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THE EFFECTS OF RENEWABLE ENERGY SOURCES ON VOLTAGE STABILITY

ABSTRACT

Power systems are exposed to significant structural changes in recent years. One of the main reasons for this is the integration of renewable energy sources into power systems. Today, especially renewable energy sources such as wind and sun are densely connected to power systems at various points. As a result, changes occur in the structures of the power systems. These structural changes also affect the parameters of power systems. One of these parameters, voltage stability, is considered as an important criterion in terms of the quality of electric energy and the continuity of electric energy. In this study, the voltage stability analysis of the power system was made by adding the renewable energy sources to various points on six bus power system. The review focuses wind power plants heavily used in renewable energy sources. Various scenarios have added renewable energy sources at various levels to the consumption points of the power system. As a result of these scenarios, stability limit values of the power system are investigated. The study was performed through the Power World simulation program. In addition, the P-V curves of the buses are plotted with continuous load flow. According to the results obtained, it is observed that the system has improved stability limits, voltage and power.

Keywords: Power System, Voltage Stability, Renewable Energy Sources, Wind Energy, Solar Energy

1. INTRODUCTION

Today, the continuous increase in world population, accordingly the increase in the demand for energy, and the decrease in fossil fuel reserves dictates the use of new energy sources. These sources are called renewable energy sources (RES) and they are environment-friendly, pollution-free and costless energy resources [1]. The integration of these resources into power systems has emerged as a new subject. Some of the difficulties are the integration of renewable energy sources into the power systems, the discontinuity of the energy, and the changes in voltage in the buses to which they are connected [2]. In the transmission system, frequency and voltage stability are of interest for power integration from various points [3]. Before any renewable energy source is connected to the power system, the possible effects must be investigated. In some cases it can have positive effects on the system and sometimes it can cause instability in the system. The RESes near to consumer may improve voltage quality and may cause a decrease in the losses in the line.

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RESes connected far away from the loads overload the transmission lines and further increase the line losses [4 and 5].

2. RESEARCH SIGNIFICANCE

In this study, the variation of the power system's voltage stability or critical values, the losses in the power system and the variation of the power flow between the buses were investigated by adding RESes to a 6-bus power system. This work has been simulated through the Power World program specifically designed for power systems.

Voltage Stability: Voltage stability is directly related to the maximum load capacity of power system transmission line and it is defined as the ability of keeping load busses in determined limit values [6 and 7]. In electric power systems, load demands of the consumers increase in parallel to the technological developments. Loads, lines and sources create a dynamic structure. In this dynamic structure, load, angle and voltage values which are the critical values of load busses, the connection points of the system need to be determined. A system that does not reach these critical values should be designed and operated. Otherwise, voltage would collapse and this cause economic losses [8]. In this study, the voltage stability calculations are done by Newton Raphson (NR) load flow algorithm.

NR Power Flow: NR is an analysis method used for the solution of multivariable nonlinear equations. In this method, initial values of the variables are selected randomly at starting. Using these random initial values, new values are derived with a certain analysis pattern as expressed in (5). In equations 1-7, V is bus voltage value, δ is bus angle, J is jacobian matrix of the power system, ΔP and ΔQ represent active and reactive power equilibrium of the bus, g and b depict the real and imaginary values of bus admittance matrix, P and Q represent the active and reactive power values, y is admittance value of transmission line, S is complex power value. The sample power system, which the equations are formed from this system, can be seen in Figure 1.

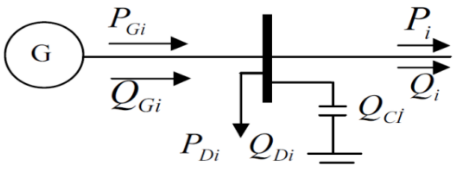

Figure 1. Sketch of a general purpose bus

$$P_i = v_i \sum_{j=1}^{n} v_j (g_{ij} \cos\delta_{ij} + b_{ij} \sin\delta_{ij}) \tag{1}$$

$$Q_i = v_i \sum_{j=1}^{n} v_j (g_{ij} \sin\delta_{ij} - b_{ij} \cos\delta_{ij}) \tag{2}$$

$$P_i - (P_{Gi} - P_{Di}) = \Delta P_i = 0 \tag{3}$$

$$Q_i - (Q_{Ci} - Q_{Di}) = \Delta Q_i = 0 \tag{4}$$

$$\begin{bmatrix} V_i \\ \delta_i \end{bmatrix}^{(n+1)} = \begin{bmatrix} V_i \\ \delta_i \end{bmatrix}^{(n)} - [j]^{(n)-1} x \begin{bmatrix} \Delta P_i \\ \Delta Q_i \end{bmatrix}^{(n)} \tag{5}$$

$$\begin{bmatrix} V_i \\ \delta_i \end{bmatrix}^{(n+1)} - \begin{bmatrix} V_i \\ \delta_i \end{bmatrix}^{(n)} \leq \kappa \tag{6}$$

Iteration is continued until the difference between the last two derived values reach to an acceptable value, (κ), as in (6). Final values obtained from this algorithm depict the solution of the problem.

$$S_{ij} = p_{ij} + q_{ij=} v_i(v_i^* - v_j^*)y_{ij}^* + v_i v_i^* (\frac{y_{ij}}{2})^* \tag{7}$$

Objective of the NR load flow analysis is determination of voltage amplitude values of all load buses, and angle values of all buses except the slack bus. Voltage amplitude and angle values of the buses are determined via substituting Eqs. (1-4) into (5) till (6) is satisfied. After this, the expression $S_{ij}+ S_{ji}$ is calculated using (7). Real part of this summation depicts the active power loss between *i th* and *j th* buses. Imaginary part, on the other hand, depicts the reactive power loss [9]. In the power system, the voltage and angle values at the maximum power flow are expressed as critical values. Continuous load flow analysis is required to establish the relationship between voltage and maximum load parameter (V-P). Continuous load flow analysis is an algorithm that iteratively processes estimation and correction functions. The basic principle behind the continuous charge flow technique is based on the estimation correction step. As shown in Figure 2, the estimation step is performed along the tangential direction at the current operating point. As the correction vector, a plane perpendicular to the tangential direction was used [10]. The algorithm proceeds step by step until the load flow cannot provide a solution [11]. This condition is the one that the algorithm does not provide a solution when the Jacobian matrix is singular.

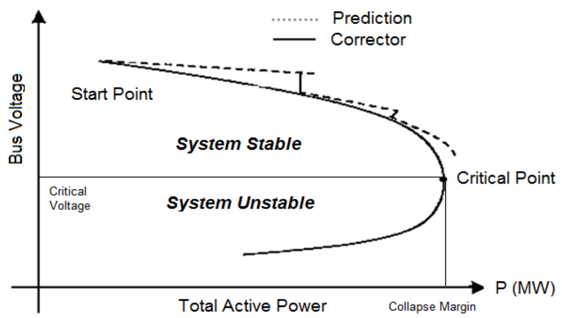

Figure 2. Characteristic P-V curve and prediction and correction lines

Solutions of the multi-buses power systems with algorithms such as Newton Raphson's are very time-consuming to solve. However, these analyses are more simple today due to existing computer technology. Due to the speed, reliability and precision, the computers have become the most used tool in recent years. Both numerical methods and simulation programs developed in computer environment are widely used today [12, 13, 14 and 15].

3. DEFINITION OF THE PROBLEM

In Figure 3, a 6-bus power system is shown, in which the RES is connected and the critical values are to be determined. In this system, the bus 1 is slack bus, the buses 2 and 3 are generator buses, and the buses 4, 5, and 6 are load buses. The power system has been simulated through the Power World Program. The Power World program is designed for power systems and is also used by professional operators. The program can make various analysis such as stability, power flow, transient situation and economic analysis. The program is used free of charge in systems containing up to 13 buses. In the program, load values are obtained between the load flow result, generator, buses, load and lines. Then critical bus values were obtained by continuous load flow. RES, a 10 MW wind energy source, has been connected to the power system from 5th bus first, and then both 5th and 6th buses. After that, critical values that are voltage stability parameter values of the power system have been obtained.

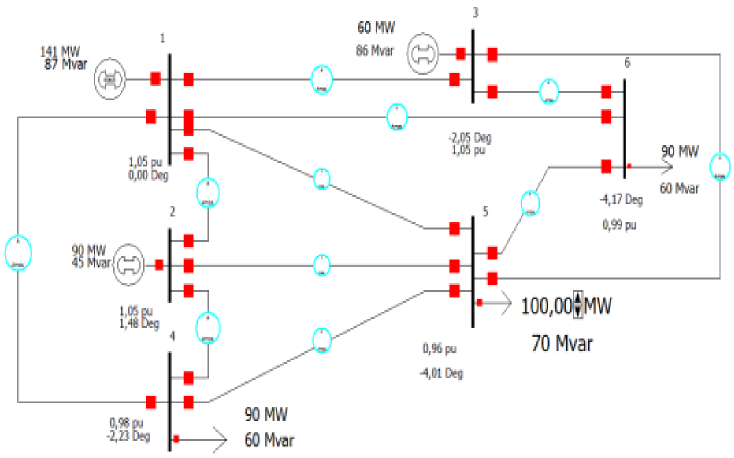

Figure 3. 6-bus test system

4. FINDINGS AND DISCUSSIONS

The transmission line parameters of the 6-bus test system analyzed in Figure 3 are given in Table 1 as pu. In Table 1, *R* is the ohmic resistance of the line, *X* represents the inductive resistance of the line, and *B* depicts the shunt admittance of the line.

Table 1. Line parameters of 6-bus system

Line		Line Impadence		
		R(pu)	X(pu)	B(pu)
1	2	0.1	0.2	0.004
1	3	0.5	0.25	0.006
1	4	0.05	0.1	0.002
1	5	0.1	0.3	0.004
1	6	0.07	0.2	0.005
2	4	0.05	0.2	0.004
2	5	0.08	0.3	0.006
3	5	0.12	0.26	0.005
3	6	0.02	0.1	0.002
4	5	0.2	0.4	0.008
5	6	0.1	0.3	0.06

The active and the reactive power, voltage amplitude and phase angle values obtained in the generator and load buses via load flow in the power system given in Figure 2 are given in Table 2.

Table 2. Load flow resulting values

		Without Wind	Wind in Bus 5	Wind in Buses 5 and 6
Slack Bus	P (MW)	181	130	119
	Q (MVAr)	87	84	82
	V (pu)	1.05	1.05	1.05
	δ (°)	0	0	0
Gen 2	P (MW)	90	90	90
	Q (MVAr)	45	40	39
	V (pu)	1.05	1.05	1.05
	δ (°)	1.48	1.67	1.75
Gen 3	P (MW)	60	60	60
	Q (MVAr)	86	80	71
	V (pu)	1.05	1.05	1.05
	δ (°)	-2.05	-1.78	-1.40
Load 4	P (MW)	90	90	90
	Q (MVAr)	60	60	60
	V (pu)	0.98	0.98	0.98
	δ (°)	-2.23	-2.11	-2.06
Load 5	P (MW)	100	100	100
	Q (MVAr)	70	70	70
	V (pu)	0.96	0.97	0.97
	δ (°)	-4.01	-3.59	-3.38
Load 6	P (MW)	90	90	90
	Q (MVAr)	60	60	60
	V (pu)	0.99	0.99	1
	δ (°)	-4.17	-3.94	-3.45

In Table 2, P is the active power, Q stands for the reactive power, V is the voltage amplitude, and δ represents the phase angle. During normal operation of the power system, voltage amplitude and phase angles were found to be within normal limits. When the wind power plant in the 5th bus is connected, the active power of the generator connected to the slack bus and the reactive power values of the other buses' generators decrease. Some improvements in the voltage amplitude of the 5th load bus have been observed. In addition, all the buses have been seen to improve at the phase angle. When the wind power plant is connected to the 5th and 6th buses, it is observed that the voltage magnitudes of the 5th and 6th buses to improve.

Table 3. Load flow resulting losses

Power Flow		P (MW) Loss			Q (MVAr) Loss		
From	To	Without Wind	Wind in Bus 5	Wind in Buses 5 and 6	Without Wind	Wind in Bus 5	Wind in Buses 5 and 6
1	2	0.15	0.19	0.21	-0.15	-007	-0.03
1	3	0.11	0.08	0.05	-0.12	-0.25	-0.41
1	4	2.55	2.39	2.35	4.89	4.58	4.49
1	5	1.33	1.06	0.99	3.59	2.78	2.55
1	6	1.5	1.36	1.04	3.75	3.37	2.46
2	4	1.07	1.07	1.07	3.88	3.85	3.86
2	5	1.46	1.26	1.2	4.88	4.11	3.89
3	5	1.4	1.12	1.1	2.53	1.91	1.88
3	6	1.06	1.02	0.82	5.11	4.91	3.87
4	5	0.14	0.08	0.07	-0.47	-0.6	-0.63
5	6	0.08	0.04	0.07	-0.34	-0.45	-0.38
Total		10.85	9.67	8.97	27.55	24.14	21.55

The angle values of all buses have improved further. In addition, active and reactive powers drawn from generators have been observed to fall. In Table 3, active and reactive losses that were formed when the wind power plants without RES have been given.

Line-to-line losses and total losses are given in Table 3. According to the values obtained from the Table, the losses are reduced as the wind power plant is connected to the line. Particularly, it has been observed that there is a marked decrease in the losses in the lines connected to bus that is connected to RES. The reason for this is that less power is drawn from the generator buses and therefore the power flowing from the lines is decreasing. This is also directly related to losses. When the total loss from the table is considered, the reduction in active losses is 17.3%, while the decrease in reactive losses is 21.7%. The reason for this is that the impedance of the lines is reactive. The power flowing between the buses as a result of the load flow are given in Table 4 as a comparative example.

Table 4. Power values that load flow between the buses

Power Flow		MW Loss			MVAr Loss		
From	To	Without Wind	Wind in Bus 5	Wind in Buses 5 and 6	Without Wind	Wind in Bus 5	Wind in Buses 5 and 6
1	2	-11.3	-12.7	-13.4	5.6	6.4	6.7
1	3	15.2	13.2	10.4	-3.1	-2.8	-2.3
1	4	61.5	59.1	58.2	42.7	42.1	42.1
1	5	31	27.9	26.6	22.4	19.6	19.3
1	6	44.5	42.3	37.2	19.2	18.7	16
2	4	40.2	40.6	40.8	27.2	26.3	26.1
2	5	38.3	36.5	35.6	23.1	19.9	19.4
3	5	25.1	228	23.5	25.4	22.3	21.3
3	6	50	50.3	47	57.9	55.6	47.8
4	5	8.1	6.3	5.6	1.2	-0.1	-0.1
5	6	-1.8	-0.1	-2.1	-8.5	-6.5	-7.9

As shown in Table 4, if the RESes are connected, the powers flowing between the buses are reduced; especially at the bus the RES is connected. Even in some buses, the direction of the flowing power has changed, as is the line between the buses 4 and 5. As a result, they have improved in buses voltages and there have been decreases in losses. Table 5 shows the critical values obtained when continuous load flow is performed with respect to the 5th bus, while the loads of the 4th and 6th buses are fixed so as to determine the critical values of the 5th load bus in the power system.

Table 5. Critical values resulting from continuous load flow

Bus		Without Wind	Wind in Bus 5	Wind in Buses 5 and 6
5	P (MW)	338.89	350.96	352.48
	V (pu)	0.55	0.54	0.54
	δ (°)	-24.05	-24.71	-24.42

It is observed that the critical values of the power system are improved by adding RESes to the power system according to the values in Table 5. Active power is increased at the bus that RES is connected, and some improvements have been observed at voltage collapse value at that bus. The P-V curves showing this state are given in Figure 4.

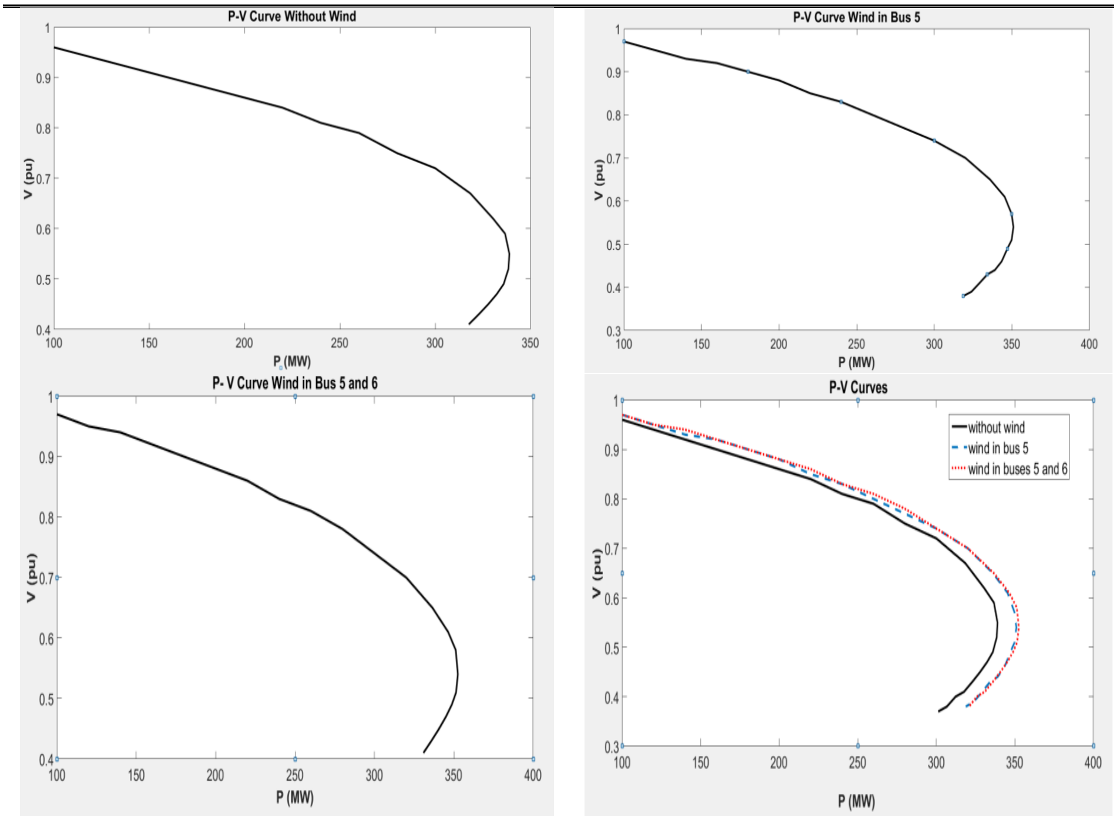

Figure 4. P-V Curves (5. bus)

As shown in Figure 4, when a wind power plant was added to the 5th bus, the power that can be transferred from this bus is increased from 338.9MW to 350.9MW. However, when the second wind power plant is added to the 6th bus, 5th bus is not affected much. In this case the maximum power that can be drawn from the 5th bus increases from 350.9MW to 352.48MW. The critical voltage value drops from 0.55pu to 0.54pu when the RES is in the 5th bus. When the 6th bus RES is added, the critical voltage value of the 5th bus is still fixed at 0.54pu.

5. CONCLUSION AND RECOMMENDATIONS

Today, RES is connected to power systems at every voltage level. Depending on the power of the source, it sometimes occurs at the distribution level and sometimes at the transmission level. These sources provide advantages to the power system and also provide some disadvantages. Analyses such as power flow and voltage stability are important for the operation and planning of power systems. In this study, the wind power plant is connected to the load buses in the 6-bus power system. As a result, the voltage stability values and the states of the losses were investigated in load buses. As a result of the study, critical values, which are indicative of the voltage stability values, are improved. In particular, the critical value of the bus which the RES is attached is increased by 3.4% in terms of power to be withdrawn. In terms of critical voltage, 1.8% improvement was achieved. When examined in terms of losses, the decrease in active losses was 17.3%, while the decrease in reactive losses was 21.7%.

NOTICE

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