Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 3159-0040
Vol. 2 Issue 11, November - 2015

Assessment Of Power System Stability In The Presence Of DFIG Wind Turbine

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***Abstract*— Undoubtedly that there is a trend to bring renewable energy instead of fossil fuels Because of the global energy crises, fluctuations of fossil fuels and the complexities of the construction Wind energy is considered to be the most technically and economically viable among all renewable energy sources. The integration of wind farms poses serious problems on the stability of a power system with the increase in penetration of these wind turbines, the power system dominated by synchronous machines will experience a change in dynamics and operational characteristics. the present paper focus on the effect of wind turbine generator based on DFIG on the small signal and transient stability of IEEE14 bus system, using the Eigen value sensitivity for small signal stability analysis to show the behavior of the system by replacing the synchronous generator by wind turbine generator based on DFIG on aspect of location of wind energy, level of penetration of wind energy , contingency cases and the variation of the system load, Besides, time domain simulations were carried out using simulation program power system analysis tool box (PSAT)**

Keywords—Wind energy; DFIG; small signal stability; congested lines; PSAT; Eigen value sensitivity.

I. INTRODUCTION

The higher percentage of generators used in the power system networks are operates by fossil fuel which have many problems among of them environmental pollution and energy shortage especially after the oil shocks of the 1970s , more efforts are put in electricity generation from renewable energy sources which are reproducible, resourceful and pollution-free characteristics [1]. Among the various renewable energy sources, wind energy is one of the most important energy sources in power systems and expanding the wind power plants and its technology has demonstrated it. Wind turbines can either operate at fixed speed or variable speed. For a fixed speed Wind turbine the generator is directly connected to the electrical grid.therefore all fluctuations in the wind speed are further transmitted as fluctuations in the mechanical torque and then as fluctuations in the electrical power on the grid [2], For a variable speed wind turbine the generator is controlled by power electronic equipment . so less mechanical stress, more energy can be generated for a specific wind speed regime, aerodynamic efficiency due to variable speed operation, operation in both sub-synchronous and super synchronous speed regime extracting maximum power from wind and reducing the drive train torque variations. Currently, three main wind turbine types are on the market. The main differences between the three concepts are the generating system and the way in which the aerodynamic efficiency of the rotor is limited during high wind speeds these types are Squirrel cage induction generator, Doubly fed (wound rotor) induction generator and Direct drive synchronous generator [3,4] .

The majority of wind farms are using variable speed wind turbines equipped with double fed induction generators (DFIG) due to their advantages over other wind turbine generators. Is preferred more than direct drive generator because it use large converter necessary equal to the total power of the generator so more power losses in the power electronic equipment and use heavy and complex generator. With increasing the power generation from wind energy the investigation of wind power system stability becomes essential. However, the integration of wind farms could cause stability problems [5]

Many studies have been focused on the effect of wind turbine generators on the power system stability

In [6] the effect of wind generation on oscillation damping as compared in to synchronous generator at various penetration levels of wind generation in to 15 bus distribution feeder in the Kumamoto area of Japan as a tested system. The small signal stability of a 15 bus test distribution comprising conventional thermal power plants and a SCIG based wind power plant were evaluated through modal analysis and time domain simulations respectively.

In [7] using power system stabilizer (PSS) to improve the small signal stability of nine bus three generator tested system including wind turbine , In [8] studying the optimal location of induction generators based wind power plants in power system using small signal and transient stability for determination . In [9] studying the impacts of varying wind speed, slip and field excitation on the small signal stability analysis of multi-machine power system interfaced with DFIG.

II. METHODOLOGY

A. THE THEORETICAL ANALYSIS OF SMALLSIGNAL STABILIT

The power system dynamic behavior can be described by a set of n first order nonlinear ordinary differential equations in vector-matrix notation[10]

$$\dot{X} = f(x, u, t) \quad (1)$$

Where $x=(x_1, x_2.....x_n)^T$ is the vector of state variables, $y= (y1, y2,....ym)^T$ is the vector of system outputs variables, $u=(u_1, u_2,....u_r)^T$ is the vector of system input variables, $f= (f1, f2,....fn)^T$ and $g= (g1, g2,....gm)^T$ are the vectors of nonlinear functions defining the states and the outputs respectively of the system, time is denoted by t and the derivative of sate variable X with respect to time is $\dot{X}$ .if the derivative of the state variables are not explicit function of the time, equation (1)can be simplified as:

$$\dot{X} = f(x, u) \quad , Y = g(x, u) \quad (2)$$

Where the vector Y is the output of the system.

For small signal stability analysis a small perturbation is considered, the non-linear function f and g can be linearized using Taylor series with the initial points x=x0 and u=u0,

the system can expressed in the following equation

$$\Delta\dot{x} = A\Delta x + B\Delta u, \Delta y = C\Delta x + D\Delta u \quad (3)$$

Where Δx is a small deviation in the state vector, Δy is a small deviation in the output vector, A is the state matrix, B is the input matrix, C is the output coefficient matrix and D is the feed forward matrix.

According to Lyapunov's first method, the eigenvalues of the state matrix A can be illustrate the behavior of the system according to small signal stability

The eigenvalues of the state matrix A may be :

1- a real eigenvalue corresponds to a non-oscillatory mode where A negative real Eigen value represents a decaying mod A positive real represents aperiodic instability.

2- Complex eigenvalues occur in conjugate pairs, and each pair corresponds to an oscillatory mode.

– When the Complex eigenvalues have negative real parts, the original system

– When at least one of the Complex eigenvalues has a positive real part, the original system is unstable

3- When at least one of the eigenvalues has zero value, the original system is critical stable [11].

For any eigenvalue λi, the n-column vector Φi is called the right eigenvector which gives the mode shape and the n- row vector Ψi is called the left eigenvector identifies which combination of the original state variables displays only the ith mode , are satisfies Equations:

$$A\,\Phi i = \lambda\,\Phi i \quad (4)$$
$$\Psi i\,A = \lambda i\,\Psi i \quad (5)$$

Where $\Psi i\,\Phi i = 1$

A measure of the association between the state variables and the modes is the participation factors

$p=[p1 \;\; p2 \ldots \ldots pn]$ With

$$Pi=\begin{bmatrix} P1i \\ p2i \\ \vdots \\ pni \end{bmatrix} = \begin{bmatrix} \Phi 1i\,\Psi i1 \\ \Phi 2i\,\Psi i2 \\ \vdots \\ \Phi ni\,\Psi in \end{bmatrix}$$

B. Modeling of Doubly Fed Induction Generator

Steady-state electrical equations of the doubly fed induction generator are assumed, as the stator and rotor flux dynamics are fast in comparison with grid dynamics and the converter controls basically decouple the generator from the grid.

As a result of these assumptions [12]:

-For the stator circuit:

$$vds = -Rs\,ids + (xs + xm)iqs + xm\,iqr \quad (7)$$
$$vqs = -Rs\,iqs - (xs + xm)ids + xm\,idr \quad (8)$$

-For the rotor circuit:

$$vdr = -Rr\,idr + (1 - \omega)\,(xr + xm)iqr + xm\,iqs \quad (9)$$
$$vqr = -Rr\,iqr + (1 - \omega)\,(xr + xm)idr + xm\,ids \quad (10)$$

Where

vds, vqs: direct and quadrature axes stator voltages; vdr, vqr direct and quadrature axes rotor voltages, ids ,iqs: direct and quadrature axes stator currents; idr, iqr, direct and quadrature axes rotor currents; Rs, Rr, Stator and rotor resistances; xs Stator self-reactance; xr, Rotor self-reactance; xm Mutual reactance; ω Rotor speed.

The active and reactive powers at the stator are defined as:

$$Ps = vds\,ids + vqs\,iqs \quad (11)$$

$$Qs = vqsids - vds\,iqs \quad (12)$$

The active and reactive powers at the rotor are defined as:

$$Pr = vdr\,idr + vqr\,iqr \quad (14)$$

$$Qr = vqr\,idr - vdr\,iqr \quad (15)$$

The electromagnetic torque is represented by:

$$Te = xm\,(\,iqr\,ids - idr\,iqs\,) \quad (16)$$

The wind is modeled by using the Weibull distribution available in [12], with a shape factor equal to two,which results in a Rayleigh Distribution.

III. RESULTS AND SIMULATION

A. small signal stability analysis

The presented studies are based on the IEEE 14-bus benchmark system. Thus, in this system, one of the synchronous generators is replaced by an aggregated DFIG based wind turbine according to the following cases, which are discussed in the various subheadings

1) base case-case(A)

In this case the IEEE 14-bus benchmark system is used without containing any wind energy.

a) normal case

In this case all generators in the system are synchronous generator and there is no wind farm based on doubly fed induction generator (WF based on DFIG) in the system .Small signal stability of the tested system are computed with positive and zero Eigen values of the system with its dominant states as shown in table (1) and Fig.1

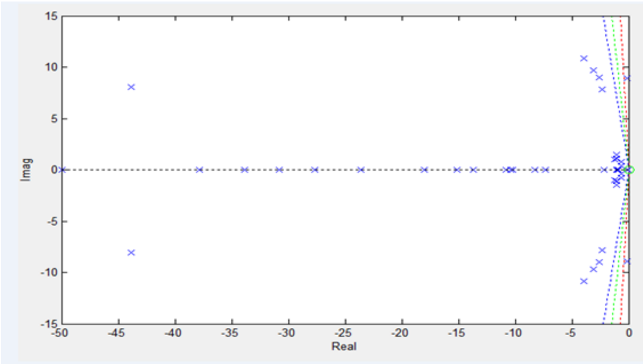

Fig. 1. *Computed Eigen values of IEEE 14-bus without wind farm*

TABLE 1: EIGEN VALUES AND DOMINANT STATE OF IEEE 14-BUS WITHOUT WF

	Positive Eigen number	**Dominant states of Positive Eigen**	**Zero Eigen number**	**Dominant states of Zero Eigen number**
No Wind farm	--	--	Eig As 44	delta of synchronous 1

As seen from figure (1) and table (1) for IEEE 14 bus system has 55 Eigen number all Eigen numbers are negative except the Eigen number λ 44 is zero value so the system is critically stable. The participation factors associate the delta of synchronous generator connected at bus1 with this critically stable of the system.

b) Contingency cases.

In this cases the congested lines1-5, 2-3and7-9 (13) will disconnecting from system in base case and compute the small signal stability of the system without connecting any WF based on DFIG Then replace the synchronous generator at generation buses2, 3,6and 8 by WF based on DFIG of Equivalent size and compute small signal stability of the system as shown in table (2), (3) and (4).

From result shown in tables (2), (3) and (4), when the system as in base case not containing WF and lines2-3 and 7-9are disconnected as shown in tables 2,3and 4 respectively is critically stable ,The participation factors associate the rotor angle(delta) of synchronous generator connected at bus1 with this critically stable of the system

But the system unstable when disconnected line 1-5 as shown in table (2) The participation factors associate the quadrature-axis component of transient voltage of synchronous generator connected at bus1 and field voltage of automatic voltage regulator (AVR) of the same generator with this instability of the system. When WF at bus 6 the system is stable in case of lines1-5 and 2-3are disconnected unlike disconnected line 7-9, the participation factor associate the speed of DFIG with this instability of the system.

TABLE 2: EIGEN VALUES AND DOMINANT STATE OF IEEE 14-BUS WHEN LINE1-5DISCONECTING

	Positive Eigen number	**Dominant states of Positive Eigen number**	**ZERO Eigen number**	**Dominant states of ZERO Eigen number**
Without wind	Eig As 20	E1q of synch1-vf of AVR1	Eig As 44	delta of synchronous 1
	Eig As 21	E1q of synch1-vf of AVR1		
Wind farm at bus 2	Eig As 19	E1q of synch1-vf of AVR1	--	--
	Eig As 20	E1q of synch1-vf of AVR1		
Wind farm at bus 3	Eig As 28	Ω of DFIG	--	--
Wind farm at bus 6	-	-	-	-
Wind farm at bus 8	Eig As 13	E1q of synch1-vf of AVR1	-	-
	Eig As 14	E1q of synch1-vf of AVR1		

2) *Effect of Increasing loads to110%&120%of normal system loads - Case (B)*

a) Normal case

In this case the loads of the system is increased by 10and 20% of its normal ratings for the original system without containing WF and when replaced the synchronous generator by WF based on DFIG of equivalent size .the small signal stability with positive and zero eigenvalues and dominant state are computed in each case as shown in tables (5-8).

b) Contingency case

TABLE 3: EIGEN VALUES AND DOMINANT STATE OF IEEE 14-BUS WHEN LINE 2-3DISCONECTED

	Positive Eigen number	Dominant states of Positive Eigen number	ZERO Eigen number	Dominant states of ZERO Eigen number
No wind farm	-	-	Eig As 44	delta of synchronous 1
Wind farm at bus 2	-	-	-	-
Wind farm at bus 3	Eig As 19 Eig As 20	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--
Wind farm at bus 6	-	-	-	-
Wind farm at bus 8	Eig As 13 Eig As 14	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	-	-

In these cases we will disconnect the congested lines1-5, 2-3and7-9 from the system described in case (B). The small signal stability with positive, zero eigenvalues and dominant state are computed in each case as described in tables (6,7and8).

From results shown in tables (5), (6),(7) and (8) for increasing the loads of the system into 110%and 120% of its normal rating ,the original tested system as in base case is stable when disconnecting the congested lines 1-5and 2-3 and 7-9 .for increasing 120%that system is stable in that contingency cases except disconnecting line 7-9 the system unstable The participation factors associate the rotor angles(delta) of synchronous generators connected at buses 8 and 2.for all location of WF in the system which described in contingency case of case (B) at equivalent size the system unstable except when WF connecting at bus 6 for increasing loads by 110% of its normal rating .

3) Effect of Decreasing MVA rating of generating units of WF based on DFIG to 80%of its normal rating - case (C)

a) Normal case

In this case replacing the synchronous generator at buses 2,3,6and8 by WF based on DFIG at reduced output rating by 20% of its normal MVA of the original system ,so when connecting the WF at bus 2 or bus 3 its output will be 48MVA and when connecting at bus 6 or bus 8 its output will be 25MVA . The small signal stability with positive and zero eigenvalues and dominant state are computed in each case as described as shown in table (9).

TABLE 4: EIGEN VALUES AND DOMINANT STATE OF IEEE 14-BUS WHEN LINE 7-9DISCONECTED

	Positive Eigen number	Dominant states of Positive Eigen	ZERO Eigen number	Dominant states of ZERO Eigen number
Without wind	-	-	Eig As 44	delta of synchronous 1
Wind farm at bus 2	Eig As 17 Eig As 18	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	-	-
Wind farm at bus 3	Eig As 16 Eig As 17	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--
Wind farm at bus 6	Eig As 29	Ω of DFIG	-	-
Wind farm at bus 8	Eig As 13 Eig As 14	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	-	-

The result as shown in table (9), for location of WF at Buses 2, 6 show that the system is stable unlike other location of WF at buses 3, 8 the system unstable, the participation factor associate the speed of DFIG with this instability of the system.

b) Contingency cases

In these cases the congested lines1-5, 2-3and7-9 are disconnecting from the system described in case (C) one by one as a Contingency cases. The small signal stability with positive and zero eigenvalues and dominant state are computed in each case as described as shown in tables (10and11).

From result shown in tables (10) and (11) for location of WF at bus 6 the system is stable when lines 1-5 and 2-3 disconnected , when WF at bus 2 the system is stable when Line 2-3 disconnected.

TABLE 5: EIGEN VALUES AND DOMINANT STATE OF IEEE 14-BUS WITH 110%AND 120%INCREASING IN SYSTEM LOADS

	110% increasing in system loads				120% increasing in system loads			
	Positive Eigen number	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***	***Positive Eigen number***	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***
Without wind	-	-	-	-	-	-	-	-
Wind farm at bus 2	Eig As17 Eig As 18	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1.	--	--	Eig As 19 Eig As 20	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1.	--	--
Wind farm at bus 3	Eig As 15 Eig As 16	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1.	--	--	Eig As 17 Eig As 18	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1.	--	--
Wind farm at bus 6	-	-	-	-	Eig As 17 Eig As 18	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1.	--	--
Wind farm at bus 8	-	-	-	-	-	-	-	-

TABLE 6: EIGEN VALUES AND DOMINANT STATE OF IEEE 14-BUS WITH 110%AND 120%INCREASING IN SYSTEM LOADS.-DISCONNECTING LINE 1-5

	110% increasing in system loads				120% increasing in system loads			
	Positive Eigen number	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***	***Positive Eigen number***	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***
Without wind	-	-	-	-	-	-	-	-
Wind farm at bus 2	Eig As 19 Eig As 20	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--	Eig As 19 Eig As 20	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--
Wind farm at bus 3	Eig As 15 Eig As 16	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--	Eig As 20 Eig As 21	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--
Wind farm at bus 6	Eig As 31	Ω of DFIG	--	--	Eig As 20 Eig As 21 Eig As 31	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1 Ω of DFIG	--	--
Wind farm at bus 8	Eig As 21	Ω of DFIG	--	--	-	-	-	-

TABLE 7: EIGEN VALUES AND DOMINANT STATE OF IEEE 14-BUS WITH 110%AND 120%INCREASING IN SYSTEM LOADS-DISCONNECTING LINE 2-3-

	110% increasing in system loads				120% increasing in system loads			
	Positive Eigen number	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***	***Positive Eigen number***	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***
Without wind	-	-	-	-	-	-	-	-
Wind farm at bus 2	Eig As 19 Eig As 20	E1q of synch1-vf of AVR1 E1q of synch1-vf ofAVR1	--	--	Eig As 22 Eig As 23	Delta of synch2–omega of synch 2 Delta of synch2 – omega of synch 2	--	--
Wind farm at bus 3	Eig As 15 Eig As 16	E1q of synch1-vf ofAVR1 E1q of synch1-vf ofAVR1	--	--	Eig As 18 Eig As 19	Delta of synch 2 – omega of synch 2 Delta of synch 2 – omega of synch 2	--	--
Wind farm at bus 6	Eig As 31	Ω of DFIG	--	--	Eig As 22 Eig As 23	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--
Wind farm at bus 8	Eig As 21	Ω of DFIG	--	--	Eig As 21	Ω of DFIG	-	-

TABLE 8: EIGEN VALUES AND DOMINANT STATE OF IEEE 14-BUS WITH 110%AND 120%INCREASING IN SYSTEM LOADS.-DISCONNECTING LINE 7-9-

	110% increasing in system loads				120% increasing in system loads			
	Positive Eigen number	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***	***Positive Eigen number***	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***
Without wind	-	-	-	-	Eig As 13 Eig As 16	Delta of synch 4 Delta of synch 2	-	**-**
Wind farm at bus 2	Eig As 17 Eig As 18	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--	Eig As 19 Eig As 20	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	**--**
Wind farm at bus 3	Eig As 17 Eig As 18	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--	Eig As 17 Eig As 18	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	**--**
Wind farm at bus 6	--	--	--	--	Eig As 17 Eig As 18	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	**--**
Wind farm at bus 8	Eig As 21	Ω of DFIG	-	-	Eig As 21	Ω of DFIG	-	-

TABLE 10: COMPUTED EIGEN VALUES - WF BASED ON DFIG AT 80%OF NORMAL MVA OUTPUT -LINES (1-5) AND (2-3) OUTAGE -

	Disconnecting line 1-5				Disconnecting line 2-3			
	Positive Eigen number	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***	***Positive Eigen number***	***Dominant states of Positive Eigen***	***Zero Eigen number***	***Dominant states of Zero Eigen number***
Wind farm at bus 2 P= 48 MW	Eig As19 Eig As20	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1	--	--	--	--	--	--
Wind farm at bus 3 P= 48 MW	Eig As 28	Ω of DFIG	--	--	Eig As 19 Eig As 20	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1	--	--
Wind farm at bus 6 P= 20 MW	-	-	-	-	-	-	-	--
Wind farm at bus 8 P= 20 MW	Eig As13 Eig As14	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1	-		Eig As 13 Eig As 14	E1q of synch1-vf of AVR1. E1q of synch1-vf of AVR1	-	--

TABLE 11: COMPUTED EIGEN VALUES - WF BASED ON DFIG AT 80%OF NORMAL MVA OUTPUT -LINE (7-9) OUTAGE -

	Positive Eigen number	**Dominant states of Positive Eigen**	**Zero Eigen number**	**Dominant states of Zero Eigen number**
Wind farm at bus 2 P= 48 MW	Eig As 19 Eig As 20	E1q of synch1-vf of AVR1 E1q of synch1-vf of avr1	--	--
Wind farm at bus 3 P= 48 MW	Eig As 16 Eig As 17	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	--	--
Wind farm at bus 6 P= 20 MW	Eig As 24	Ω of DFIG	-	-
Wind farm at bus 8 P= 20 MW	Eig As 13 Eig As 14	E1q of synch1-vf of AVR1 E1q of synch1-vf of AVR1	-	

B. Transient stability analysis

From fig 3,4,5,6,7,8,9and 10 there's an oscillation in all quantities at all buses due to a three phase fault at bus 11, Voltages value at all buses of the system are shown in fig.2and 3, the voltages varies between maximum instantaneous value of oscillation 1.197 p.u for original IEEE14 bus –clear from WF- is occur at bus 1 and the minimum instantaneous value of oscillation 0.9806 p.u occur at bus 14. But, for second case by connecting WF at bus 6 the maximum instantaneous value of oscillation of voltage is 1.114 p. u occur at bus 6 and minimum instantaneous value of oscillation is 0.9739 p.u occur at bus 14 , after this oscillation the system reaches it steady state value after 3 seconds in both cases .

TABLE 9: Eigen values and dominant state of IEEE 14-bus containing WF based on DFIG at 80%of its normal MVA.

	Positive Eigen number	Dominant states of Positive Eigen	Zero Eigen number	Dominant states of Zero Eigen number
Wind farm at bus 2 P= 48 MW	-	-	--	--
Wind farm at bus 3 P= 48 MW	Eig As 28	Ω of DFIG	--	--
Wind farm at bus 6 P= 20 MW	-	-	-	-
Wind farm at bus 8 P= 20 MW	Eig As 25	Ω of DFIG	-	

The active and reactive power at all busses shown in fig.4 and fig. 5, the maximum instantaneous value of active power at bus 1 increases to 3.993 p.u whereas increases to 3.849 p.u when the system contains WF based on DFIG at bus 6, from fig .6and fig. 7 the maximum instantaneous value of reactive power at bus 1 is 1.818 p.u instantaneously whereas increases to 1.486 p.u when the system contains WF based on DFIG at bus 6 ,the steady state value is reached after 6 seconds .

From fig.8 and fig.9 the maximum rotor speed is 1.0105 p.u and minimum rotor speed is 0.9962 p.u

for the original IEEE14 bus system, for connecting WF at bus 6 the Maximum value is 1.0025p.u and minimum value is 0.9983p.u. So the speed oscillation in case of WF at bus 6 is lower than that of original system, the oscillation of the speeds of synchronous generators is vanish at t= 6s for both cases , but there is oscillation in speed of DFIG after that time as shown in fig.10

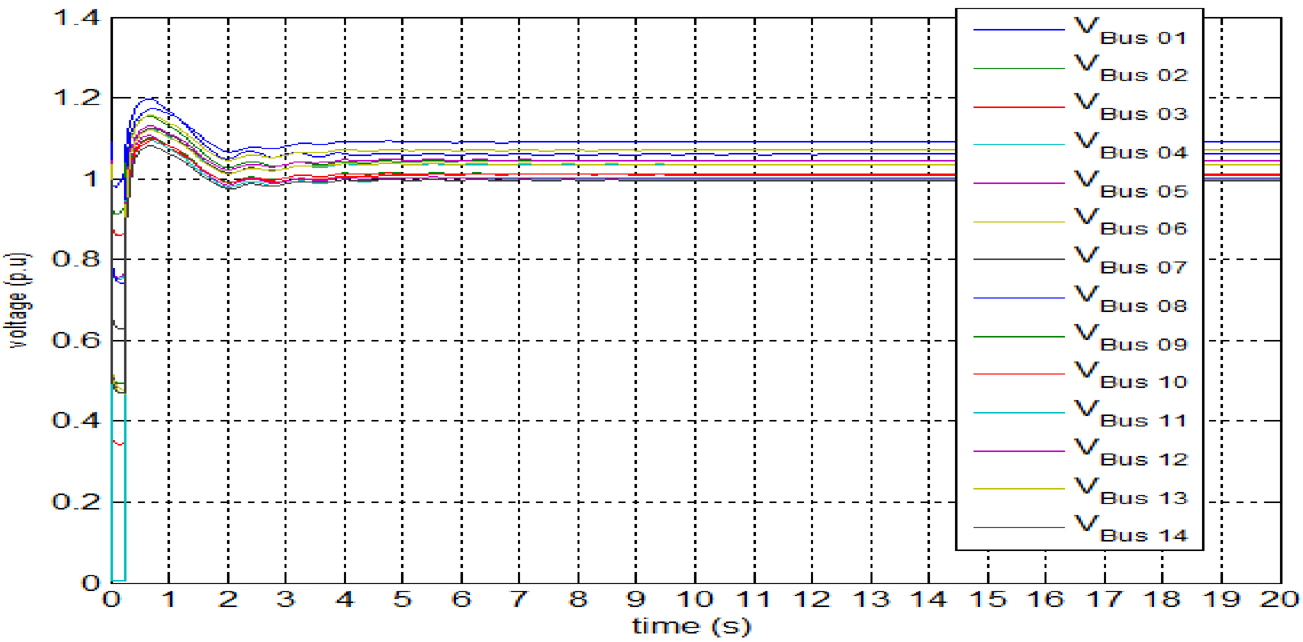

Fig. 1. *The voltages at all busses –fault at buss 11 –no wind energy in the system*

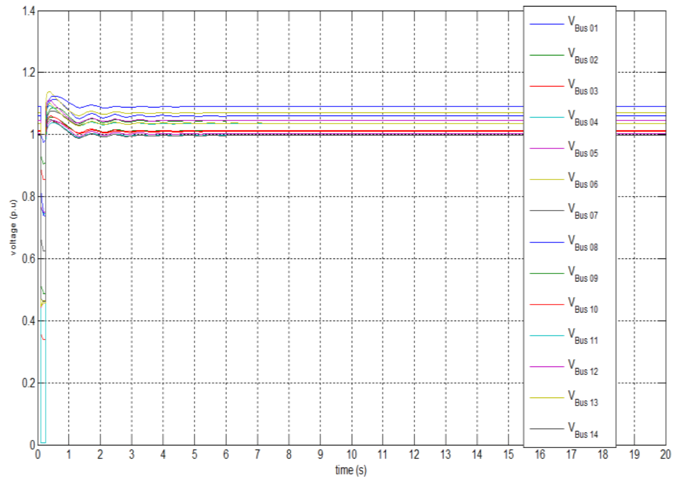

Fig. 3. The voltages at all busses –fault at buss 11 – WF based on DFIG at buss 6-

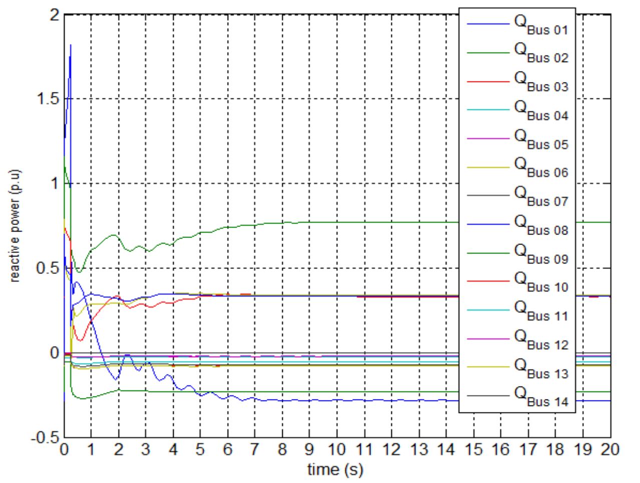

Fig. 6. The reactive power at all busses –fault at buss 11 –no wind energy in the system-

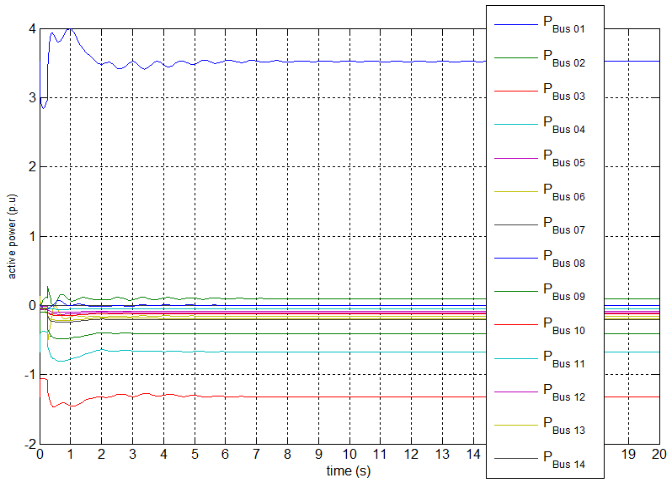

Fig. 4. the active power at all busses –fault at buss 11 –no wind energy in the system-

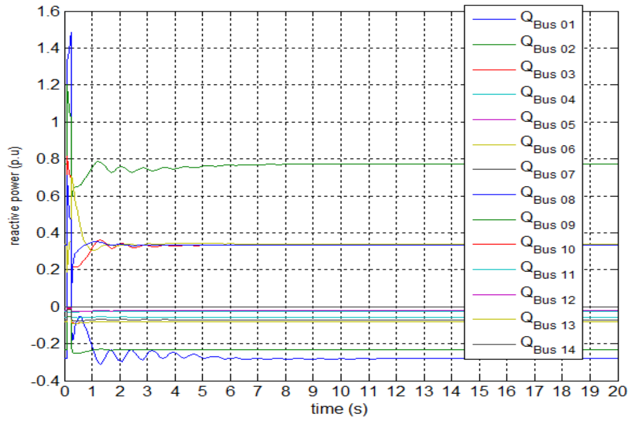

Fig. 7. The reactive power at all busses –fault at buss 11 – WF based on DFIG at buss 6-

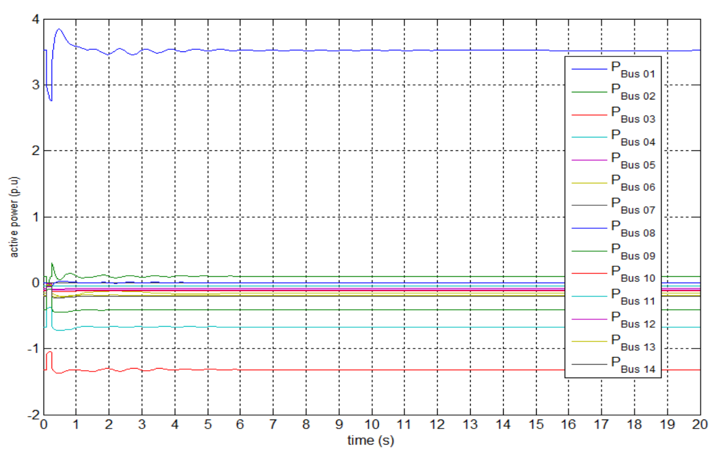

Fig. 5. The active power at all busses –fault at buss 11 – WF based on DFIG at buss 6-

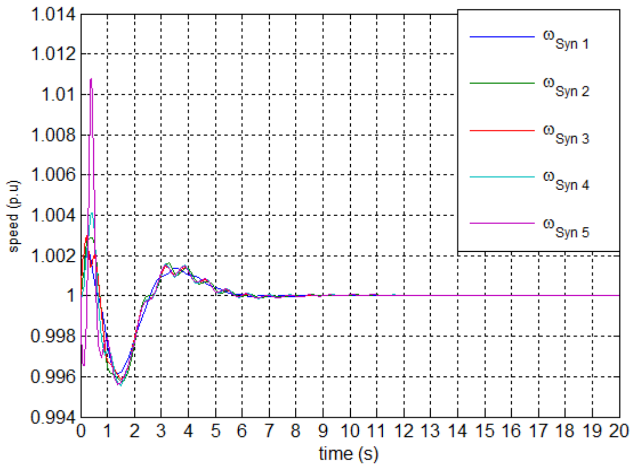

Fig. 8. The speed (omega)of all generators –fault at buss 11 –no wind energy in the system-

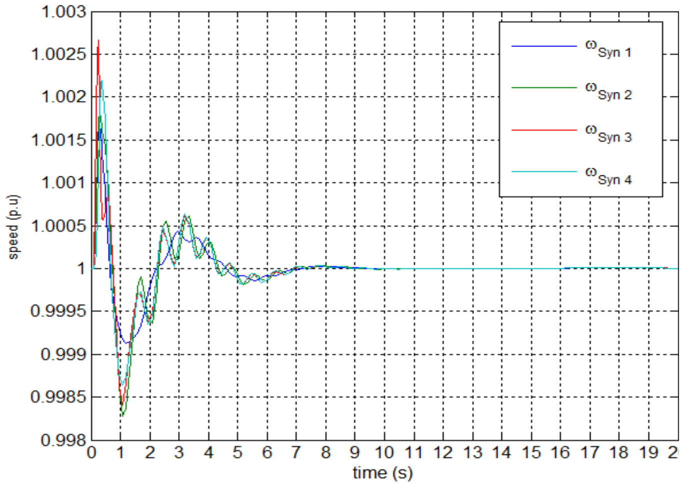

Fig. 9. The speed (omega) of all synchronous generators –fault at buss 11–

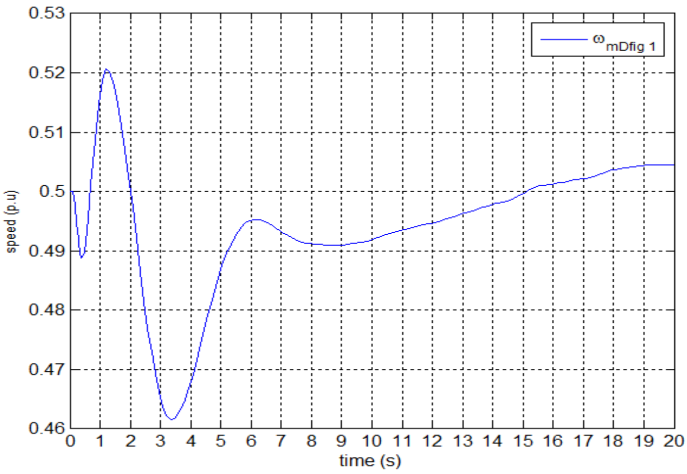

Fig.10 The speed (omega)of DFIG generator –fault at buss 11– WF based on DFIG at buss 6-

IV. CONCLUSION

Small signal analysis and Transient stability analysis has been carried out for IEEE 14-bus power systems whit and without injection of wind power based on doubly fed induction generators. The eigenvalue sensitivity has been used to observe the effect of wind power on the small signal stability of the system considering some factors, location of the wind power, level of integration of the wind power, increase of the load of the system and disconnecting of some congested lines of the tested system. It shown that improvement in small signal stability of the system is location, level of integration of wind power and fault location dependent. The results shown that the best location of wind farm in this system at bus 6 which have a higher percentage of stability for number of cases done. Transient stability analysis performed through time domain simulations, shown that the system contains DFIG are able to restore voltage and power after a grid fault as conventional generators though a quick response in restoration .

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