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Abstract

Wind energy represents one of the most important renewable energy resources that can support electrical power systems. Behaviour of wind turbines following contingencies may deteriorate system stability. This requires an extensive analysis of the possible effect of wind energy on the entire power system performance. This paper investigates the effect of wind energy on power system dynamic response. This is achieved by replacing conventional generators gradually by wind turbine (WT). Also, the optimal location of WT has been determined by checking influence on steady state operation. In addition, the effect on total fuel cost is considered to determine the optimal location of WT. The IEEE 30-bus system is used during the study. The results indicate that the system stability is enhanced in most cases with integrating wind energy into power system. The results can provide a scope for future planning and expansion in electric power systems.

Keywords*:* Wind energy, Transient Stability, Renewable Energy Resources, Critical Fault Clearing Time.

Introduction

In recent years, there are increased amounts of carbon emission because of the utilization of fossil fuels in conventional power sources and rapid increase in electrical loads. As a consequence, the world has tended to incorporate renewable energy sources such as wind farms in electrical power systems.

There is a large incorporation of wind energy which can be observed in many European countries, Australia, USA, Canada and also India. This increased amount of wind installation has considerable effects on the operation of existing electrical networks. Therefore, the influence of wind energy on power system performance should be analysed.

There are several constraints, including steady-state and transient stability that may affect wind power integration into a power system. A majority of large wind farms are geographically away from load centres and connected into relatively weak transmission networks. The presence of wind farms in such weak transmission networks results in serious concerns about system performance[1], [2]. Therefore, the wind farm location should be carefully selected to enhance system performance.

Wind energy systems and conventional synchronous generators have different transient responses because of their different dynamic characteristics. Additionally, wind turbines (WTs) results in reduction of the overall system inertia in relation to the installed capacity [3]. Transient stability is the ability of the power system or a single machine to maintain a synchronism when subjected to a large disturbance in the power system such as faults and generators trip [4]. Critical clearing time (CCT) is an important transient stability index. CCT is the maximum duration that a disturbance can sustain without losing of the power system's synchronism [5], [6].

In [7][8][9], the impact of large penetration of wind energy on power system transient stability is examined, but they considered a simple network structure.

In [3], the effect of WT on power system transient stability has been analysed when the conventional units are replaced by WT. This has been achieved by evaluating the system response in terms of real and reactive power and voltage profile. The analysis is performed on small system, i.e., Two-area weakly coupled test network.

In[10], the impact of increased integration of wind power on power system dynamic behaviour is discussed. The case studies have been carried out using the IEEE 30-bus system. But the effect of WT on real power deviation and voltage profile have not considered. Also, the critical buses have not been considered when the WT best location is determined.

The objective of this work is to determine the influence of wind energy integration on power system performance. The paper briefly discussed the effect of wind energy on power system dynamic stability. Conventional generators are replaced gradually by wind turbine generators. Besides, to determine the best location of WT, the influence on steady state operation (e.g. voltage profile and total system power losses) is determined. Also, the economic operation is considered to determine the optimal location of WT by calculation of total fuel cost. These executions are compared with the case of system without wind turbine to determine the suitable location of WT.

This paper is organized as follows. The next section will clarify the test system and WT technology description then, the used methodology will be highlighted. This will be followed by some simulation results and finally the conclusions will be introduced.

I. System Description

The investigated network is the IEEE-30-bus system [11]. The time domain simulation is accomplished using ETAP software package. The standard IEEE-30 bus system consists of 30 buses, 6 generators, 24 loads and 4 transformers. The generator bus data, load data and line data are presented in the appendices IX. Generator 1 is adopted in the swing mode, while other generators are assumed to operate in the voltage control mode. To investigate the dynamic behaviour of the power system, the conventional power plants are used as thermal-type generators.

II. Methodology

The main objective of the work is to study the impact of wind energy integration on the power system performance. The capability to achieve this strategy is associated by performing the following:

- Since the test system consists of relatively large number of buses, it is necessary to determine the critical buses which have minimum CCTs to reduce the time of computation.
- A conventional generator is partially replaced by WT and the effects of this replacement on power system transient operation are investigated.

• All loads are assumed to be increased randomly and the WT is added to compensate this increase in power demand. Then, the system behaviour is examined to determine the best location of WT.

III. Wind Turbine technology description

The WT technology that has been used in this study is variable-speed WT equipped with a doubly-fed induction generator. The average wind speed (ν_{av}) is chosen as 10 m/s and the rated speed (ν_{rated}) of WT is 15 m/s. Also the cut in speed (ν_i) and cut out speed (ν_o) are 4 m/s and 25 m/s respectively. The total per unit inertia constant of the generator shaft including the turbine, gear and generator is 4 MW-sec/MVA.

IV. Determination of critical buses

The critical buses have been determined by calculating the CCT at each bus individually after subjecting it to three-phase fault with different fault durations. Then, the buses are ranked according to their corresponding CCT, where the higher CCT refers to higher stability for the system. The CCT is computed using the bisection technique to reduce the time consumed in calculations as introduced in [12]. Based on the CCT, the critical buses are determined as follows: bus-4, bus-6, bus-9 and bus-12. The generator at bus-13 is the critical generator for faults at critical busses. These buses are the candidate locations for wind energy integration, which have the minimum CCT. The CCTs associated with faults at the critical buses are presented in table 1.

Table 1: CCT for critical buses

Bus No.	CCT (s)	Bus No.	CCT (s)
4	1.885	**9**	0.602
6	1.116	**12**	0.929

V. Replacement of conventional generators by WT

The generator at bus-2 is selected to be replaced by WT. The capacity of the generator is 100 MVA. The WT power integration is employed in steps of 25% of its capacity. To investigate the performance of the system following critical contingencies, a self-clearing three phase faults of 150 ms duration is applied at bus-4 as a critical bus. Then, the effect of the replacement on the system behaviour is investigated as follows:

a) Effect on active power

The active power deviation is a major aspect in power system transient stability. The results for the real power deviation of generators G_1, G_5, G_8, G_{11} *and* G_{13} are presented in figure 1.

From this figure, as the percentage capacity of the WT increases, the maximum overshoot decreases except for the generator G_8. In addition, the real power of all generators quickly settles at pre-fault values except for G_5. In other words, the effect of adding wind generation on the overall behavior of the power system improves the active power deviation by reducing the time required to reach the steady state. Besides, during fault all generators deliver less active power with increasing penetration of WT power.

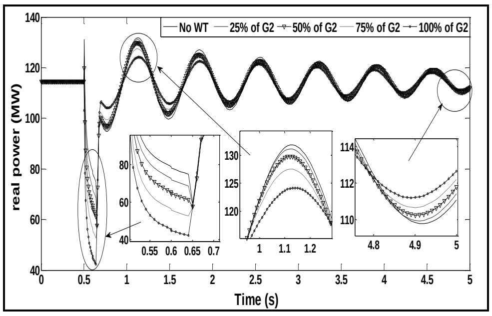

Figure 1-A: active power deviation of G1

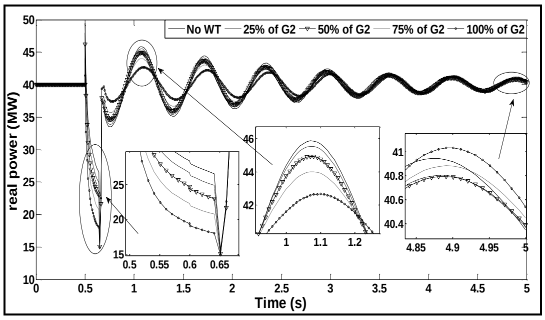

Figure 1-B: active power deviation of G5

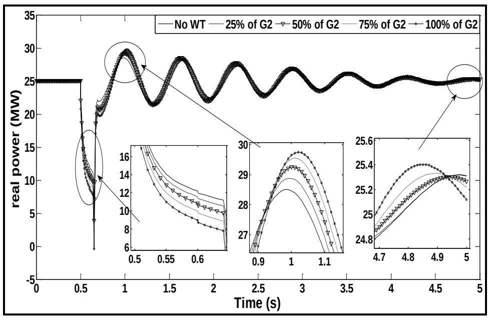

Figure 1-C: active power deviation of G8

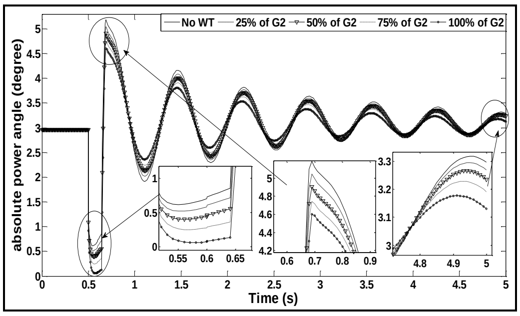

Figure 1-D: active power deviation for G11

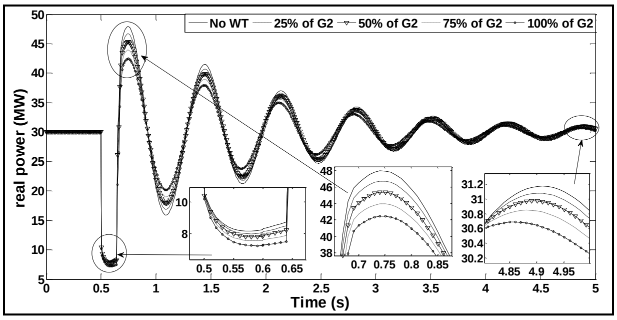

Figure 1-E: active power deviation of G13

Figure 1: active power deviation of different generators with replacement of G2 by WT

b) Effect on power angle:

The power angle deviation is an important issue in transient stability problem. The simulation results for the power angle of generators G_1, G_5, G_8, G_{11} *and* $G_{13}$are shown in figure 2. It has been observed that at higher level of wind power penetration, the power angle of the generators decreases during fault and the maximum swings after fault clearance decrease except for generator G_8. Also, as the sharing of WT power increases, the power angle reaches the pre-fault value faster excluding G_5in which the power angle reaches the pre-fault value slower.

c) Effect on voltage profile:

The impact of WT power on voltage profile of buses 9, 12 and 2 is presented in figure 3. The voltage decreases with increasing the replacement ratio during fault duration. During fault conventional generators are capable of supplying larger reactive power so, the voltage decreased during fault for 100% replacement. Also, the voltage quickly settles at the pre-fault value.

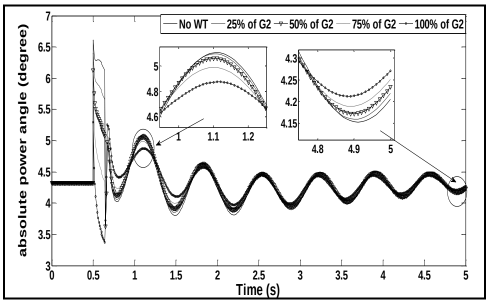

Figure 2-A: power angle deviation of G1

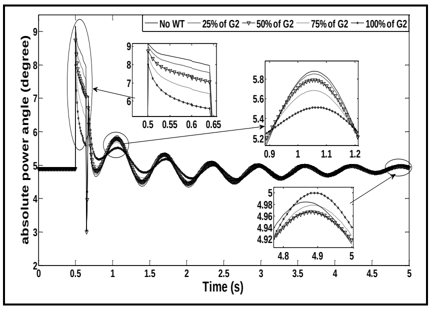

Figure 2-B: power angle deviation of G5

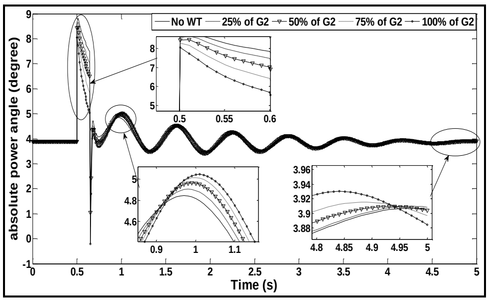

Figure 2-C: power angle deviation of G8

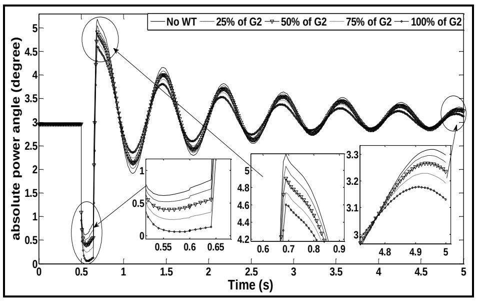

Figure 2-D: power angle deviation of G11

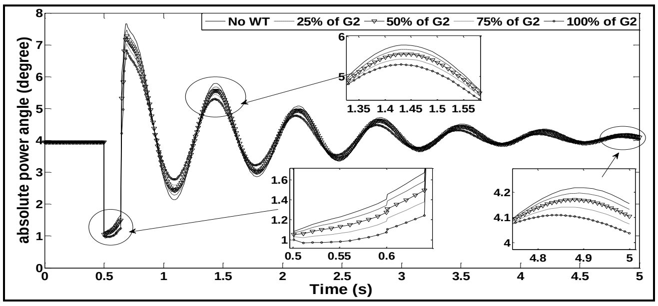

Figure 2-E: power angle deviation of G13

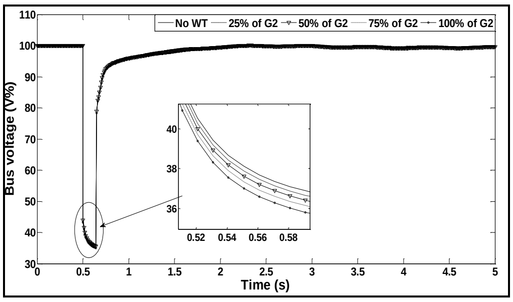

Figure 3-A: Voltage variation at bus-9

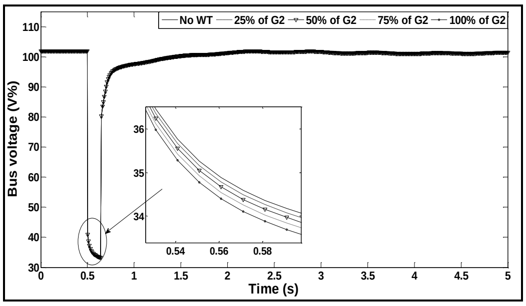

Figure 3-B: Voltage variation at bus-12

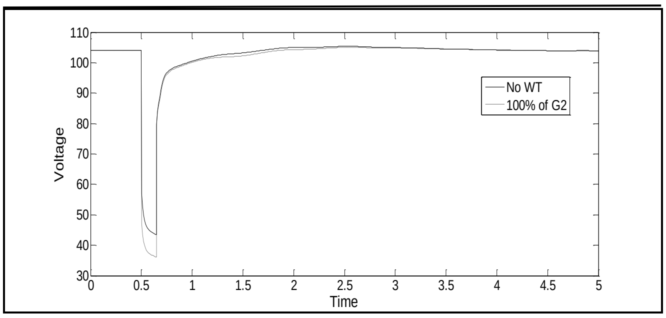

Figure 3-C: Voltage variation at bus-2

Figure 2: power angle deviation of different generators with replacement of G2 by WT

Figure 3: Voltage variation at buses 9, 12 and 2 with increasing WT penetration

VI. Determination of wind turbine best location:

To determine the best location of wind turbine, the loads are assumed to be increased by 15%. Hence, the difference between the total maximum generation and total demand is 100 MW approximately. This capacity will be added to the spinning reserve of the power system. Then, the effect of adding wind turbine on system performance is investigated. After increasing the load, the system is checked again to determine the new critical buses at the new operating point by the same methodology in section IV. The new critical buses are bus-6, bus-9 and bus-12.

The effect of adding WT on system performance after the load increase is performed by connecting WT with different capacities (10-50 MW) with step of 10 MW. The WT is connected at the critical buses, i.e., bus-6, bus-9 and bus-12. Then, the effect of connecting WT is determined on total system active power losses, voltage profile and fuel cost. Then, the results are compared with the system without WT to determine the WT best location.

a) Effect on power losses:

The total system real power losses are calculated each time when WT is located at each critical bus with different capacities. The power losses in each case are illustrated in figure 5. The values of power losses are compared with the case of the system without WT to specify the best location of WT with respect to real power losses. From the figure, the best place of WT is at bus-6 at which the minimum total real power loss is achieved. The second best location of WT is at Bus-9 and then at Bus-12.

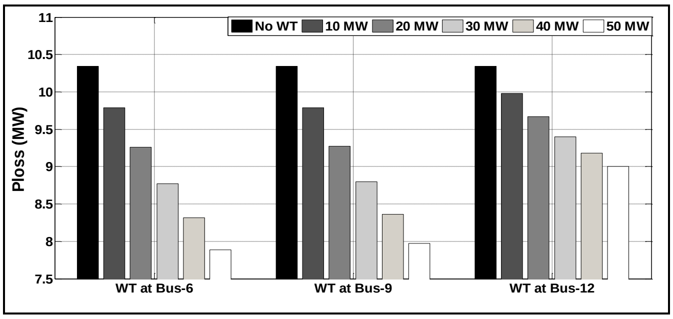

Figure 5: System active power losses with increasing WT capacity

b) Effect on voltage profile

The voltage at the critical buses is also calculated when WT is located at each critical bus with different capacity. The value of voltage is compared each time with the case of the system without WT. Then, the buses are ranked to determine the best location from the viewpoint of voltage. By comparing the results shown in figure 6, the voltage profile is the best when WT is at bus-12 compared to buses 6 and 9. Then, the priority will be for locating WT at Bus-6 and finally at Bus-9.

c) Effect on fuel cost:

The fuel cost is calculated each time when WT is connected at one of the critical buses with different capacities. Table-2 presents the values of cost coefficients of conventional generators. The fuel cost ($/hr) of each generator is calculated using the following equation

$$F = \alpha + \beta * P_g + \gamma * P_g^2 \quad (\$/hr)$$

where α, β and γ are the cost coefficients

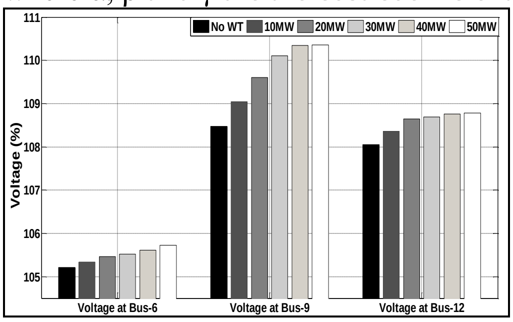

Figure 6-A: Voltage at critical buses with WT at Bus-6

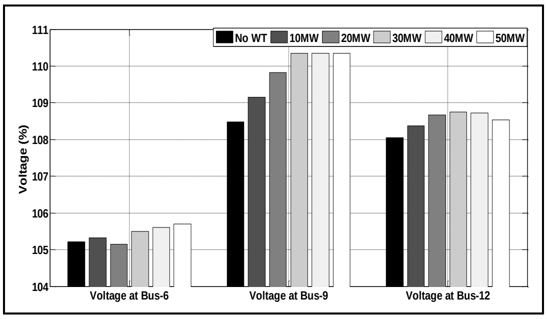

Figure 6-B: Voltage at critical buses with WT at Bus-9

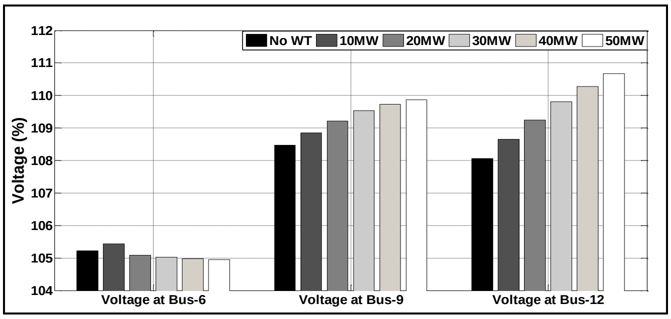

Figure 6-C: Voltage at critical buses with WT at Bus-12

Figure 6: Voltage at critical buses with different WTs capacities

Table 2: Cost coefficients of generators

Generator number	Cost coefficients			P_g (MW) (Without WT)	Q_g (MVAR) (Without WT)	Fuel cost (Without WT)
		β	γ			
1		2	0.00375	185.365	8.183	499.58
2		1.75	0.0175	41.367	28.56	120.338
5		1	0.0625	15	32.295	29.0625
8		3.25	0.00834	35	48.73	123.9665
11		3	0.025	29.711	28.759	111.2015
13		3	0.025	29.273	35.79	109.2417

By adding WT to the system, the value of fuel cost is less than the value of fuel cost of the system without WT. The value of fuel cost of the system without WT equals 975.391 ($/hr). Table-3 shows the fuel cost of the system with WT located at critical buses with different capacities. From this table, when WT is at Bus-6, the minimum fuel cost is achieved with different WT capacities.

Table 3: Fuel cost with WT at critical buses

Capacity of WT (MW)	Fuel cost with WT at Bus-6 ($/hr)	Fuel cost with WT at Bus-9 ($/hr)	Fuel cost with WT at Bus-12 ($/hr)
10 MW	937.6653	937.67	938.3199
20 MW	900.612	900.644	901.9666
30 MW	864.234	864.32	866.30577
40 MW	828.5237	828.6941	831.339
50 MW	793.4753	793.7562	797.058

VII. Conclusion

In this paper, the impact of large wind energy integration on the performance of power system has been investigated using the IEEE 30-bus test system. The simulation results of real power variations, power angle variations and voltage profiles are analysed. It has been observed that while the WT power penetration increases, the maximum swings of real power and power angle deviations of the conventional generators decrease. It can thus be summarized that the larger sharing of wind power generation, the better the transient stability performance of conventional generators. Taking into account the post fault transient performance, the time needed to reach the steady state is reduced with increasing of WT power generation in the power system. It can also be concluded that the best location of WT could be identified considering important factors such as voltage profile, system real power losses and fuel cost.

VIII. References

[1] M. J. Hossain, H. R. Pota, M. A. Mahmud and R. A. Ramos, "Investigation of the Impacts of Large-Scale Wind Power Penetration on the Angle and Voltage Stability of Power Systems", Systems Journal, IEEE, Vol. 6, 2012, pp. 76 - 84.

[2] M. R. Rathi and N. Mohan, "A novel robust low voltage and fault ride through for wind turbine application operating in weak grids," in Proc. 31st Annu. Conf. IEEE Indust. Electron. Soc., Vol. 1. Nov. 2005, pp. 2481–2486.

[3] F. Shewarega, I. Erlich and J. L. Rueda "Impact of Large Offshore Wind Farms on Power System Transient Stability", Power Systems Conference and Exposition, March 2009, Vol. 8, pp. 1-8.

[4] P. Kundur, "Power System Stability and Control", McGraw-Hill Professional Publishing, 1994.

[5] C. Liu; Z. Chen; C.L. Bak, Z. Liu, P. Lund, P. R. Hansen, "Transient stability assessment of power system with large amount of wind power penetration: The Danish case study," IPEC, 2012 Conference on Power & Energy, pp. 461,467, 12-14 Dec. 2012.

[6] M. A. Pai, "Transient Stability of Power System" Massachusetts, USA: Kluwer Academic Publishers, 2000.

[7] S. Mohandas and A. Kumar, "Transient Stability Enhancement of the Power System with Wind Generation," TELKOMNIKA, Vol. 9, no. 2, pp. 267-278, Aug. 2011.

[8] L. Shi, D. Ni, L. Yao and M. Bazargan, "Transient stability of power system with high penetration of DFIG based wind farms," in IEEE Power & Energy Society General Meeting, 2009. PES '09. Univ., Shenzhen, China, 26-30 July 2009, pp. 1-6.

[9] S. Sheri, B. Shankar Prasad, V. Bhat, and S. Jagadish, "Effect of Doubly Fed Induction Generator on Transient Stability Analysis of Grid" IEEE Transactions on Energy Conversion, Vol. 20, no. 2, p. 388–397, June 2005.

[10] A. Mohammed and B. Tarek, "Power System Transient Stability Analysis with High Wind Power Penetration," International Electrical Engineering Journal (IEEJ), Vol. 4 (2013) No. 1, pp. 907-913.

[11] O. Alsac, B. Stott, "Optimal Load Flow with Steady-State Security," Power Apparatus and Systems, IEEE Transactions on, Vol. PAS-93, no.3, pp.745, 751, May1974.

[12] A. Hoballah and I. Erlich "Generation Coordination for Transient Stability Enhancement using Particle Swarm Optimization", IEEE Middle East power system conference, 2008, Aswan, Egypt.

IX. appendices

A. Line data for the IEEE-30-bus test system

B.

Line No.	From bus	To bus	R+j x (p.u.)	y/2 (p.u.)
1	1	2	0.0192+j0.0575	0.0264
2	1	3	0.0452+j0.1652	0.0204
3	2	4	0.057+j 0.1737	0.0184
4	3	4	0.0132+j0.0379	0.0042
5	2	5	0.0472+j0.1983	0.0209
6	2	6	0.0581+j0.1763	0.0187
7	4	6	0.0119+j0.0414	0.0045
8	5	7	0.046+j 0.116	0.0102
9	6	7	0.0267+j 0.082	0.0085
10	6	8	0.012+j 0.042	0.0045
11	6	9	0+j 0.208	0
12	6	10	0+j 0.556	0
13	9	11	0+j 0.208	0
14	9	10	0+j 0.11	0
15	4	12	0+j 0.256	0
16	12	13	0+j 0.14	0
17	12	14	0.1231+j0.2559	0
18	12	15	0.0662+j0.1304	0
19	12	16	0.0945+j0.1987	0
20	14	15	0.221+j 0.1997	0
21	16	17	0.0524+j0.1923	0
22	15	18	0.1073+j0.2185	0
23	18	19	0.0639+j0.1292	0
24	19	20	0.034+j 0.068	0
25	10	20	0.0936+j 0.209	0
26	10	17	0.0324+j0.0845	0
27	10	21	0.0348+j0.0749	0
28	10	22	0.0727+j0.1499	0
29	21	22	0.0116+j0.0236	0
30	15	23	0.1+j 0.202	0
31	22	24	0.115+j 0.179	0
32	23	24	0.132+j 0.27	0
33	24	25	0.1885+j0.3292	0
34	25	26	0.2544+j 0.38	0
35	25	27	0.1093+j0.2087	0
36	28	27	0+j 0.396	0
37	27	29	0.2198+j0.4153	0
38	27	30	0.3202+j0.6027	0
39	29	30	0.2399+j0.4533	0
40	8	28	0.0636+j 0.2	0.0214
41	6	28	0.0169+j0.0599	0.0065

B. Generation bus data for the IEEE-30-bus test system

Bus No.	P_{min} (MW)	P_{max} MW)	Q_{min} (MVAR)	S_{max} (MVA)
1	50	200	-20	250
2	20	80	-20	100
5	15	50	-15	80
8	10	35	-15	60
11	10	30	-10	50
13	12	40	-15	60

C. Load data for the IEEE-30-bus test system

Bus No.	Load		Bus No.	Load	
	MW	MVAR		MW	MVAR
1	0.0	0.0	16	3.5	1.8
2	21.7	12.7	17	9.5	5.8
3	2.4	1.2	18	3.2	0.9
4	7.6	1.6	19	9.5	3.4
5	94.0	19.0	20	2.2	0.7
6	0.0	0.0	21	27.5	11.2
7	22.8	10.9	22	0.0	0.0
8	30.0	30.0	23	3.2	1.6
9	0.0	0.0	24	8.7	6.7
10	5.8	0.0	25	0.0	0.0
11	0.0	0.0	26	3.5	2.3
12	11.2	7.5	27	0.0	0.0
13	0.0	0.0	28	0.0	0.0
14	6.2	1.6	29	2.4	0.9
15	8.2	2.5	30	10.6	1.9