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Unified Control of Doubly Feed Induction Generator in Wind Farm by using Genetic Algorithms

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Abstract: The integration of wind farms into the electricity grid has become an important challenge for the utilization and control of electric power systems, because of the fluctuating and intermittent behavior of wind power generation. Doubly Fed Induction Generators (DFIG) are commonly used Wind Turbine Generators (WTG) in electricity networks. In DFIG there are three control loops which should be implemented in order to appropriate performance of WTG. These control loops are pitch angle control, rotor speed control and voltage control. In this study a unified scheme is used to adjust these controllers in the same time. Genetic Algorithm (GA) is used to adjustment the proposed controllers. The results of wind power on the system performance are compared with a conventional thermal power plant.

Key words: Doubly fed induction generators, genetic algorithm, multi machine electric power system, pitch angle control, wind turbine generators

INTRODUCTION

Wind Turbines Generators (WTGs) are usually controlled to generate maximum electrical power from wind under normal wind conditions. However, because of the variations of the wind speed, the generated electrical power of a WTG is usually fluctuated. Currently, wind energy only provides about 1-2% of the U.S.'s electricity supply. At such a penetration level, it is not necessary to require WTGs to participate in automatic generation control, unit commitment, or frequency regulation.

In order to meet power needs, taking into account economical and environmental factors, wind energy conversion is gradually gaining interest as a suitable source of renewable energy. The electromagnetic conversion is usually achieved by induction machines or synchronous and permanent magnet generators. Squirrel cage induction generators are widely used because of their lower cost, reliability, construction and simplicity of maintenance (Heier, 1998). But when it is directly connected to a power network, which imposes the frequency, the speed must be set to a constant value by a mechanical device on the wind turbine. Then, for a high value of wind speed, the totality of the theoretical power cannot be extracted. To overcome this problem, a converter, which must be dimensioned for the totality of the power exchanged, can be placed between the stator and the network. In order to enable variable speed operations with a lower rated power Converter, Doubly-Fed Induction Generator (DFIG) can be used as shown on Fig. 1. The stator is directly connected to the grid and the rotor is fed to magnetize the machine. Control of electrical power exchanged between the stator of the DFIG and the power network by controlling independently the torque (consequently the active power) and the reactive power is an important issue in DFIG utilization (Xu and Cheng, 1995). Several investigations have been developed in this direction using converters and classical proportional-integral regulators (Yamamoto and Motoyoshi, 1991; Rifai and Ortmeyer, 1993; Hopfensperger *et al*., 2000).

In this study a unified scheme is used to adjust DFIG controllers in the same time. Genetic Algorithm (GA) is used to adjustment the proposed controllers. The results of wind power on the system performance are compared with a conventional thermal power plant.

MATHEMATICAL MODEL OF THE DFIG

For a doubly fed induction machine, the Concordia and Park transformation's application to the traditional a, b, c model allows to write a dynamic model in a d-q reference frame as follows:

$$\begin{cases} V_{ds} = R_s I_{ds} + \dfrac{d\Psi_{ds}}{dt} - \dot{\theta}_s \Psi_{qs} \\ V_{qs} = R_s I_{qs} + \dfrac{d\Psi_{qs}}{dt} - \dot{\theta}_s \Psi_{ds} \\ V_{dr} = R_r I_{dr} + \dfrac{d\Psi_{dr}}{dt} - \dot{\theta}_r \Psi_{qr} \\ V_{qr} = R_r I_{qr} + \dfrac{d\Psi_{qr}}{dt} - \dot{\theta}_r \Psi_{dr} \end{cases}$$

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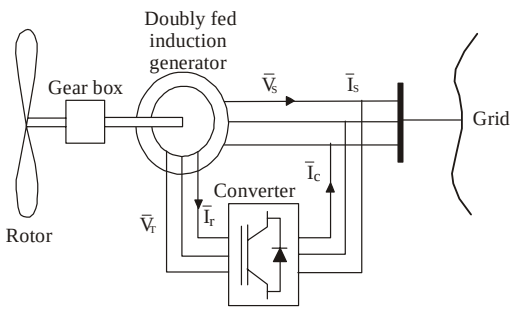

Fig. 1: Variable speed wind turbine with doubly fed induction genrator

$$\begin{cases} \Psi_{ds} = L_s I_{ds} + MI_{dr} \\ \Psi_{ds} = L_s I_{qs} + MI_{qr} \\ \Psi_{dr} = L_r I_{dr} + MI_{ds} \\ \Psi_{qr} = L_r I_{qr} + MI_{qs} \end{cases}$$

$$\Gamma_m = \Gamma_e + J\frac{d\Omega}{dt} + f\Omega$$

$$\Gamma_e = p\frac{M}{\Gamma_s}\left(\Psi_{qs} I_{dr} - \Psi_{ds} I_{qr}\right)$$

DFIG control: In DFIG there are three control loops which should be implemented in order to appropriate performance of wind farm. These control loops are pitch angle control, rotor speed control and voltage control. These control schemes are thoroughly explained in Fig. 2-4. In this study GA is used to adjust proposed controllers. In the next section an introduction about GA is incorporated.

Genetic algorithms: Genetic Algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetics. They operate on a population of current approximations-the individuals-initially drawn at random, from which improvement is constructed sought. Individuals are encoded as strings (Chromosomes) over some particular alphabet, e.g., the binary alphabet {0, 1}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation Genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into three main categories: Reproduction, crossover and mutation (Randy and Sue, 2004).

Illustrative test case: In order to evaluate the effect of WTG on the system performance, a multi machine electric power system which is IEEE 14 bus test system is considered ascase study (Milano, 2010). In the proposed test system two following cases are considered:

Case 1: Power generator at bus 1 is a thermal power plant
Case 2: Power generator at bus 1 is a wind turbine power plant

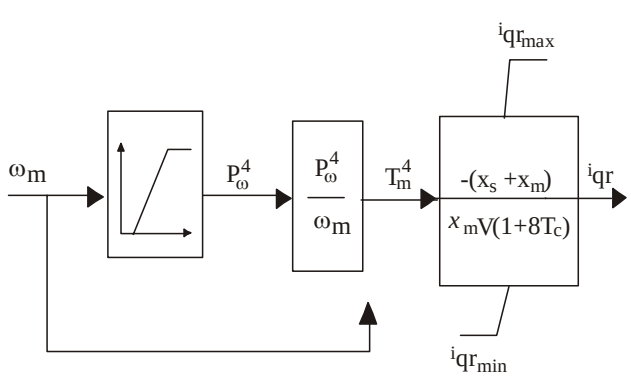

Fig. 2: Rotor speed control scheme

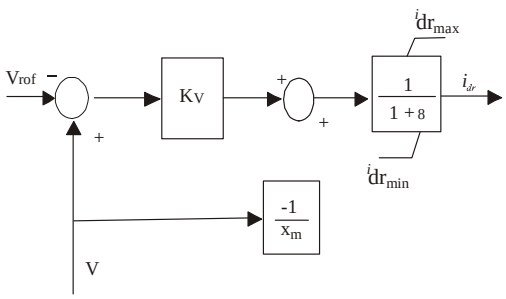

Fig. 3: Voltage control scheme

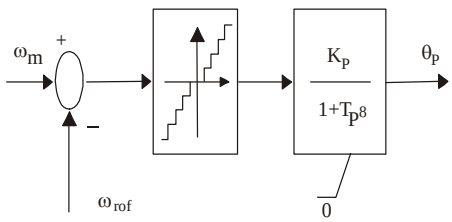

Fig. 4: Pitch angle control scheme

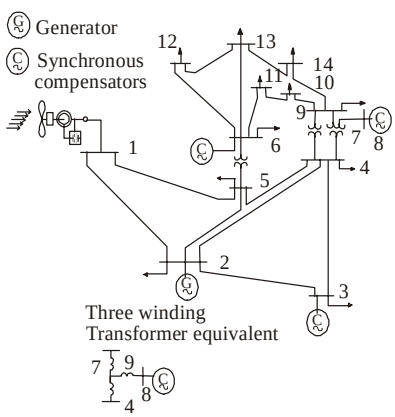

Fig. 5: IEEE 14-bus test system

Table 1: Optimum values of controller

Pitch angle gain	14.89
Pitch angle time constant	0.0348
Voltage control gain	70.91
Power control time constant	0.012

Both the cases are simulated and compared under disturbance. Figure 5 shows the proposed test system with a WTG installed in bus 1. Also in this paper the wind speed is modeled as Weibull Distribution (Milano, 2010).

Controllers adjustment using GA: In this section the parameters of the proposed controllers are tuned using GA. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as (2). In fact, the

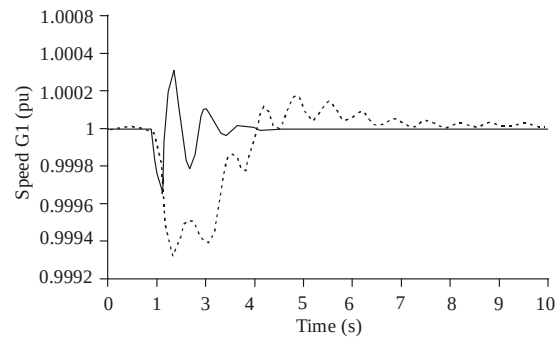

Fig. 6: Speed generator, 1 Solid (Wind power plant at bus 1); Dashed(thermal power plant at bus 1)

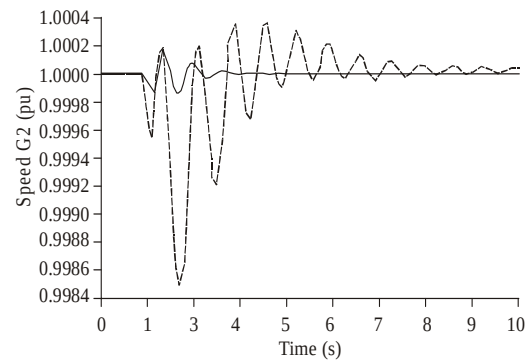

Fig. 7: Speed generator 2, Solid (Wind power plant at bus 1); Dashed (thermal power plant at bus 1)

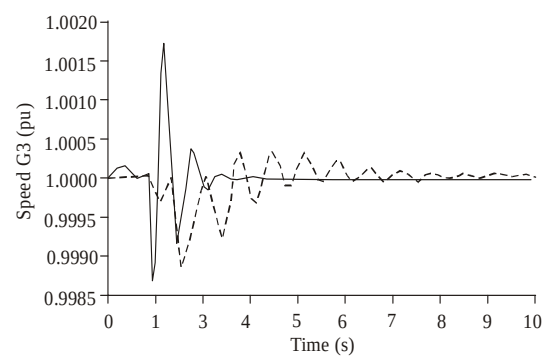

Fig. 8: Speed generator 3, Solid (Wind power plant at bus 1); Dashed (thermal power plant at bus 1)

performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$ITAM = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt + \int_0^t t|\Delta\omega_3|dt + \int_0^t t|\Delta\omega_4|dt + \int_0^t t|\Delta\omega_5|dt \quad (2)$$

It is clear to understand that the controller with lower ITAE is better than the other controllers. To compute the

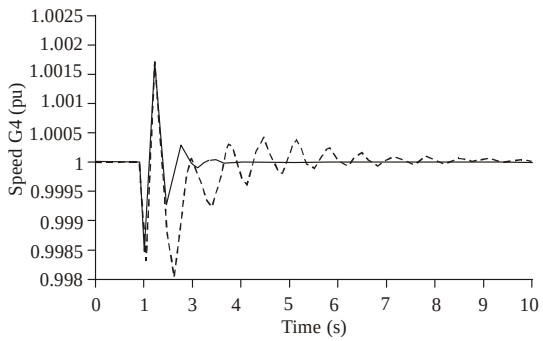

Fig. 9: Speed generator 4, Solid (Wind power plant at bus 1); Dashed (thermal power plant at bus 1)

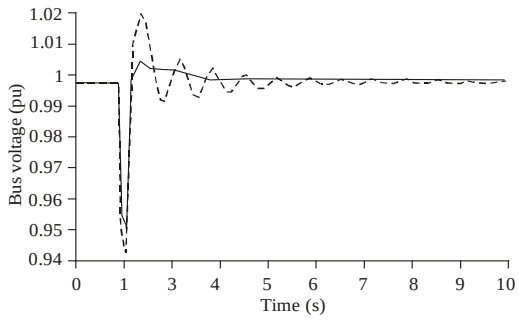

Fig. 10: Speed generator 5, Solid (Wind power plant at bus 1); Dashed (thermal power plant at bus 1)

optimum parameter values, a three phase short circuit is assumed at bus 4 and the performance index is minimized using GA. The following genetic algorithm parameters have been used in present research.

- Number of Chromosomes: 4 Population size: 24
- Crossover rate: 0.5 Mutation rate: 0.1

It should be noted that GA algorithm is run several times and then optimal set of parameters is selected. The optimum values parameters are obtained using GA and summarized in the Table 1.

RESULTS AND DISCUSSION

The simulation results are carried out on the proposed test system with both the cases. Figure 6-10 shows the results following a 10 cycle three phase short circuit is assumed at bus 9. It is clearly seen that WTG has a great effect on the system stability and increasing damping of oscillations. With WTG, in all figures the oscillations are damped out.successfully and the transient and dynamic stability margin of the system in increased. Also, voltage of bus 4 is demonstrated in Fig. 10. It is clearly seen that WTG not only has a great effect on system stability but also has a positive effect on the voltage of bus.

CONCLUSION

A unified tuning of DFIG controllers successfully carried out in this paper. GA used to adjust the DFIC controllers. The proposed DFIG was compared with conventional generators in thermal power plants. It showed that DFIG has a great effect on the system stability and performance. DFIG also successfully controlled the voltage. The paper showed that utilization of DFIG not only is suitable from view of energy and environmental effects, but also is appropriate from view of system stability and performance.

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