Dynamic control of DFIG based Wind Energy Conversion System using fuzzy controller

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Abstract

The probabilistic model wind energy conversion system (WECS) is developed in this paper comprising of wind turbine, doubly fed induction generator (DFIG), back to back converter and grid. It deals with the dynamic control of parameters of wind energy conversion system with doubly fed induction generator. The controls of the DFIG are based on the feedback technique by using the suitable vector control on the rotor side as well as in grid side. The current harmonics at the grid side are controlled using an appropriate fuzzy controller. The control approach is implemented through the simulation result of the feedback controller assembled with DFIG wind turbine.

Key Words: Doubly fed Induction Generator, Vector control, Fuzzy control.

1 INTRODUCTION

Due to the increasing demand of energy the world is in need of more efficient renewable energy sources. Wind energy produces
financial and economic benefits in addition to environmental benefits. It ranks among the most popular and cost-effective sources of alternative energy. Since wind provides us with such a source it is important to study the dynamics of how the wind energy is utilised. With swift development of wind power technologies and significant growth of wind power capacity installed worldwide, various wind turbine concepts have been developed. A generic procedure combining available wind farm data with that of output of wind power probability curve to obtain a wind farm reliability model was proposed by Giorsetti and Utsurogi [1]. To ascertain the annual energy output of a wind farm connected to a grid Wang et al [2] came up with an algorithm to obtain a wind turbine generator model. In short terms, there must be an ability to support dynamic frequency of wind energy rapidly in the near future to ensure the frequency of the system is stable.

In addition, it can be contributed to the inertia of wind energy to further improve the accessibility of wind power in the grid [3]. The generator speed is controlled using rotor side converter (RSC) and reactive power is controlled with grid side converter (GSC) of a grid integrated system. The dc link voltage and reactive power exchange with the grid can also be controlled using grid side converter. The majority of the articles cited above mainly focus on control of speed, even when current control is the primary component of Direct Field Oriented Control (DFOC) method. Conventional DFOC method uses two PI controllers. This paper proposes fuzzy controller to replace both the PI controllers. The direct (d-axis) and quadrature (q-axis) components of the stator voltage vector are calculated by the fuzzy controller that is characterized in rotor flux oriented reference frame. The d-axis stator current error and q-axis stator current error form the inputs of the fuzzy controller. The functions of these inputs define the rule base of the proposed fuzzy controller. The input membership functions are chosen as triangular and trapezoidal shapes, as these functions are suitable for real time operation [6]. For electricity production through wind energy, DFIG is commonly used for this purpose because of its numerous advantages over its counterparts [4]. Variable speed operation of the DFIG wind turbine based on the active and reactive power abilities, lower cost of the converter and power losses are decreased as compared to wind turbine by using the fixed speed generator.
Wind turbines with variable speed and new standards are effective due to their improved efficiency in achieving higher power quality by pulling in more wind power [5].

2 WIND TURBINE

A device which transforms kinetic energy of the wind into mechanical power is called the wind turbine. This paper involves wind turbine consisting of a constant wind speed along with a pitch angle control and drive train in order to provide variable input to the generator. The mechanical torque is given by

\[ T_w = \frac{P_w}{W_w} \]  

Where \( T_w \) : Wind turbine torque  
\( P_w \) : Power Generated  
\( W_w \): Angular speed of wind turbine

Pitch Angle Controller

The main function of pitch angle controller is to maintain rated output power and to keep the speed of wind turbine constant even at higher wind speeds. This is achieved by regulating pitch angle \( \theta \), thereby changing \( (\lambda, \theta)C_p \) [10]. Hence, the generator output power is maintained at rated power point. Thus, any damage to wind turbine can be prevented at high wind speeds as well as the speed of the wind turbine can be regulated using pitch angle [7].

3 DOUBLY FED INDUCTION GENERATOR (DFIG)

Doubly Fed Induction Generators are the type of generators in which both field winding and armature windings are separately connected to the equipment outside machine. DFIG is similar to ac generator with additional feature which allows them to run at speeds slightly above and below synchronous speed. This is helpful as when the winds hit the turbine suddenly, the turbine tends to speed up and since DFIG has the capability to speed up, there will be no large forces developed in gearbox or generator to cause wear
and tear. In DFIG one winding is directly connected to the output and produces three phase ac power at desired frequency and the other winding to 3-phase ac at variable frequency. Any changes in the speed of the wind turbine are compensated by adjusting the phase and frequency of the input power [7]. In DFIG the slip rings connect the rotor windings to grid fed through a back to back converter thereby controlling the rotor currents as well as the grid currents. The active and reactive power of the grid can be varied by controlling the rotor currents using the converter independent of generator speed. The doubly fed generator windings have turns which are 2 to 3 times that of stator. It is due to this that the rotor voltages are high and currents are respectively low. This leads to low cost of converter.

![Block diagram of DFIG based Wind Energy System](image)

Fig 1. Block diagram of DFIG based Wind Energy System

4 VECTOR CONTROL

Vector control is a control method in which the stator currents are identified as two mutually rectangular vector components. These two vectors are visualised as Torque and Magnetic flux of the motor. In a DFIG machine connected to power grid, closed loop vector control of active and reactive power produce the reference flux and torque currents [8]. The flux and the voltage equations of nonlinear
The dynamic model of the DFIG can be denoted as [9]:

\[
\begin{align*}
\frac{d}{dt}\lambda_{ds} &= V_{ds} - r_s I_{ds} + \omega_s \lambda_{qs} \quad (2) \\
\frac{d}{dt}\lambda_{qs} &= V_[qs] - r_s I_{qs} - \omega_s \lambda_{ds} \quad (3) \\
\frac{d}{dt}\lambda_{dr} &= V_{dr} - r_r I_s + (\omega_s - p\omega_r) \lambda_{qr} \quad (4) \\
\frac{d}{dt}\lambda_{qr} &= V_{qr} - r_r I_s - (\omega_s - p\omega_r) \lambda_{dr} \quad (5) \\
\lambda_{ds} &= l_s I_{ds} + l_m I_{dr} \quad (6) \\
\lambda_{dr} &= l_r I_{dr} + l_m I_{ds} \quad (7) \\
\lambda_{qs} &= l_s I_{qs} + l_m I_{qr} \quad (8) \\
\lambda_{qr} &= l_r I_{qr} + l_m I_{qs} \quad (9) \\
\end{align*}
\]

where, \( R_s \) and \( R_r \) are the stator and rotor resistance, \( l_s \) and \( l_r \) are the stator and rotor inductance while \( l_m \) represents the mutual inductance, \( \omega_s \) is the synchronous frequency respectively. In addition, \( V_s, I_s \) and \( \lambda_s \) represent the stator voltage, current and stator flux, \( V_r, I_r \) and \( \lambda_r \) are represent the rotor voltages, current and flux vectors. The controller has been implemented for the nonlinear dynamic model of the DFIG.

The Rotor Side Control (RSC) and Grid Side Control (GSC) are required only for voltage orientation due to simpler control design for DFIG. The RSC is to improve the performance of DFIG, and the real power of the DFIG is controlled with rotor voltages to increase the efficiency of the machine. Under normal operating conditions the main aim of the controller is to enhance the performance of wind energy system while the system remains stable [10]. The feedback linearization techniques are typically controlled to the real power of DFIG wind turbine based on wind energy conversion system. The feedback control strategy is used for the stator voltage and current control of the DFIG wind turbine system. These input parameters \( V_{dr}, V_{qr}, V_{ds} \) and \( V_{qs} \) are used to control the stator real power and reactive power. The active and reactive powers are controlled independently via \( V_{dr} \) and \( V_{qr} \), respectively. The pulse width modulation technique is employed to produce the control signal \( V_r \) and \( V_s \), both of which are derived from the RSC and GSC. It is an
easy way to use the voltage single $V_r$ and $V_s$ as input parameters of the controller [12].

![Diagram of vector control of DFIG]

**5 FUZZY CONTROL**

The most common control technique is the active and reactive power decoupled by PI control to improve dynamic behaviour of wind turbines [13]. But uncertainty about the exact model and behaviour of some parameters such as wind, wind turbine, and also variation of parameter values, during operation because of the temperature, events or unpredictable wind speed are the main problems in the PI control method. Fuzzy controller outputs are more reliable because the effect of parameters like noise, online change of control parameters is taken into consideration. Moreover, without the need of a detailed mathematical model of the system and just using the knowledge of the total operation and behaviour of the system, tuning of parameters can be done more easily.

The fuzzy controller works on a set of fuzzy rules, which are obtained from the internal structure of the system being controlled. The design of fuzzy controller involves the steps given below.

1. Suitable rule set development;
2. Input/output variables selection and their quantization in fuzzy sets;
3. Membership functions definition and association to the input variables;
4. Defuzzification technique selection.

The inputs to the fuzzy controller are the d-axis and q-axis component of stator current error $E_{ids}$ and $E_{iqs}$ respectively. The output of the controller is the direct and quadrature components of the stator voltage vector. The Membership Functions (MFs) of the fuzzy controller inputs are shown:

![Fig 3. Membership function for the direct-axis component of the stator current error $E_{ids}$](image)

Fig 3. Membership function for the direct-axis component of the stator current error $E_{ids}$.

![Fig 4. Membership function for the quadrature-axis component of the stator current error $E_{iqs}$](image)

Fig 4. Membership function for the quadrature-axis component of the stator current error $E_{iqs}$.

The Fuzzy Rule Base is as follows:

<table>
<thead>
<tr>
<th>$E_{ids}$/$E_{iqs}$</th>
<th>N</th>
<th>ZE</th>
<th>P</th>
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<tbody>
<tr>
<td>N</td>
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Table 1. Fuzzy Rule Base

The Membership Functions (MFs) of the fuzzy controller outputs are shown:

![Fig 5. Membership function for the output direct-axis component](image)

Fig 5. Membership function for the output direct-axis component.
6 SIMULATIONS AND EXPERIMENTAL RESULTS

The performance of proposed fuzzy logic controller of WECS is estimated in this section using MATLAB/Simulink. Figures 8–10 shows the various outputs of WECS using fuzzy control.
Fig 8. Voltage and current using fuzzy controller

Fig 9. DC link voltage with fuzzy controller
FFT analysis is done with PI and fuzzy controller. The results shown in the Fig 11 13 indicates that the current THD level is minimum in the system with fuzzy controller, which signifies the effectiveness of proposed controller.

Fig 11. THD with PI controller
7 Conclusion

This paper presents a model and simulation of grid integrated wind energy conversion system. Vector control has been incorporated in conventional Wind Energy Conversion System to decouple the magnetising flux. With vector control, torque and speed could be varied independently which conventionally follows an inverse relationship. Different aspects of the models were analysed and the parameter that showed any significant differences were the THD levels, which was checked using the FFT analysis tool in MATLAB. The system with conventional vector control had moderate THD levels and the system with Fuzzy Control showed better THD levels. The performance of proposed fuzzy controller is better than the conventional PI controller in Wind Energy conversion system.

References


[12] Jos L. AZCUE-PUMA1, Alfeu J. SGUAREZI FILHO2, Ernesto RUPPERT1 Universidade Estadual de Campinas (1), Universidade Federal do ABC.