Stability Analysis of DFIG-Based Wind Farms using Different Bus Systems

Mustafa Jawad Kadhim, D.S.Chavan

Abstract— this paper shows an overview of the power system stability of DFIG based wind farms and conventional synchronous generator. For the optimized computation, the reduced order DFIG model was used in order to restrict calculation to the fundamental frequency component. It depends on accurate model of DFIG wind generator, modal analysis, PV curves, as well as time domain simulations could be used to study the effect on system stability of replacing conventional generation by DFIG-based wind generation on the IEEE 14-bus, IEEE 30-bus, IEEE 18-bus benchmark system, for fixed power factor and voltage control operation. This paper presents the block diagram of IEEE 14 bus system by using Wind Turbine. This paper indicates that the oscillatory behavior associated with the dominant mode of the synchronous generator, is improved when the DFIG-based wind turbine is connected to the system; this improvement in the damping ratios is more evident when the wind turbines are operated with terminal voltage control.

Index Terms—Power System, IEEE 14 bus system, IEEE 18 bus system, stability, wind power generation, time domain, power flow analysis, PSAT.

I. INTRODUCTION

The past ten years has seen the emergence of wind as the most dynamically growing energy source in the world. The installed wind turbine (WT) capacity already surpassed 20 GW by the end of the year 2006 in Germany. A total wind power capacity of nearly 50 GW is expected, which is more than 50% of the German peak load in 2020, In the future, increase of wind power will take place offshore where wind farms with several thousand megawatts connected to the 400-kV grid are expected to be built [1], [2] . The dynamic behavior of the power system will change considerably by the reason of different technologies used for wind and conventional generators due to the increasing share of wind in power generation. Therefore, WTs and wind parks have to be considered in power system dynamic stability studies for however, suitable WT models are needed. WT models have to compromise between accuracy, for considering relevant dynamic interactions between grid and WT, and simplicity required for the simulation of large systems. WT modeling is a topical research now conducted by many academic institutions and developers. Different publications came out in latest time from which, taking into account the aspect of large-scale stability studies, [3]–[11] should be added. In spite of the effort made, the WT model still needs some refinements, extensions, and adaptations. Based on the experienced authors working in the development, control, and implementation of a huge number of WT up to the 5-MW class, in this paper a comprehensive report about modeling of WT based on the doubly-fed induction generator (DFIG) for stability kind power system dynamic studies. Conventional synchronous generators are denoted for stability analysis by reduced-order models [12].

The similarity applied to the DFIG results in a similar model [13], which is applicable with some condition. In case of several grid faults, the DFIG and its related converter system have to be protected against damage, for which the crowbar (CB) is a mostly used approach. The CB is a resistance connected to the rotor circuit for a short time for de-energizing the machine while the converter is disconnected. CB switching is triggered on the basis of rotor current and/or converter dc-link voltage values.

This paper shows allusive study over the power system stability in DFIG based Wind Farms with conventional synchronous generators over different IEEE bus systems. The practical analysis of suggested model will be taken and the stability analysis will be prepared using IEEE 14 bus system, This paper talks about the important parameters and properties that has to be manipulate for the power system stability. Further in below sections, in II discussing the related work, in section III literature review study, in section IV presenting the proposed approach of stability analysis using IEEE 14 bus system.

II. RELATED WORK

There were several endeavors to build large scale wind powered system to generate electrical energy. The 1st production of electrical energy with wind power was done in 1887 by Charles brush in Cleveland, Ohio. DC generator was the base for power production and was designed to charge the batteries. Various studies have been carried out with respect to modeling of DFIG for stability analysis.

A full analysis of transient stability all things considered the point of connection of the DFIG at distribution levels, transmission and sub transmission are presented in [14]. In [11], the impact of the increased diffusion of DFIG-based wind turbines on small and transient stability is assessed by changing the DFIG by synchronous generators and calculating the sensitivity of the eigenvalue with respect to inertia. This methodology shows inter-area modes that are worsen, and electromechanical modes whose consuming is increased by the penetration of DFIG based wind turbines. In [12], the steady state voltage stability of power systems with high penetration of wind turbines is studied using time-series ac power flow techniques. The approach used in [12] incorporates resource and system assessment for wind power, unit commitment and economic dispatch;

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the historical data of loading and wind power output are time proportion, and the worst operating point is identified as the point when wind generation feeds the largest portion of load.

The voltage control capabilities of the DFIG wind turbines improves the voltage stability margin at distribution and transmission levels. Also, the eigenvalue trajectories as a function of the load for a power system containing DFIGs could be computed.

III. LITERATURE REVIEW

3.1 Challenges of Power System Stability

Ancient power systems, including their generation, were run by monopolies, but after the late 1990s governments over the world have worked at deregulating electricity markets on the assumption that competition will result in their more efficient activities [14]. As more electrical power has been generated and used, the expansion of the electricity grid to send this electricity from producers to consumers has progressed relatively slowly, because of the much costs involved. Resulting of this the transmission system is being operated at its limits, and it was not designed in for using this ways. Interconnections which were once built to help improve reliability levels are now used for energy selling.

Increasing the transfer of power along transmission lines accents the power system. Once the system is accents, many undesirable phenomena come, and these can reason for damage to different parts of the system. In order to keep the system operating with security, limits must be placed on power transfers.

One limit placed on transfers relates to warming. This is the thermal limit, which create the maximum electrical current that a transmission line or electrical facility can conduct over a described time period before it sustains permanent damage by over-heating, or before it violates public safety needs [15].

In order to keep the power system stable Limits on power transfer are also important. When the system becomes unstable, the security of the supply of electricity can be compromised. Power system stability can be characterized into three categories.

1. Rotor angle stability refers to the ability of synchronous machines in an interconnected power system to remain in synchronism after being subjected to a disturbance. Instability may come in the form of increasing angular swings of some generators, due to increasing their loss of synchronism with other generators. Even maintained oscillations that are damped slowly may results in faulty tripping of protection equipment, and undesirable strain on the turbine shafts in power plants. This stability can be divided into these two types.

- Small-signal rotor angle stability, it refers to the ability of the power system to maintain synchronism under small disturbances.

These disturbances are small in the sense that to analyze system performance linearization of system equations can be used. This type of stability lies on the initial operating state of the system.

- Transient stability, it is concerned with the ability of the power system to maintain synchronism when subjected to a severe disturbance.

2. Frequency stability shows the ability of a power system to maintain steady frequency following a severe system upset which results in a significant imbalance between load and generation. Kinetic energy from generators is used to supply the loads due to excess of load; it causes the generators to decelerate and the system frequency to decrease. Similarly kinetic energy will build up in the generators if there is a load deficit, causing the frequency to increase.

3. Voltage stability shows the ability of a power system to maintain acceptable voltages at all nodes in the system. When not enough reactive power is being produced to energies the power system components a voltage collapse typically occurs, and is often a slow process. A possible outcome of voltage instability is, tripping of transmission lines or loss of load in an area and other elements by their securing systems, leading to cascading blackout.

To determine the system's security, the N-1 criterion is often applied. This criterion was came after the 1965 Northeast USA blackout. The N-1 criterion, in its simplest form, says that the system should be able to withstand the loss of any component, for example, line, generator or transformer, without jeopardizing the operation of the system. It is commonly used in power system operation today across the world. By examining contingencies arising from the loss of 1 component, and calculating the resulting stability, power system security may be tested.

3.2 Types of Wind Turbines:

Fixed speed induction generator

One or two asynchronous squirrel cage induction generators are used in the first kind of turbine, or a pole switchable induction generator, to transform mechanical energy into electricity. The generator slip varies a little depending on the amount of power generated and so is not totally constant. This type is normally referred as a fixed-speed turbine the main cause is the speed variations are in the order of 1%. Now a day the constant-speed design is nearly always combined with a stall control of aerodynamic Energy.

This turbine uses one of the most common machines in power systems. Because of its simple design, it is lower cost, robust and easy to maintain and use. However it does experience mechanical stresses in its drive train and it cannot deliver a steady output power to the grid or contribute reactive power which is important for voltage stability caused by its lack of power electronics,

Doubly fed induction generator

A DFIG instead of a squirrel cage induction generator are used in the second kind of turbine. Like the first type, it needs a gear box. The stator winding of the generator is attached to the grid, and the rotor winding is attached with a power electronics converter, which is a back-to-back voltage source converter (VSC).

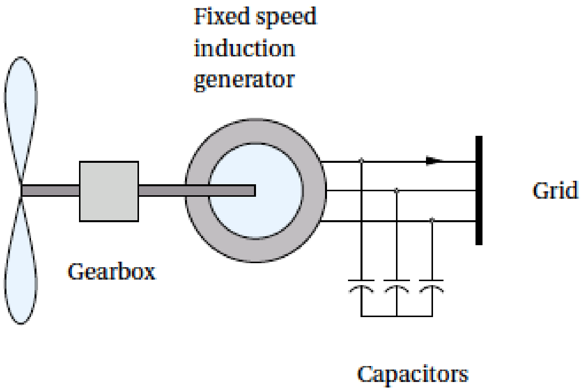

Figure 1: Fixed speed induction generator system

Through the use of mechanism, the electrical and mechanical rotor frequencies are decoupled, for the reason that the power electronics converter compensates for the difference between mechanical and electrical frequencies by providing a rotor voltage with a changing frequency. In this way variable speed operation becomes possible. By regulating the difference between the mechanical input and the generator output power the rotor speed is controlled. In this type of conversion system, by controlling the pitch of the blades the required control of the aerodynamic power is normally achieved.

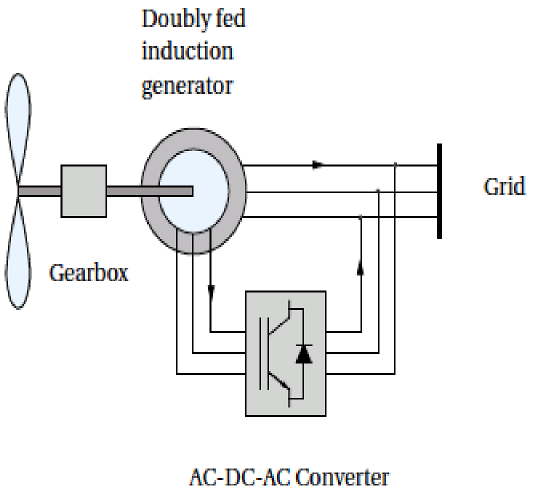

Figure 2: Doubly fed induction generator system

Fixed-speed induction generators, their variable speed operation is essential for decreasing the mechanical stresses in the turbine system while variable speed turbines were designed to extract more energy from the wind. The converters in DFIGs are only a fraction of the rated power of the turbine, and can be used for on and off power control. These turbines can do the frequency control and contribute to rotor angle stability if their active power is controlled. They may also be able to contribute to voltage stability and rotor angle stability if their reactive power is controlled.

3.3 Full converter synchronous generator

A synchronous generator with a full-scale power electronics converter used by the third type of turbine, it may use either, a fast speed synchronous generator with a gearbox or a direct drive low speed multiple synchronous generator with the same regular speed as the wind turbine rotor. The generator can have either a rotor equipped with permanent magnets or a wound rotor. The stator is not directly connected to the grid but connected to a power electronics converter, which is connected to the grid. The converter may consist of a diode rectifier with a single VSC or a back-to-back VSC and makes variable speed makes operation possible.

Power limitation is gained by pitch control, as with the double fed induction generator. This type of turbine shares the adv. of the DFIG, but its converter is a fully rated power converter. This converter can take or give a larger amount of reactive power than a DFIG turbine, but is more costly. If the synchronous generator is directly driven, then the turbine requires minimum maintenance, has reduced losses and costs, and a higher efficiency.

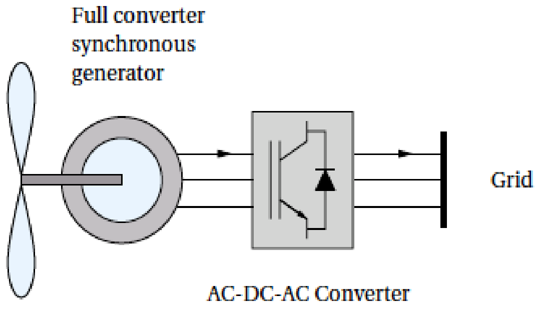

Figure 3: Full converter synchronous generator system

IV. PROPOSED INVESTIGATED APPROACH

The presented studies presents a comparative study of the effect on stability of DFIG-based wind turbines and conventional synchronous generators. PV curves are shows analyzing static load margins, and the effect on the damping ratio of the dominant mode of oscillation for the DFIG operating at fixed power factor and terminal voltage control.

The presented studies are based not only on IEEE 14-bus, but it is also considering other bus systems such as IEEE 30-bus, IEEE-18 bus benchmark system. So, in this system, one of the synchronous generators is take the place of an aggregated DFIG based wind turbine of equivalent size. The best suggest is doing the simulation analysis using the Mat lab-based toolbox (PSAT), which contains power flow, continuation power flow, optimal power flow and small-disturbance stability and time domain simulation equipments.

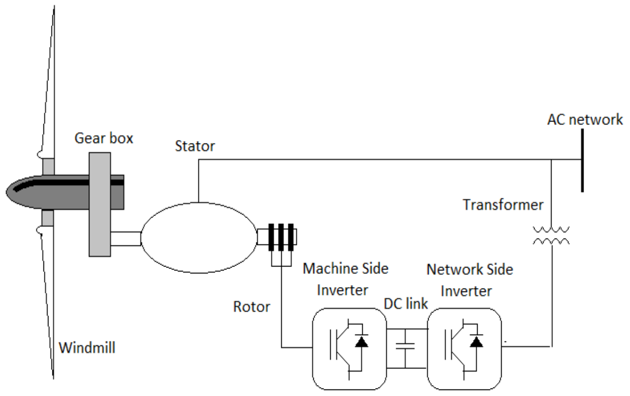

Figure 4: Overall DFIG Model

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The overall arrangement for a wind farm based on DFIG is depicted in Fig. 4. So, it is made by two voltage fed PWM converters in back-to-back manner. These allow the decoupled control of the active and reactive power management between the DFIG and the ac network by using the switch adjustor of the IGBTs. For this structure, the equations of the double feed induction generator in terms of the d and q axes and neglecting the stator and rotor flux transients can be given as:

- For the stator circuit:
  $V_{ds} = -R_s i_{ds} + (xs + x_m) i_{qs} + x_m i_{qr}$ (1)
  $V_{qs} = -R_s i_{qs} - (x_s + x_m) i_{ds} + x_m i_{dr}$ (2)
- For the rotor circuit:
  $V_{dr} = -R_r i_{dr} + (1-\omega) \{(x_r + x_m) i_{qr} + x_m i_{qs}\}$ (3)
  $V_{qr} = -R_r i_{qr} - (1-\omega) \{(x_r + x_m) i_{dr} + x_m i_{ds}\}$ (4)

where:
V_{ds}, V_{qs} : d and q axes stator voltages;
i_{ds}, i_{qs} : d and q axes stator current;
i_{ds}, i_{qs} : d and q axes rotor currents;
R_s, R_r : Stator and rotor resistances;
x_s : Stator self-reactance;
x_r : Rotor self-reactance;
x_m : Mutual reactance;
ω : Rotor speed.

The generator shaft, wind turbine, and the gearbox are shown in [16] as a lumped inertia *H*; in that way, the motion equation can be represented by:

$$\frac{d\omega}{dt} = \frac{1}{2H}(T_m - T_e) \tag{5}$$

where:
T_m : Mechanical torque;
T_e : Electromagnetic torque.

This simplification in the inertia is valid only if it is assumed that the controllers associated to the DFIG(s) are able to fast minimize the shaft oscillations [19]. The electromagnetic torque is represented by:

$$T_e = x_m (i_{qr} i_{qs} - i_{dr} i_{qs}) \tag{6}$$

Vector control schemes decouple the control of active and reactive power in the rotor. Thus, the active power P derived from the wind turbine power-speed characteristic Pw(ω) is associated with the rotor current in the q axis as follows:

$$\frac{di_{qr}}{dt} = \left(-\frac{x_s + x_m}{v x_m} P_w(\omega) - i_{qr}\right)\frac{1}{T_e} \tag{7}$$

Whereas the reactive power Q is associated with the rotor current in the d axis trough the following voltage control equation:

$$\frac{di_{dr}}{dt} = K_v (V - V_o) - \frac{v}{x_m} - i_{dr} \tag{8}$$

Where
V: Actual terminal voltage;
V_o: Desired terminal voltage.

This controller is using the current rotor speed to optimize the energy obtain from the wind. Furthermore, for rotor speeds greater than 1 p.u., the power is set to 1 p.u. and for rotor speeds lower than 0.5 p.u. The power is set to zero. In PSAT the limits for the rotor currents are then computed as follows:

$$i_{qr\ \max} \approx -\frac{x_s + x_m}{x_m} P_{\min} \tag{9}$$

$$i_{qr\,\min} \approx -\frac{x_s + x_m}{x_m} P_{\max} \tag{10}$$

$$i_{dr\,\max} \approx -\frac{x_s + x_m}{x_m} Q_{\min} - \frac{x_s + x_m}{x_m^{\ 2}} \tag{11}$$

$$i_{dr\,\min} \approx -\frac{x_s + x_m}{x_m} Q_{\max} - \frac{x_s + x_m}{x_m^{\ 2}} \tag{12}$$

These limits are carefully selected to ensure a proper dynamic and steady state operation of the model.

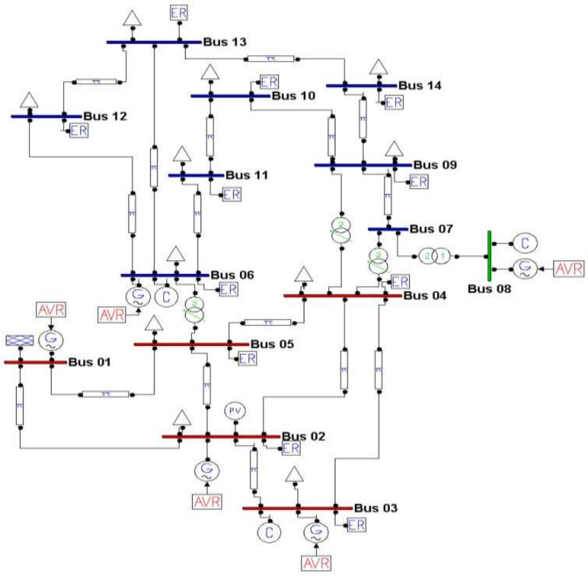

Figure 5: IEEE 14 bus system (PSAT).

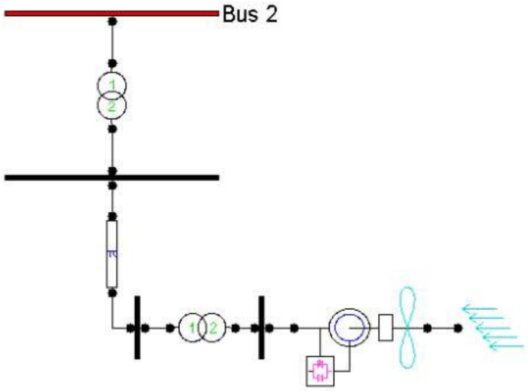

Figure 6: DFIG Collector system (PSAT).

V. CONCLUSION

This paper has presented the power system stability model for DFIG based wind turbine made by modeling the IEEE 14 bus system and presenting an overview about the stability of the wind system improved when the DFIG is connected instead of synchronous generator. It has to take out the same things for other IEEE bus systems.

In future work the simulation of this investigated block and design the same thing will be done using the other bus systems such as IEEE 18 and IEEE 30 bus systems.

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