Interfacing and Control of DFIG Wind Turbine With Grid and Harmonic Supervision

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Abstract—**With the increase in the demand of power supply, conventional power supply unit may not be able to fulfill the increased demand of power supply. To fulfill such a demand an additional power supply is to be incorporated in conventional system. As there is constraint on power generation of existing conventional sources the need for incorporation of renewal resources for power generation is required. In this regard the power supply based on wind supply is in greater demand. To harness the wind power efficiently the most reliable system in the present era is grid connected doubly fed induction generator. In this paper we focus on analyzing Interfacing and Control of DFIG Wind Turbine With Grid using MATLAB SimPower Systems. In today's power systems, the proliferation of nonlinear load along with DFIG wind turbine increases harmonics which causes many problems in power systems, such as reactive power burden and decreased reliability. Harmonic supervision is highly valuable in relieving these problems. An optimal placement of DFIG wind farm in the grid is proposed aiming to give minimum modes and harmonics. In this paper, Prony analysis method is used for harmonic supervision and mode calculation. The result shows that the proposed method found the optimal position of wind farm with minimum harmonics and modes.**

I. INTRODUCTION

A. Practical Use of Wind Turbines

Mankind has used the wind as a source of energy for several thousands of years. It was one of the most utilized sources of energy together with hydro power during the seventeenth and eighteenth centuries. By the end of the 19th century the first experiments were carried out on the use of windmills for generating electricity. Electricity is traded like any other commodity on the market and there are, therefore, standards which describe its quality. In the case of electric power they are commonly known as the Power Quality standards. Any device connected to the electric grid must fulfill these standards and this is particularly interesting and important issue to be considered in the case of wind power installations, since the uncertain nature of wind and standardized parameters of electricity are joined together. A mathematical model of a wind turbine capable of predicting its interaction with the grid is thus an important topic.

B. Need of DFIG

In a doubly-fed induction generator, the mechanical power generated by the wind turbine is transformed into electrical power by an induction generator and is fed into the main grid through the stator and the rotor windings. The rotor winding is connected to the main grid by self commutated AC/DC converters allowing controlling the slip ring voltage of the induction machine in magnitude and phase angle. In contrast to a conventional, singly-fed induction generator, the electrical power of a doubly-fed induction machine is independent from the speed. Therefore, it is possible to realize a variable speed wind generator allowing adjusting the mechanical speed to the wind speed and hence operating the turbine at the aerodynamically optimal point for a certain wind speed range.

C. Indirect Grid Connection

The advantage of indirect grid connection is that it is possible to run the wind turbine at variable speed. The primary advantage is that gusts of wind can be allowed to make the rotor turn faster, thus storing part of the excess energy as rotational energy until the gust is over. Obviously, this requires an intelligent control strategy, to differentiate between gusts and higher wind speed in general. The secondary advantage is that with power electronics one may control reactive power (i.e. the phase shifting of current relative to voltage in the AC grid), so as to improve the power quality in the weak electrical grid.

D. Objective

Withstanding abnormal grid behavior becomes an obligation for the bulk wind generation units connected to the transmission network and it is highly desired for distribution wind generators. The penetration of wind generation into power systems is rapidly increasing since it is clean, renewable and having minimal running cost requirements. Therefore, the mode with response of bulk wind generators to the abnormal condition can lead to unhealthy system operation and in due course affect the system stability. Doubly-Fed Induction Generator (DFIG) technology is widely used in large and the modern wind turbines since it permits variable speed operation at reasonable cost and provides a reactive power control. With the increasing penetration of wind turbines employing DFIG, it becomes a necessity to investigate their behavior during transient disturbances and support them with control.

II. CONCEPT OF DFIG

A. Operating Principle

Wind turbines of DFIG-type show behavior close to that of the traditional induction machine due to their technical similarities. There are however significant differences: One; the DFIG slip can be far from zero, whereas the induction machine always operate close to zero slip. There are also some clear differences due to the controllability of the rotor current in a DFIG, since the electrical torque is no longer governed by the slip. The prime mover, consisting of a pitch-angle controlled wind turbine, the shaft and the gear-box drives a slip-ring induction generator. The stator of the DFIG is directly connected to the grid; the slip-rings of the rotor are fed by self-commutated converters. These converters allow controlling the rotor voltage in magnitude and phase angle and can therefore be used for active and reactive power control. The physical properties of the stator in the DFIG remain the same, but the rotor circuit is fed from the generator side converter, by which the rotor current is fully controlled. When the voltage drops at the generator terminals, the rotor current from the converter increases in a compensation effort to stabilize the active power output from the turbine and together with the passive response of the stator-circuit, the resulting transient currents can high. It is essential to assess voltage stability of large farms during faults in the transmission or distribution network. This situation cannot last very long without any controlling action or a special design to cope with the situation. LVRT-strategies can be implemented either on the stator or the rotor side of the generator. Over-sizing of the converter transistors will ensure that the set point for controlling action can be delayed, but does not change the physical situation very much. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator for further generation. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes.

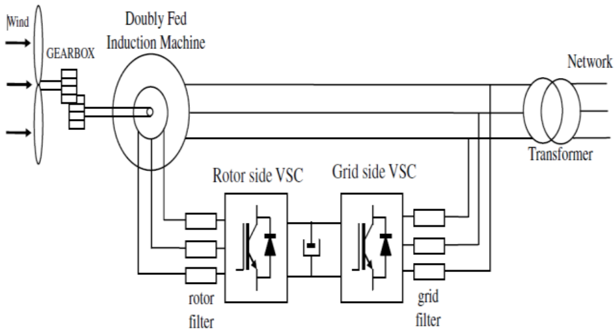

Fig.1.Doubly-fed induction generator (DFIG)

B. Modeling of the wind-turbine doubly-fed induction generator

The Simulink discrete-time WT_DFIG model, presented here, is based on the Wind Turbine Doubly-Fed Induction Generator (Phasor Type) available in version 7.9 of Matlab/ Sim Power Systems library. The wind turbine and the doubly-fed induction generator are shown in Fig 1. The AC/DC/AC converter is divided into two components: the rotor-side converter (C rotor) and the grid-side converter (C grid). Crotor and Cgrid are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor L is used to connect Cgrid to the grid. The three-phase rotor winding is connected to Crotor by slip rings and brushes and the three-phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generates the pitch angle command and the voltage command signals Vr and Vgc for Crotor and Cgrid respectively in order to control the power of the wind turbine, the DC bus voltage and the voltage at the grid terminals. An average model of the AC/DC/AC converter is used for real-time simulation. In the average model power electronic devices are replaced by controlled voltage sources. Vr and Vgc are the control signals for these sources. The DC bus is simulated by a controlled current source feeding the DC capacitor. The current source is computed on the basis of instantaneous power conservation principle the power that flows inside the two AC-sides of the converter is equal to the power absorbed by the DC capacitor. With the average model, the high frequency components of the voltage, generated by the PWM switching of electronic devices, are not simulated. This allows to simulate with a relatively large sample time, which is about ten-times larger than would be required to simulate PWM switching.

C. Basic Relationships

The power flow, illustrated in Fig.2, is used to describe the operating principle. The mechanical power and the stator electrical power output are computed as follows

$$P_m = T_m \omega_r$$
$$P_s = T_{em} \omega_s$$

For a lossless generator the mechanical equation is:

$$\frac{d\omega_r}{dt} = T_m - T_{em}$$

In steady-state at fixed speed for a lossless generator

$$T_m = T_{em} \quad \text{and} \quad P_m = P_s + P_r$$

It follows that:

$$P_r = P_m - P_s = T_m \omega_r - T_{em} \omega_s = -sP_s$$

Where ‘s’ is defined as the slip of the generator.

Generally the absolute value of slip is much lower than 1 and, consequently, Pr is only a fraction of Ps. Since Tm is positive for power generation and since ωs is positive and constant for a constant frequency grid voltage, the sign of Pr is a function of the slip sign. Pr is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For super synchronous speed operation, Pr is transmitted to DC bus capacitor and tends to rise the DC voltage. For sub-synchronous speed operation, Pr is taken out of DC bus capacitor and tends to decrease the DC voltage. Cgrid is used to generate or absorb the power in order to keep the DC voltage constant. In steady-state for a lossless AC/DC/AC converter Pgc is equal to Pr and the speed of the wind turbine is determined by the power Pr absorbed or generated by Crotor. The power control will be explained below. The phase sequence of the AC voltage generated by Crotor is positive for sub-synchronous speed and negative for super synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. Crotor and Cgrid have the capability for generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

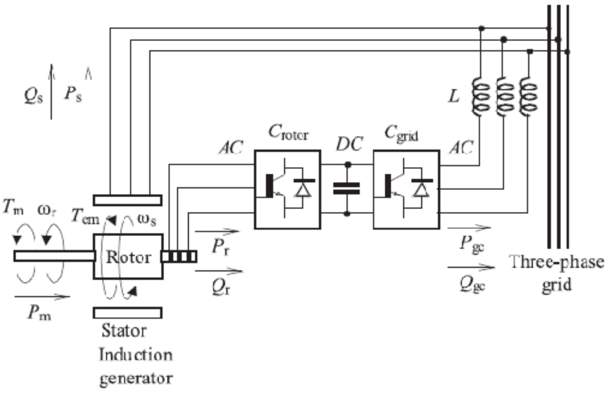

Fig.2. Power flow through DFIG

III. Simulink model for continuum TEST systems

This section is organized as follows. Section A describes a continuum model for a power system with dynamic load, fault and DFIG wind turbine connected at one end of the continuum grid. Section B describes a continuum model for a power system with dynamic load, fault and DFIG wind turbine connected in between the continuum grid..Two test systems are used to supervise the harmonic disturbance occurred due to various factors with DFIG wind turbine system connected at different locations in grid.

A. TEST SYSTEM 1

Fig.3. shows the configuration of test system 1, which includes original test system with DFIG wind turbine connected at one end of the continuum grid.

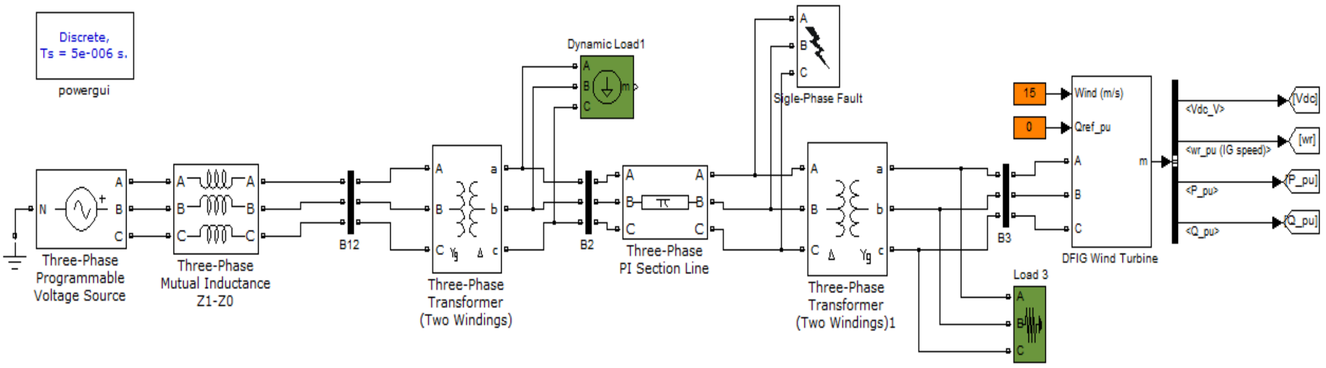

Fig.3. Simulink model of DFIG Wind turbine connected at one end of grid.

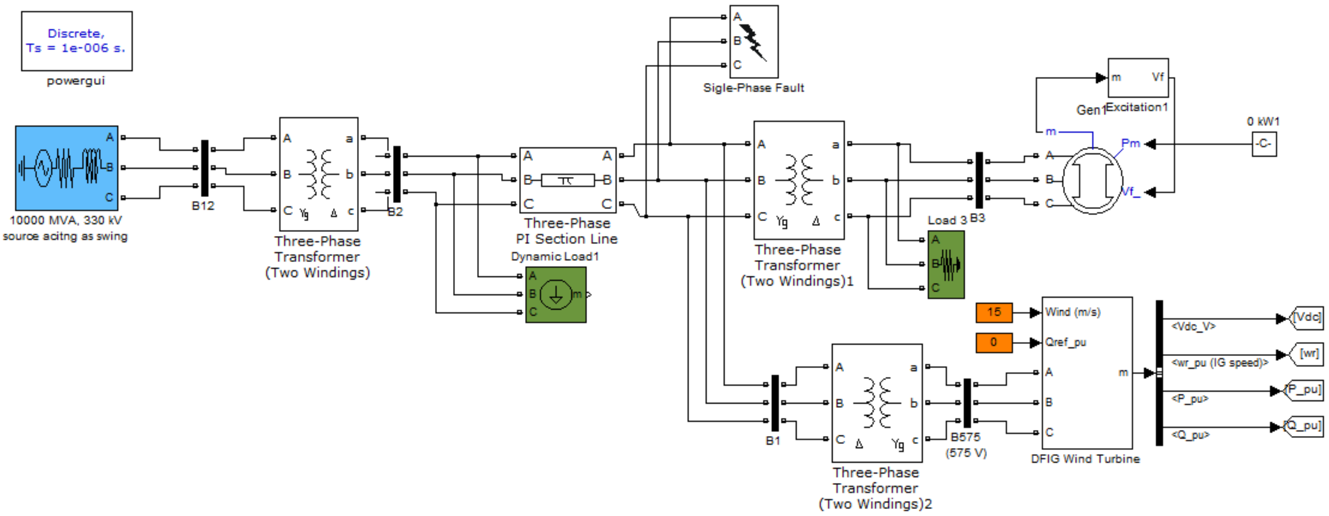

Fig.4. Simulink model of DFIG Wind turbine connected between the grid.

B. TEST SYSTEM 2

Fig.4. shows the configuration of test system 2, which includes original test system with DFIG wind turbine connected in between the continuum grid.

IV. Prony Analysis Method

A. INTRODUCTION

Prony analysis was first introduced into power system, it has been widely used for power system transient studies, but rarely used for power quality studies. The unique features of Prony analysis, such as frequency identification without prior knowledge of frequency and the ability to identify damping factors, are useful to power system quality study. Due to the ability to identify the damping factors of transients, Prony analysis can accurately identify growing or decaying components of signals.

B. Effectivness

The Prony-based harmonic supervisor identifies transient harmonics during transformer energization more accurately than the Fourier-transform-based harmonic supervisor. With Prony analysis as the harmonic reference generation method, harmonic selective active filters cancel transient harmonics during abnormal condition. The Prony-based harmonic active filter cancels transient harmonics more effectively during transient conditions than the Fourier transformed harmonic active filter does. Prony analysis is used for harmonic supervisors. Transient harmonics thus can be correctly identified from the Prony-based harmonic supervision and the harmonic reference generation. Some results of Prony analysis for supervising power system transient harmonics are presented in this paper. Important factors in power transmission and distribution systems, which induces harmonics are dynamic load and fault. we have considered two conditions here

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a.) DFIG connected at one end of the continuum connected power system

b.)DFIG connected in between the string connected power system

After simulating the model in MATLAB 7.9, readings were taken at different bus locations such as source, transmission line and generator for the following two test systems

Readings obtained after simulation are used as input for the PRONY algorithm, which gives readings for different parameters presented below for two different test systems as mentioned above.

Table 1: Prony Algorithm for Test System 1

Energy	Amplitude	Frequency	Damping
0.015783	0.004372	-4.15114	0.071582
2.88128	0.173587	-2.29555	0.015992
99.92595	2.432264	-1.56109	-0.04812
176.2781	3.223543	0	Inf
99.92595	2.432264	1.561093	-0.04812
2.88128	0.173587	2.295545	0.015992
0.015783	0.004372	4.151136	0.071582

From Table 1 we observed the modes in the test system 1,which has large magnitude. Here the magnitude goes on increasing or decreasing exponentially but if there is modes in system , we observed that rate of change of magnitude is more than normal exponential change which suggest that compensation is required at this position.

Table 2: Prony Algorithm for Test System 2

Energy	Amplitude	Frequency	Damping
27.13728	3.74015	-4.28501	-0.76864
0.047391	0.010761	-3.55156	0.06223
159.6681	2.620554	-1.33832	-0.18418
159.6681	2.620554	1.338317	-0.18418
0.047391	0.010761	3.551559	0.06223

From 2 Table 2 we can observe that modes obtained for test system 2, has less amplitude compared to test system 1. so compensation required is less for Test System 2.

V. RESULTS AND DISCUSSION

We can have analogy of our test system with the standing wave in Electromagnetics. These waves are produced by causing vibrations on a string or other piece of material whose ends are fixed in place. Standing waves are really a series of pulses that travel down the string and are reflected back to the point of the original disturbance. When you hold a string in one hand, with the other end attached to a wall and if you give the string a shake, the behavior of this wave helps us to understand what happens within the larger framework of wave motion. As with wave motion in general, the movement of the pulse involves both kinetic and potential energy. The tension of the string itself creates potential energy; then, as the movement of the pulse causes the string to oscillate upward and downward, this generates a certain amount of kinetic energy. Over long distances, electric signals act more like traveling waves than instantaneous changing signals. In electrical signals, reflections occur due to mismatched impedances creating distortions. Matching the electrical impedance of the continuum test systems at one or both ends can reduce reflections dramatically. A simple equation giving the ratio of reflected '*Vr'* to incident '*Vi'* amplitude is

$$V_r/V_i = (R_L - Z_0) / (R_L + Z_0)$$

Three cases show the range of values of standing wave ratio for the reflected wave

1)Matched load: $R_L = Z_0$,$V_r / V_i = 0$, no reflection.
2)Open Load: R_L $= \infty$, $V_r / V_i = 1$, Full reflection, same polarity.
3)Shorted Load: $R_L = 0$,$V_r / V_i = -1$, Full reflection, inverted polarity.

The impedance of DFIG is Z0 and the load of grid is RL.In test system 1, load seen by the DFIG is high so,more modes are observed. In test system 2, load seen by the DFIG decreases so observed modes are less compared to previous case. Therefore compensation required for test system 1 is much higher than test systems. DFIG wind turbine supplies or extract reactive power depending upon its control action and various grid conditions. When DFIG wind turbine extracts reactive power, due to unbalancing condition harmonics are generated. From above explained wave nature, when disturbance is occurred at one of the string, more harmonics are formed compared to case where disturbance is occurred at middle of string. Similar analysis is applied to our continuum grid system. From simulation and prony algorithm results we established a relationship between continuum grid system and wave behavior

VI.Conclusion

In this paper, PRONY algorithm has been used to find best location of wind farm on power system with minimum harmonics and modes. Wind farm is formulated in form of doubly fed induction generators to inject electric power into power system. The simulation result demonstrates that wind farm in optimum location can reduce modes and harmonics generations. In addition, the result indicated that PRONY have effectiveness to search optimum point of wind farm on power system topology.

VII. Acknowledgments

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VIII. References

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