Investigation of Voltage Profile of Grid Integrated with Wind Turbine Generator

Kavita Yadav
Student
Electrical and Instrumentation Engineering Department
Thapar University, Patiala

Manbir Kaur
Associate Professor
Electrical and Instrumentation Engineering Department
Thapar University, Patiala

Abstract— **In a power system network, identification of weaker buses is critical and it is vital to improve the voltage profile and to minimize losses for its steady state stability. A comprehensive analysis is conducted about the optimum bus location of wind turbine generator in an IEEE 9 bus system. In this paper the impact of wind source penetration on voltage profile and losses is investigated on the system with load variation from 25% to 100%. The uncertain nature of wind speed is mathematically modeled and load demand pattern is considered for 24 hour. The result obtained shows that the lower wind penetration supports the voltage profile under the variations in load demand.**

Keywords— Squirrel Cage Induction Generator, Voltage Profile.

I. INTRODUCTION

In the era of global energy crisis, the volatility of incessant oscillation of fossil fuel prices and complications of suffering ecological balance has acquired an accelerating significance and awareness towards alternative sources of energy. Wind power generation has thrived rapidly worldwide among distinctive competitive alternative sources of energy. Although, wind power generation may cause complications to the existing grid regarding power quality issues. One of the major concern for power system utilities is voltage stability which occurs due to several events in power systems such as generator reaching reactive power limits, action of tap changing transformers, and increase in loading, load recovery dynamics and line or generator outages. They may cause a progressively and uncontrolled fall of voltages leading to voltage instability or voltage collapse. The integration of the wind production unit in the network causes difficulties such as the absence of voltage adjustment and the sensitivity of voltage drops [1].

The major problem of wind is its intermittent nature that is great variability of its production and especially the difficulty in predicting the production precisely several hours in advance. According to the intensity and rate of change, the difficulties with the frequency and the voltage control could seem making a direct impact on the level of the provided electric power quality. Mostly, the stability and reliability studies are carried out whenever wind power is connected to power system to predict severe consequences on the power system. The proposed works in literature [2][3] suggest that the connection of wind turbines to the electric grid may affect stability of the system due to the random nature of the wind and the characteristics of the wind generator. Because of the simple design and cost-effective performance the squirrel cage induction wind turbine generators (SCIGs) are widely used in power systems. In this system, rotor speed is almost constant, thus it is sometimes called a fixed-speed wind turbine system. As wind generators can be integrated on transmission or distribution system. The impact of wind generators on the distribution system has been studied in [4][5] which shows that the integration of wind generator on the distribution system leads to improvement of the voltage profile and reduction in the losses. This is due to the characteristics of distribution system. Alternatively, when wind turbine is connected to transmission system leads to decline of the voltage profile and increase in the system losses which has been suggested in [6][7]. This is due to the interaction of power flow on the transmission system.

II. WIND GENERATION

A. *Model of Wind source*

Wind turbines produce electricity by using wind power to drive an electrical generator. Passing over the blades, wind generates lift and exerts a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox adjusts the rotational speed to that which is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy [7][8]. The wind turbine extracts kinetic energy from the swept area of the blades. The wind power is demonstrated as kinetic energy of the flowing air mass per unit time given by,

$$P_{wind} = \frac{1}{2}\rho A v^3 \qquad (1)$$

The power coefficient (Cp) describes the efficiency of a turbine that converts kinetic energy in the wind into rotational power. Cp values varies between 0.3-0.45. [9] Therefore, power output of the turbine is given by,

$$P_{wind} = \frac{1}{2}\rho A v^3 C_p \qquad (2)$$

The variation of wind power output with wind speed is expressed in equation (3),

$$P_w = \begin{cases} 0, & v < v_{cin} \\ \frac{1}{2} A v_r^3 C_p, & v_{cin} < v_r < v_{cou} \\ 0, & v > v_{cou} \end{cases} \qquad (3)$$

where,

P_w is the wind power output (watts),

ρ is the air density (1.225 kg/m3 at 15◦C and normal pressure), A is the swept area (m2),

V_{cin} is cut in speed (m/sec),

V_r is rated speed (m/sec),

V_{cou} is cut out speed (m/sec)

Figure 1 shows the wind power obtained for the variation in wind speed.

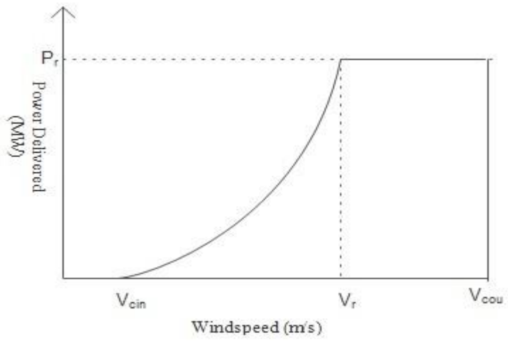

Fig. 1. Wind power output

B. *Modeling of Wind source Generator*

Induction machines are used extensively in the system as motors, but not generators. It is mainly due to the defined relationship between the export of active power and absorption of reactive power, (Q). But, the benefit of induction generator to provide large damping torque in the prime mover, makes it suitable for the application in fixed speed wind turbines[10][14]. The SCIG is modeled as a PQ bus with the real power and reactive power demand specified.

Rs and Rr are stator and rotor resistance per phase respectively,

Xs and Xr are stator and rotor leakage reactance per phase respectively,

θ is the power factor angle.

From the equivalent circuit, input impedance is expressed as

$$Z_{in} = R_s + jX_S + (jX_m \,||\, (\frac{R_r}{s} + jX_r)) \quad (4)$$

Circuit parameters can be express as equation (5) to (8)

$$I_s = \frac{V_s}{Z_{in}} \quad (5)$$

$$V_a = V_s + I_s(R_s + jX_S) \quad (6)$$

$$P_w = 3|V_s||I_s|\cos\theta \quad (7)$$

$$Q_w = 3|V_s||I_s|\sin\theta \quad (8)$$

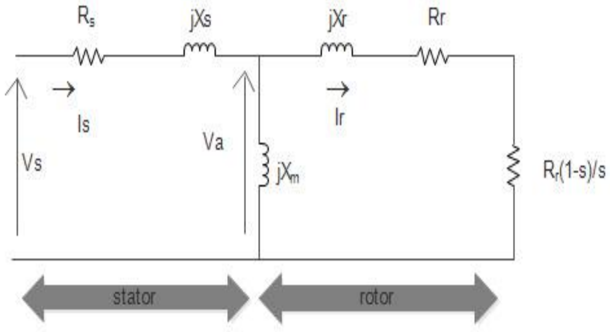

Fig.2: Equivalent circuit of SCIG

Figure 2 shows the per phase equivalent circuit of squirrel cage induction generator where,

C. *Load flow Analysis Method*

The general steady-state effect of connecting wind turbine generators to the grid can be analyzed through the load-flow analysis. It calculates the voltage drop on each feeder, the voltage at each bus, and the power-flow in all branch and feeder circuits. It determines if the voltages remain within specified limits under various contingency conditions, and whether equipment such as transformers and conductors are overloaded. Load-flow studies are often used to identify the need for additional generation, capacitive, or inductive VAR support, or the placement of capacitors and /or reactors to maintain system voltages within specified limits. It is also necessary for planning, economic scheduling, exchange of power between utilities and control of an existing system as well as planning its future expansion. Here, Newton Raphson method is used to carry out load flow analysis on IEEE 9 bus system with and without wind source.

III. REQUIREMENT OF REACTIVE POWER AND VOLTAGE PROFILE

Under normal conditions, the acceptable limits of voltage ranges from 0.95 to 1.05 p.u. for a reliable power networks. It is quite difficult to maintain acceptable voltage limits without reactive power supply.

A. *Power system networks with conventional generators.*

Synchronous generators are commonly used as a conven- tional generator connected to grid that can supply or consume reactive power. For these generators reactive power produc- tions are provided by automatic voltage regulator which in turn will maintain the system voltage profile. During normal operation, variation in the generation and load profile affects the system voltage profile at different buses [15].

B. *Power system networks with wind generators*

When wind generators are connected to meet the increased load demand, the output of the conventional generator is op- timally used to meet the load demand which is tabulated in table I when wind source was connected at different locations. In case there is no output from the wind generator, demand will be met through conventional generators. In case of transmission system, the impact of wind power depend upon the location of wind generator in relation to load [16][17]. The power balance equations are given by

$$P_{gen} + P_{wind} = P_{demand} + P_{losses} \quad (9)$$

$$Q_{gen} = Q_{demand} + Q_{losses} + Q_{wind} \quad (10)$$

Table-1

Wind source at	Pcon	P_w	P_D	P_L	Qcon	Q_w	Q_D	Q_L
Bus 5	291.5	28	315	4.5	18.06	1.17	115	-95.80
Bus 6	291.3	28	315	4.7	40.75	-18.27	115	-92.50
Bus 8	29.1	28	315	5.1	53.62	-24.50	115	-85.90

IV. TEST CASE AND RESULTS

In this study, the voltage profile and losses in IEEE 9 bus system has been investigated for the optimal location of wind source in the system. The simulation is carried out using Powerworld simulator. [18] The single line diagram of IEEE 9 bus test system is shown in figure 3.

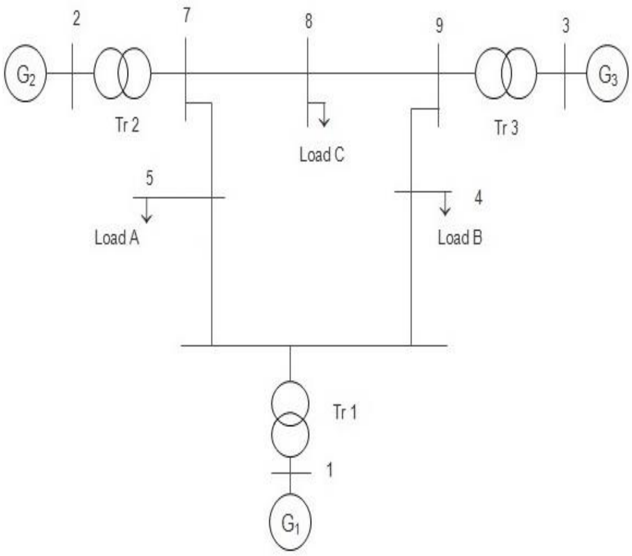

Fig.3: IEEE 9 bus

In order to arrive at the optimum bus location the following system parameters are investigated:

i). Steady-state voltage magnitudes and angle at each bus.

ii). Total transmission losses.

The outcomes are yielded for the following network states:

i). Network without the wind generators with standard load and varying loading conditions.

ii). Network with integration of the wind generators at different locations and varying load.

iii). Network with wind generator with variation in wind power and load in a day at different penetration levels.

A. *Network without the wind generator with varying loading conditions*

The load flow analysis on the test system is carried out with variation in load demand from 25% to 100%. The result obtained is tabulated in table II.

Table-2: Result of load flow analysis

Bus	Standard load		25 % load increase	
	Voltage(p.u.)	angle(Deg)	Voltage(p.u.)	angle(Deg)
1	1.040	0.00	1.040	0.0
2	1.025	9.280	1.025	3.63
3	1.025	4.665	1.025	-0.85
4	1.025	-2.217	1.016	-4.69
5	0.995	-3.989	0.977	-8.60
6	1.012	-3.6870	0.997	-7.99
7	1.025	3.7200	1.017	-1.98
8	1.015	0.728	1.002	-5.52
9	1.032	1.907	1.02	-3.57

Bus	50 % load increase		100 % load increase	
	Voltage(p.u.)	angle(Deg)	Voltage(p.u.)	angle(Deg)
1	1.040	0.00	1.040	0.0
2	1.025	-2.36	1.025	-12.63
3	1.025	-6.75	1.025	-17.4185
4	1.002	-7.26	0.971	-11.34
5	0.95	-13.45	0.908	-20.62
6	0.975	-12.60	0.924	-21.00
7	1.00	-8.02	0.984	-18.43
8	0.986	-12.16	0.949	-24.13
9	1.01	-9.49	0.99	-20.21

As the load demand progressively increased from 25% to 100% buses 5, 6 and 8 suffer from voltage instability.

B. *Network with the wind generators at different locations with varying load conditions*

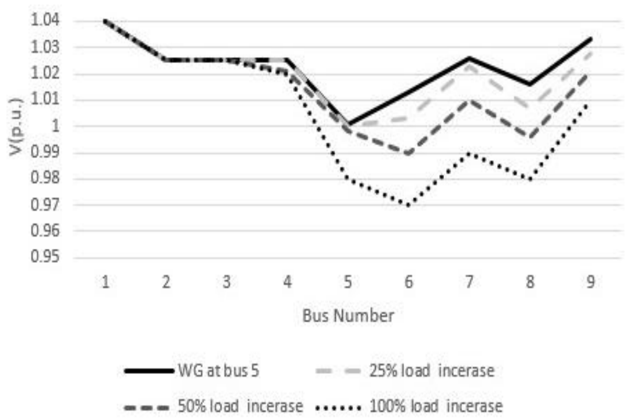

Fig.4: Voltage profile with WG at bus 5

When wind generator was connected at bus 5 with standard load and varying load condition the change in voltage profile in the buses is shown in figure 4 for fixed wind speed. Voltage at bus 5 reaches to 0.97 p.u.

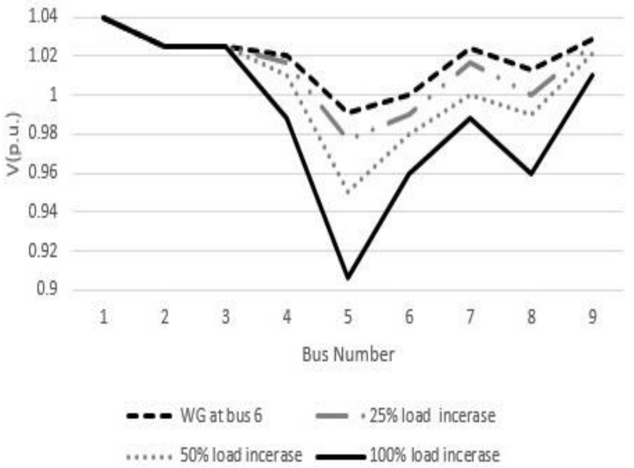

Fig.5: Voltage profile with WG at bus 6

When wind generator was connected at bus 6 with standard load and varying load condition the change in voltage profile in the buses is shown in figure 5. Voltage at bus 5 reaches to 0.908 p.u.

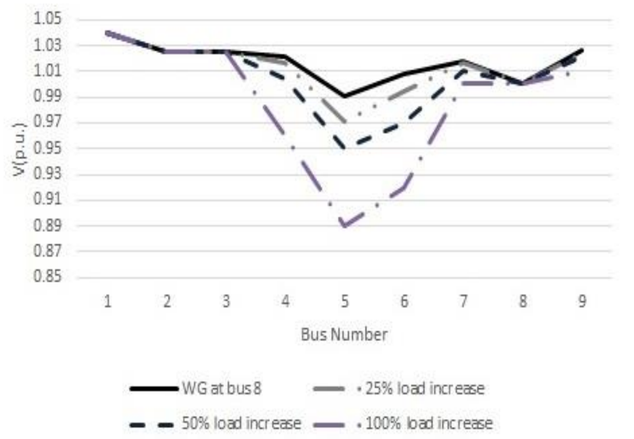

Fig.6: Voltage profile with WG at bus 8

When wind generator was connected at bus 8 with standard load and varying load condition the change in voltage profile in the buses is shown in figure 6. It can be shown that voltage profile at bus 5 reaches to 0.88 p.u.

It was observed from figures 4, 5 and 6 that voltage profile of the buses are better when the wind generator was connected at the bus 5 wherein, connected at buses 6 or 8. In order to enhance the voltage stability, the best location of wind turbine is the weakest bus which contains the largest load and that is bus 5.

C. Network with wind generator with variation in wind power and load in a day at differenet penetration level

The impact of wind generation in transmission networks is considered for increased in load demand up to 150% and wind source penetration is being investigated and results are depicted in figures 7 and 8.

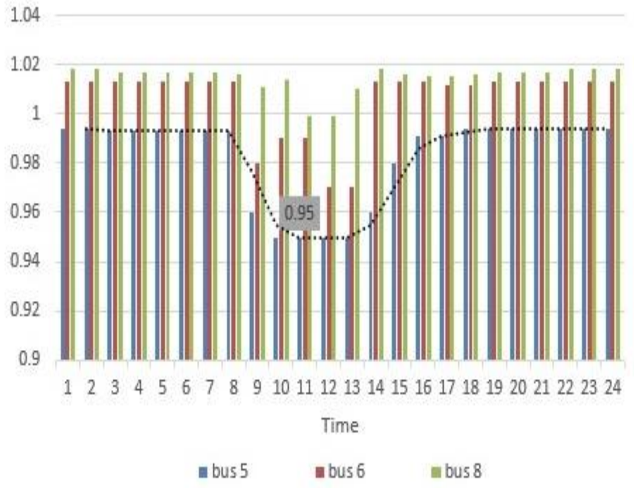

Fig.7: Voltage profile with 10% penetration level of wind

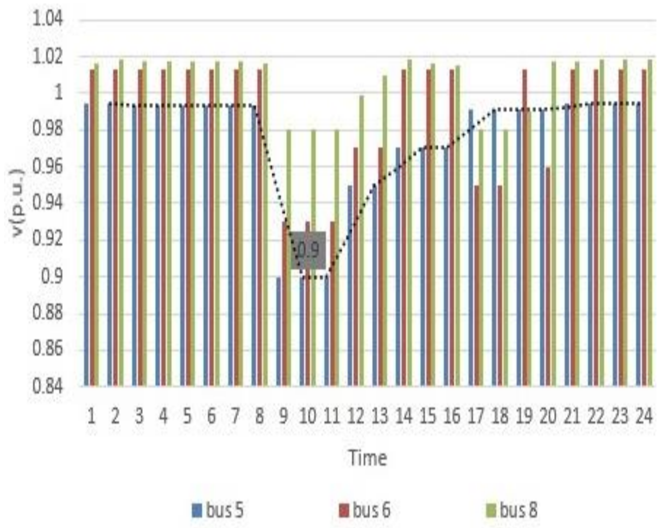

Fig.8: Voltage profile with 30% penetration level of wind

It can be analyzed from figure 7 and 8 that the system is within the limit at lower wind penetration level but become unstable at higher wind penetration level.

D. Comparision of losses.

With respect to change in location of wind generator relative to the load, there is increase or decrease in the losses. This is due to the relation between wind power production and load consumption in the transmission system.

Table-3: Active and reactive power losses

Cases	MW	MVar
Without WG	4.6	-92.2
WG at bus 5	4.5	-93.2
WG at bus 6	4.7	-91.2
WG at bus 8	5.1	-88.6

It can be analyzed that from table III that there is increase in losses when wind turbine was connected at buses 6 and 8 and decrease in losses when connected at bus 5. So, bus 5 can be considered as optimal location for the connection of wind turbine generator.

V. CONCLUSION

This paper investigates the impact of wind generation on power system network particularly on voltage profile and losses of the system. The load-flow analysis has been performed on the IEEE 9 bus system without wind generator and with wind generator at distinct locations and with varying loading condition. It can be derived from the tabulated results that the voltage profile obtained at bus 5 is more prominent than it is at bus 6 and bus 8 at different loading condition. The voltage profile of the buses are in limit at lower penetration level than higher penetration levels. The losses in the system with and without wind generator at distinct bus location are assessed. Location of wind generator at Bus 5 can be considered as the optimum choice. It can thus be concluded that optimum location and penetration level of wind generator are to be consider for a better system voltage profile.

REFERENCES

[1] Fariba Zavareh. Hadi Fotoohabadi, Reza Sedaghati. "Improvement of Voltage Profile of Grid Integrated Wind Distributed Generation by SVC". vol. 9, pp: 788-792, 2015.

[2] Trinh Trong Chuong, "voltage Stability Investigation of Grid Connected Wind Farm". vol: 2, No: 6, pp: 1163-1167, 2008.

[3] Mehdi Mohammadzadeh Rostami Rostami,S. Soleymani, Babak Moza-fari "Improve the Voltage Profile of Grid Connected Induction Generator Under Load Variation and Symmetrical Short circuit in the Presence of SVC and STATCOM ".

[4] A. P. Agalgaonkar, S.V. Kulkarni, S. A. Khaparde, Impact of Wind Generation on Losses and Voltage Profile in a Distribution System, Conference on Convergent Technologies for Asia-Pacific Region, TENCON 2003, vol. 2, pp:775-779, 2003.

[5] K.C Divya, P. S. Nagendra Rao, Models for Wind Turbine Generating Systems and Their Application in Load Flow Studies, ELSEVIER, Electric Power Systems Research vol. 76, pp: 844- 85, 2006.

[6] I. S. Naser, A. Garba, O. Lara, K.L.Lo "Voltage Stability of Transmission Network with Different Penetration Levels of Wind Generation", UPEC, 2010.

[7] Sayed M. Said, Mohamed. M. Aly and Mamdouh Abdel-Akher, "Capacity and Location Effects of Wind Turbine Energy Systems on Power Systems Stability". International Journal on Power Engineering and Energy (IJPEE), vol. 4 - No. 1, pp: 343-347, 2013.

[8] M. Ebadian, A. Edrisian, A. Goudarzi, "Investigating the effect of high level of wind penetration on voltage stability by quasi-static time-domain simulation (QSTDS)", vol. 4, No. 2, pp: 355-362, 2014.

[9] V. Salehi, S. Afsharnia, S. Kahrobaee, "Improvement of Voltage Stability in Wind Farm Connection to distribution Network Using FACTS Devices", pp: 4242-4247, 2006.

[10] Gilbert M. Masters"Renewable and Efficient Electric Power Systems" John Wiley & Sons, Inc., Publications.

[11] D. Dragomir, N. Golovanov, C. Toader, "The connection to the grid of wind turbines", 2009.

[12] P. N. Boonchiam, A. SodeYome, N. Mithulananthan, K. Aodsup "Voltage Stability in Power Network when connected Wind Farm Generators", International Conference on Power Electronics and Drive Systems (PEDS), Taipei, pp: 655 - 660, 2-5 Nov. 2009.

[13] Z.Chen, Y.Hu, F.Blaabjerg, "Stability improvement of Induction generator based wind turbine systems", pp 81-93, 2007.

[14] Murari Lal Azad, Shubhranshu Vikram Singh, Aizad Khursheed, "Improving Voltage Profile of A Grid, Connected To Wind Farm Using Static Var Compensator", vol. 7, Issue 5, pp: 1497-1506, 2014.

[15] A.D. Hansen, N. A. Cutululis, F.lov, "Grid integration impacts on wind turbine design and development", 2009.

[16] Federico Milano, "Assessing Adequate Voltage Stability Analysis Tools for Networks with High Wind Power Penetration", Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), Nanjuing, China, pp: 2492 - 2497, 6-9 April 2008.

[17] Kun Yang, A. Garba, C.S. Tan, K.L. Lo, "The Impact of the Wind Generation on Reactive Power Requirement and Voltage Profile", pp: 866-871, 2008.

[18] Power world simulator version 11.0 Users Guide, Power World Corporation, May 2005.