wind turbine is connected to the DFIG through a mechanical shaft system, which consists of a low-speed shaft and a high-speed shaft and a gearbox in between. The wound-rotor induction machine in this configuration is fed from both stator and rotor sides.

![Fig.1 Configuration of Wind Energy Conversion System.](image-url)

The generator considered is a wound rotor induction machine whose stator is connected directly to the grid and the rotor is fed through back-to-back PWM converters (Fig. 1). Stator flux-oriented vector control is applied to control the active and reactive current loops independently. The operating region of the system in the power-speed plane is indicated in Fig. 2.
Fig. 2. Operating region of WECS with wound rotor induction machine in the P–ω plane.

NEURO FUZZY CONTROLLER DESIGN

In recent years, fuzzy logic control has played an increasing and significant role in the development and design of real-time control applications. However, membership function type, number of rules and correct selection of parameters of fuzzy controller are very important to obtain desired performance in the system. Determination of membership function type and rule number of fuzzy controller and selection of parameters is made by means of trial and error method and by using the specialization knowledge. The main purpose of using the Neuro-Fuzzy approach is to automatically realize the fuzzy system by using the neural network methods. A combination of neural networks and fuzzy logic offers the possibility of solving tuning problems and design difficulties of fuzzy logic.

Variable-speed WECS control system generally includes three main control subsystems:

1. aerodynamic power control, through pitch control;
2. variable-speed operation and energy capture maximization, by means of generator control;
3. grid power transfer control, through the power electronics converter. Variable-speed WECS control system generally includes three main control subsystems:
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8. generator control;
9. grid power transfer control, through the power electronics converter.

When the wind speed is between the cut-in and the rated speed (partial load regime), the pitch control system is typically inactive, with two exceptions: when the pitch system is used to assist the start-up process, as the two- or three-bladed wind turbines have a relatively low starting torque, and when the rotational speed is limited by pitch control as the wind speed approaches the rated value. The pitch control system is active when the wind speed exceeds the rated wind speed. Its objective is to limit the aerodynamic power to the rated one and, when the wind speed reaches the cut-out value, to stop the wind turbine. Thus, the pitch control system deals mainly with alleviating the mechanical loads on the wind turbine structure.

During the partial load regime, the generator control is the only active control and aims at maximizing the energy captured from the wind and/or at limiting the rotational speed at rated. This is possible by continuously accelerating or decelerating the generator speed in such a way that the optimum tip speed ratio is tracked. At rated wind speed, the generator control limits the generator speed.

Thus, the generator control deals mainly with the power conversion efficiency optimization. Sometimes this means that the generator torque varies along with the wind speed and, in some conditions, can induce supplementary mechanical stress to the drive train. Consequently, maximizing the power conversion efficiency through generator control should be done, bearing in mind the possibility that supplementary loads are induced to the mechanical structure.

In this paper, a neuro-fuzzy controller architecture is proposed, which is an improvement over the existing fuzzy controllers to control the pitch angle of the DFIG and the grid side voltage converter controller.

The pitch angle control is made to control the wind flow around the turbine blades by controlling the moment spent on the turbine shaft. If the wind speed is lower than the rated speed of wind turbine, pitch angle is constant in its optimum value. It must be considered that the pitch angle can be changed in limited rate. This rate may be completely low because of rotor blade dimension. The maximum change rate for blade gap angle is about 10 degree/s. By means of blade pitch angle control, in speeds of rotor above slow and nominal values, no problem may occur with respect to the structure of the wind turbine. As long as the wind turbine output power is lower than that for the rated speed of wind turbine, the error signal will have a negative value and gap angle will be have optimum value. But, if the turbine output power is above the reference value, the error signal will be positive and gap angle will be replaced with a new value in limited rate.
Neuro fuzzy controller can basically learn any static input-output characteristics if the training data is available. This means that the learning algorithm can produce a neuro fuzzy controller which can copy the control surface of an existing controller if the input-output data from the controller is known. The Simulation model of Neuro-Fuzzy Controller designed for pitch-angle control is shown in Fig.3.

**SIMULATION STUDY**

The intelligent neuro-fuzzy algorithm for maximizing the performance of the wind energy conversion system has been simulated using SimPowersystems in MATLAB 7.10 software. The test environment is shown as Fig. 4, where a wind turbine simulator system is used as the prime mover to drive a asynchronous generator in replacement of a real wind turbine. The max-power algorithm is implemented using neuro-fuzzy logic based controller which effectively controls the pitch angle of the system.
Various simulation studies have been conducted based on the developed algorithm. Fig. 5&6 shows the test results of the WTG system, under a constant wind speed set at 10 m/s.
CONCLUSIONS

The Neuro-Fuzzy control system for searching the optimum operating point for a WECS in speed control mode is proposed. This technique makes peak power tracking independent of the turbine characteristics and the air density. The criteria for selecting the critical control parameters are described. Simulation results show that the performance of the control algorithm compares well with the conventional methods.

REFERENCES


