DFIG Based Wind Farm Integrated to Power Systems for Small Signal Stability Analysis.

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ABSTRACT

This research article presents WECC test system; DFIG-wind farm, 9 bus 3 generator system for small signal stability. Indian wind power production chart is included, which harnesses wind energy as world 4th installed capacity of wind energy. Model of DFIG with modified WECC test system is utilised for examination of small signal stability in integration of wind farms with power systems. Stability analysis; eigenvalue and damping ratio variations were taken into considerations.

Keywords: Small-Signal Stability; DDSG; DFIG; SCIG; Power Systems; Wind Farm

1. Introduction

At present Indian renewable energy scenario is changing with focus on Wind Energy and Solar Energy as key green energy power producers. India is presently having 34.293 GW; of wind power production installed capacity, which is world's 4th largest production capability in terms of wind power harnessing. Wind power has randomness as its inherent nature due to this the generation also varies, and integration of this varying generation with large integrated power systems lead to small signal stability. Analysis of impact for small signal stability with integrated power system and wind farms are necessity to avoid asynchronous behavior. Wind power generation capacity in different states of India is shown in Table-I; by this we understand how much small signal stability analysis is important in interconnected systems.

TABLE-I: Wind Power Generation in Capacity of Different States of M.P.; Courtesy NIWE.

S.No	State	Total Installed in FY 17-18 (MW)	Total Operation in FY 17-18 (MW)	Total Installed in FY 17-18 (MW)	Total Operation in FY 17-18 (MW)
1	Andhra Pradesh	3967.0	3967.0	4024.30	4024.30
2	Gujrat	5702.30	5613.41	5891.55	5802.66
3	Karnataka	4509.57	4509.57	4567.05	4567.05
4	Kerala	52.90	52.90	52.90	52.90
5	Madhya Pradesh	2519.90	2519.90	2519.90	2519.90
6	Maharashtra	4784.30	4783.98	4784.30	4783.98
7	Rajasthan	4297.65	4297.65	4299.65	4299.65
8	Tamilnadu	8197.08	8197.08	8333.73	8333.73
9	Telangana	100.80	100.80	128.10	128.10
10	Other	4.30	4.30	4.30	4.30
		34135.68 MW	34046.46 MW	34605.78 MW	34516.56 MW

In [2] with different wind speed there is variation of wind power generation which is not constant, this is evaluated by small signal stability of aggregated DFIG based wind farm model. In [4], by replacement of synchronous generators in the system with time varying wind speed based wind turbine from standard test system, by this changing eigenvalue and complex variables are observed to understand the behavior of stability change, this help to suggest the threshold limit of introduction of integration in existing system. In [3] New England test system is used for small signal stability evaluation with the integration of wind farms and large integrated system, and change in dynamics of the system with the instability in system. In this research paper DFIG based wind farm small signal stability study is done.

2. DFIG Modeling

When we look towards the Indian states with wind power harnessing capability, there is lots of variation in wind speed and seasonal variation; same though out the globe we have to take care. Modeling of power plant will be done on the basis of wind power generation potential analysis of the location; at least past 40 year record of climatic variation and wind flow records to be analysed and forecasted evaluation of change in wind path.

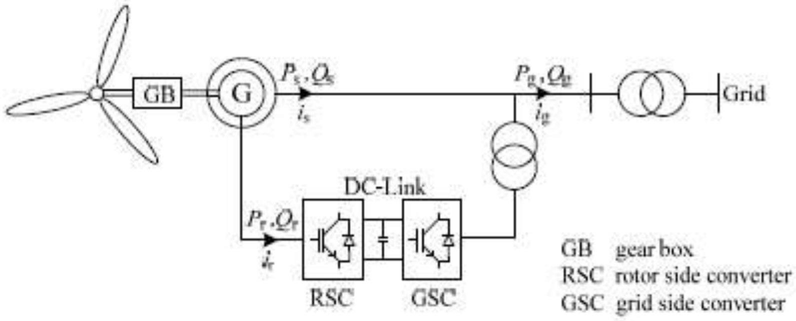


Figure 1. DFIG basic Topology

On the basis of wind penetration and need of strategic design change there are three kind of wind turbines which are globally used in present era are as:

1. Squirrel Cage Induction Generator (SCIG) with Constant Speed Wind Turbines.

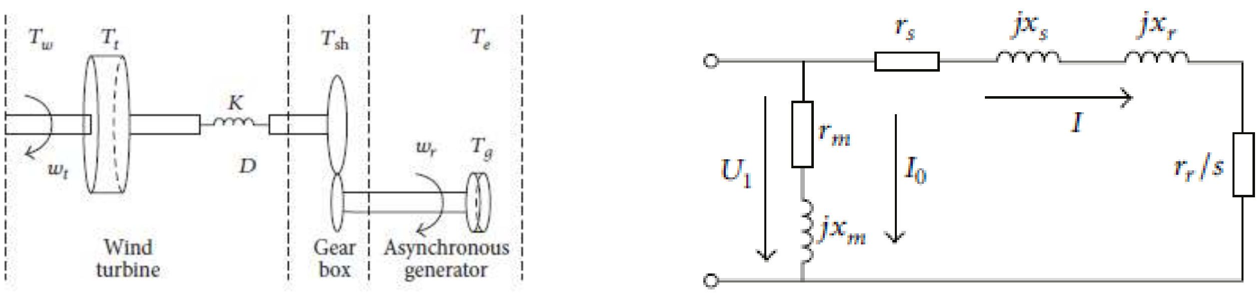
2. Doubly Feed Induction Generator (DFIG) with Variable Speed Wind Turbines.

3. Direct Drive Synchronous Generator (DDSG)

Nowadays DFIG based variable speed wind farms are installed and under construction, i.e. we are focused on this scheme in this research article. All three scheme have their own advantages and disadvantages; with variation in generation scheme; aerodynamic nature of wind turbine blades for changing rotor dynamics as shown in Figure2 (a) for variable wind speed. As it is known that DFIG is equipped with Power Electronics Converter [7] as shown in Figure 1. Asynchronous Generators generates active power but reactive power is to be feeded externally by additional means to the grid, equivalent circuit of asynchronous generator is shown in Figure.2 (b) Modeling of wind farm is done in MATLAB-SIMULINK and PSCAD-EMTDC.

2.1. Drive Train and Turbine

Drive train and turbine mass model is shown in Figure 2 (a), which represents operation of asynchronous wind generator. In the drive train mechanism Wind turbine aerodynamics shape blades were pushed by velocity of wind, which drive the turbine, this actuated gear box arrangement to shift the operation of variable speed wind turbine to swift the operation of gear box to drive Asynchronous generator at desired rate to get generation of electricity. During the study to maintain pitch angle unaltered mechanical power input to wind turbine is assumed to be constant.



(a) **(b)**

Figure: 2 (a) Wind Turbine with Asynchronous generator Mass Model. ; **(b)** Equivalent Circuit of Asynchronous generator.

The differential equations are based on two mass drive train model [8].

$$\frac{d\omega_r}{dt} = \frac{1}{2H_g}(T_{sh} - T_e) \quad (1)$$

$$\frac{d\theta_t}{dt} = \omega_b(\omega_t - \omega_r) \quad (2)$$

$$\frac{d\omega_t}{dt} = \frac{1}{2H_t}(T_m - T_{sh}) \quad (3)$$

where ω_r is angular speed of generator, ω_t is angular speed of wind turbine, ω_b is electrical base speed, θ_t is twist angle of shaft, H_g is inertia constant of generator, H_t is inertia constant of turbine, T_{sh} is shaft torque, T_e is electrical torque, T_m is mechanical torque.

2.2. Generator

In this research work, we are focused on DFIG variable speed wind turbine, topology and drive train arrangements were explained in figures depicted. For computational analysis we represent generators as equivalent circuit shown in Figure 2 (b); also in simulation of MATLAB and PSCAD, dq axes representation were needed. As generator parameters to be represented in form of direct axis and transient axis reactance's; which are dynamic and transient in nature depending on the frame which is utilized for analysis. DFIG model for balanced and unsaturated conditions, can be expressed based on equivalent circuit referred to stator or rotor.

$$\frac{\omega_s L_s'}{\omega_e}\frac{di_{ds}}{dt} = -R_1 i_{ds} - \omega_s L_s' i_{qs} + \frac{\omega_r}{\omega_s}e_{ds}' + \frac{1}{T_r\omega_s}e_{qs}' - v_{ds} + K_{mrr}v_{dr} \quad (4)$$

$$\frac{\omega_s L_s'}{\omega_e}\frac{di_{qs}}{dt} = -R_1 i_{qs} + \omega_s L_s' i_{ds} + \frac{\omega_r}{\omega_s}e_{qs}' - \frac{1}{T_r\omega_s}e_{ds}' - v_{qs} + K_{mrr}v_{qr} \quad (5)$$

$$\frac{1}{\omega_e}\frac{de_{ds}'}{dt} = -R_2 i_{qs} - \frac{1}{T_r\omega_s}e_{ds}' - \left(1 - \frac{\omega_r}{\omega_s}\right)e_{qs}' + K_{mrr}v_{qr} \quad (6)$$

$$\frac{1}{\omega_e}\frac{de_{qs}'}{dt} = R_2 i_{ds} - \frac{1}{T_r\omega_s}e_{qs}' + \left(1 - \frac{\omega_r}{\omega_s}\right)e_{ds}' - K_{mrr}v_{dr} \quad (7)$$

where i_{ds} and i_{qs} are d-axis and q-axis stator currents, respectively.

2.3. Converter

In DFIG two converters are used rotor side converter (RSC) and grid side converter (GSC), which are connected via back to back dc link. Due to this dual converter feedback and system control the technique is known as DFIG this topology is shown in Figure 1.

The power equations are as follows:

$P_r = P_g + P_{dc}$ ……………………………. (8)

Where; P_r, P_g and P_{dc} are the active power at RSC, GSC and dc link, respectively, which can be expressed as follows:

$P_r = v_{dr}\, i_{dr} + v_{qr}\, i_{qr}$ ………………………... (9)

$P_g = v_{dg}\, i_{dg} + v_{qg}\, i_{qg}$ ……………………… (10)

$P_{dc} = v_{dc}\, i_{dc}$ ……………………………… (11)

The quantities are d-axis and q-axis rotor voltages and current depending on the Grid side or Rotor side converter parameters.

2.4. Controllers for DFIG

As mentioned above, there are two back to back converters named RSC and GSC in DFIG system, some measures should be taken to control the two converters so that the DFIG can works in the appropriate condition. There are many kinds of control strategy we can choose to control the RSC and GSC, in this paper, we adopt the model of controllers built in [11], in which a decoupling control for the active power and reactive power of DFIG was developed.

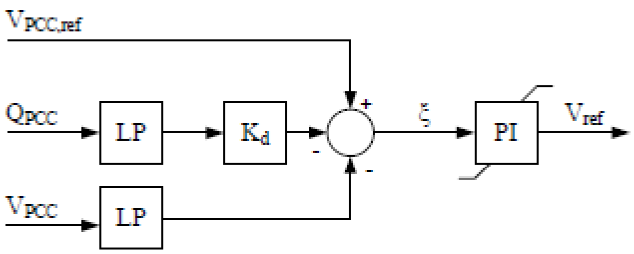


Figure 3: Block diagram of droop controller WPP.

3. Generic Test System

In this study WECC test system is used and modified, this system has 3 Generator 9 Bus system for the small signal stability evaluation. In this test system 3 large synchronous generator tied to grid were connected, with 3 constant impedance loads as a standard system. WECC test system is modified at BUS 4; large wind farm is connected which is represented as Wind Farm; but comprises of Distributed Generation Wind turbines synchronized to the system and connected for small signal stability evaluation. In the Distributed Generation (DG) wind farm, DFIG based 50 wind generation system each of capacity 1.5 MW is installed, this lead to total 75 MW integration at Bus 4 to the WECC test system. As computational analysis of the system is to be done to reduce the convergence time and earlier evaluation of the system at point of connect for stability study. WECC test system base power capacity and frequency is 100 MVA and 50 Hz.

The active and reactive power in constant impedance load bus are as:
Load Bus 5: 1.20 pu; 0.075 pu,
Load Bus 6: 0.70 pu; 0.070 pu,
Load Bus 8: 2.25 pu; 0.350 pu, respectively.

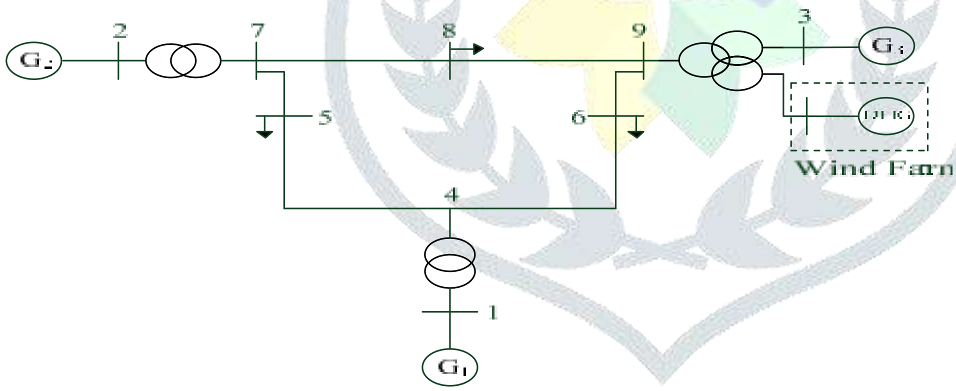


Figure 4. Single line diagram of the analyzed case network.

In order to ensure the power flow of the system unchanged, the output of generator G_3 should be adjusted simultaneously when increasing the output of wind farm.
The single wind turbine parameters are as follows:

U_N=0.69 kV, S_N=1.5 MW, f=50 Hz,

R_s=0.01 pu, X_s=0.10 pu, R_r=0.01 pu, X_r=0.08 pu, X_m=4 pu,

H_m=3 kWs/kVA, K_p=10, T_p=3 s, K_v=10, T_E=0.01s.

4. Small-Signal Stability Analysis

Stability is subjected to ability of power system to remain in synchronism when disturbances occurred in system [12]. Stability may be Voltage Stability which is 'load stability', and Rotor Angle Stability which is 'generator stability'. Thus small signal stability mainly intact with rotor angle stability, which is tangible to change of generator characteristics and parameters; and in ours case Asynchronous Generators are used so change in load angle effect the system. As system enters into the state of perturbation oscillation of system and quest for stability inertia started; by the linearization modeling system, eigenvalue, state space and small signal stability is evaluated. Small Signal analysis helps us to know the impact on the system especially dynamic characteristic which inherent in the system thus this study help us design robust technique and system which nullifies such disturbances.

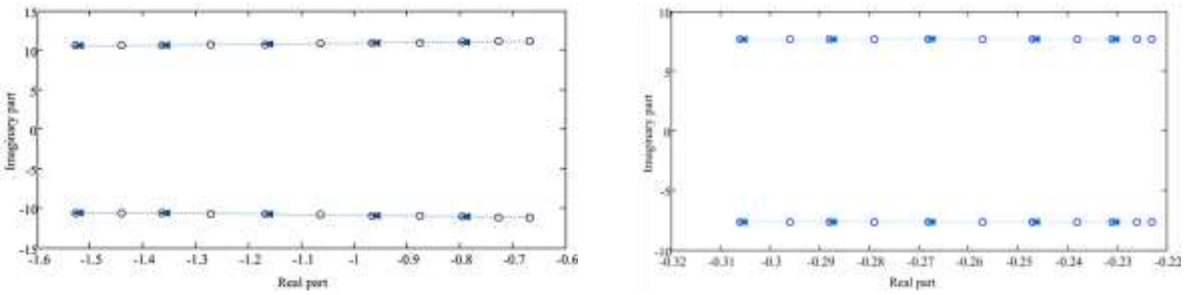
Table 2.

Oscillatory Mode No.	Eigenvalue	Frequency (Hz)	Damping ratio (%)
1	−1.16±j10.76	1.71	10.78
2	−0.26±j7.62	1.21	3.51
3	−5.47±j7.93	1.26	56.77
4	−5.17±j7.79	1.24	55.28
5	−5.24±j7.89	1.25	55.31
6	−3.64±j0.63	0.10	98.52
7	−0.49±j1.08	0.17	41.39
8	−0.46±j0.71	0.11	54.24

As oscillatory disturbances which are continuous and dynamic in nature will introduces mainly small signal stability problem in the integrated system; this is analysed via eigenvalue. In Table 2, we get different oscillatory mode of operation mainly of low frequency mode. Low frequency operation and analysis help to find the methods to eliminate such conditions when exist in real system, as this type of conditions are more vulnerable. In ours modeling wind farm is adjusted to 45 MW which is 60% of its capacity and remaining 40 MW is adjusted via G-3 generator intact with bus-3; in-order to maintain constant power flow. With increase in output of wind farms eigenvalue will change, mode I & II damping ratios are relatively small which are shown in Table 2 & 3 along with plots of value in Figure 5. As output of wind farms increase eigenvalue shifted towards left side of complex plain. When wind farms are operated at under-rated conditions then its actual rated capacity system is more unstable, this study provide this inference that system to be introduced must be loaded with at least minimum required loading so that it should not create instability of its operation.

Table 3.

Wind Farm Output (%)	Eigenvalue	Frequency of oscillation (Hz)	Damping Ratio (%)
0	−0.66±j11.15	1.77	5.96
10	−0.72±j11.10	1.76	6.52
20	−0.79±j11.04	1.75	7.17
30	−0.87±j10.97	1.74	7.94
40	−0.96±j10.90	1.73	8.81
50	−1.06±j10.83	1.72	9.77
60	−1.16±j10.76	1.71	10.88
70	−1.27±j10.70	1.70	11.79
80	−1.36±j10.64	1.69	12.70
90	−1.44±j10.60	1.68	13.40
100	−1.52±j10.56	1.68	14.34



(a) (b)

Figure 5. (a) The eigenvalue of mode I shifting with the output of wind farm increasing. (b) The eigenvalue of mode II shifting with the output of wind Farm varying.

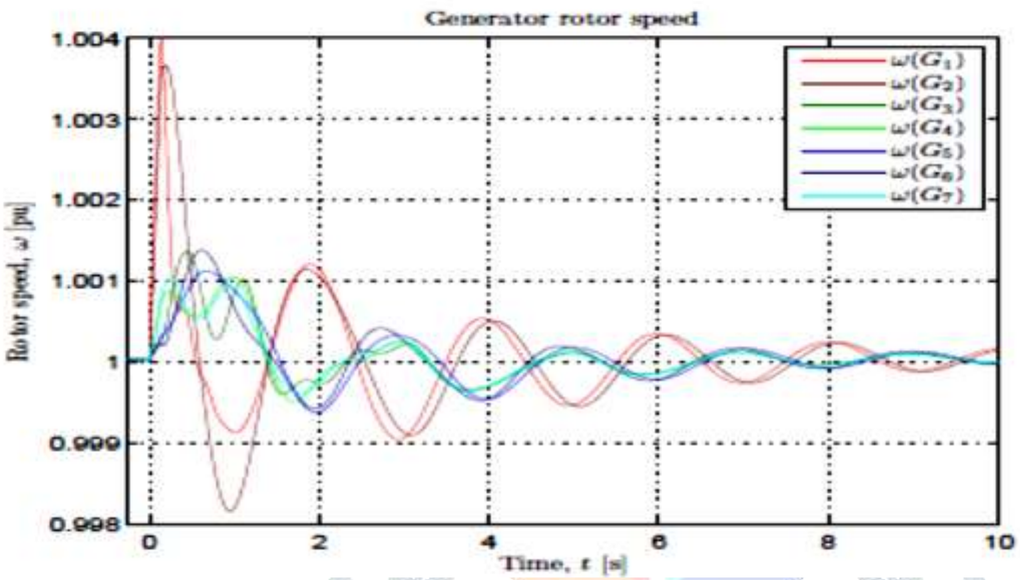


Figure 6: Generator Rotor speed after short circuit in wind farm internal system.

In Figure 6; ω is rotor speed of different generators are shown, here $G_{4,5,6,7}$ are wind farm generators; this helps to understand the stability issues in interconnected systems; by evaluating the system stability settle-down time after turbulence in system. This small disturbances and overcome strategies will be used in design and development of robust system, as power system is large entity simulation will play major role.

5. Conclusion

In this research article small signal stability is study by utilization of modified 3 generator 9 bus WECC test system. Indian State 2018 wind generation highlights are also taken in consideration, which lead to stability study initiation for DFIG based wind farms as most popular topology. Mathematical modeling of system and software utility help to evaluate, eigenvalue, damping ratio and frequency deviation of system. As standard test system WECC is used this help to compare the system response in study state and perturbation time; system resilience to overcome the turbulence. Study of small signal stability for variation of parameters and perturbation impinged in the system were also considered. As the system taken for small signal study with elementary changes, research will be continued with large integrated power systems and different level of test.

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