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Evaluation of Penetration Level of Large-Scale Photovoltaic System on Voltage Stability of Power System

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Abstract

A power system is a nonlinear one. When turbulence occurs in the power system, the stability of the system depends on the initial operating conditions and the nature of the turbulence. Nowadays renewable energy sources including photovoltaic have a key role to meet high demand of modern societies and to maintain voltage of the buses, while they also provide clean electrical energy. However, increasing the penetration level of photovoltaic systems will affect the power grid behavior. Hence, it is necessary to analyze the impact of their penetration level on the voltage stability, reliability and design of the grid, as well as the economic aspects. Investigating the voltage stability of the buses is significant in order to determine whether the amount of photovoltaic systems penetrations are enough to maintain the voltage of the bus and also to find the perfect and most beneficial location for these system in the power grid, which is discussed in this paper. In addition, a standard 30-bus test system stimulated by ETAP software, in order to evaluate the impact of Photovoltaic system penetration level on improving voltage stability.

Keywords: Voltage stability; Penetration level; Large-scale photovoltaic systems

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1. Introduction

Nowadays, a significant portion of required energy in developed countries is provided by renewable energy sources. The most important factors in the reduction of fossil fuel usage demands are non-renewability, limited resources, environmental pollution and global warming, as they produce greenhouse gases. Among renewable energy sources such as solar, geothermal and wind energy, the photovoltaic cell is an exclusive due to its direct conversion of solar energy to the electricity [1], [2], [3].

Photovoltaic systems are one of the most famous sources of renewable energies that are installed with different technologies and various capacities in the world. The installation of photovoltaic systems is increasing, since recent technological developments offer higher reliability and performance [5]. Due to improving the efficiency of photovoltaic systems and reducing the investment costs, they are becoming valuable renewable energy source to be expanded in large scale, in order to meet the high demand of modern societies.

By increasing the penetration of photovoltaic systems as power plants, we expect changes in the dynamics and performance characteristics of the power system. The penetration level and location of these power plants effect of the transient stability of the power system, or they may even change the bus frequency [4]. The focus of most studies is on the location of the photovoltaic systems connected to the distribution network and the behavior of the distribution network considering the influence of these systems. In the sphere of the penetration level of photovoltaic systems, several research works have been conducted. In [6] a study about the transient voltage stability on various buses is presented and the impact of photovoltaic system penetration level on the transient voltage stability of the power grid is examined in [7] with considering three scenarios. First, the penetration level or the transient voltage stability; second, the location of photovoltaic system; and third, analyzing the transient voltage stability at the moment of short circuit only for one of the buses. In [8] the small-signal stability of the test system and shows that the damping ratio of three critical modes in the system increases with the improvement of the PV penetration level is investigated. The increase in penetration level of PV plant causes improvement of damping ratio in the system and regulates voltage and frequency. [9] Studies the transient stability of the power system with different levels of PV penetration. Since the PV system has zero inertia, to maintain the balance of the power system, photovoltaic systems are used. Simulation results indicate that PV penetration level (up to the 30%) improves the power system transient stability [10].

This paper presents a case study that analyses the transient stability in power system with high levels of photovoltaic (PV) penetration. The simulation results show that LVRT capability would not help and the transient stability is better for the cases of PV without it. Solar panel modeling is described in Section II In section III, IEEE 30-bus network is introduced as the case study. The simulation results and discussion are illustrated in section IV. Finally, Section V concludes the paper.

2. Solar Panel Modeling

A solar panel consists of several photovoltaic cells that a series, parallel or combined type connections. The practical characteristic of a single photovoltaic cell is deduced as follows, according to the equivalent model shown in Fig. 1.

$$I = I_{\mathrm{pv}} - I_o\left[\mathrm{e}^{\left(\frac{V+R_s.I}{\alpha.k.T}\right)} - 1\right] - \frac{V + R_s.I}{R_p} \qquad (1)$$

where, I is terminal generated current, Ipv is light generated current, I0 is saturation current in dark (no light) situation, V is the terminal voltage, a diode ideality factor, k is Boltzmann's constant (1.38×10-23 J/k) and T is the temperature of the p-n junction. Rs and Rp also represent the equivalent series and parallel resistances, respectively.

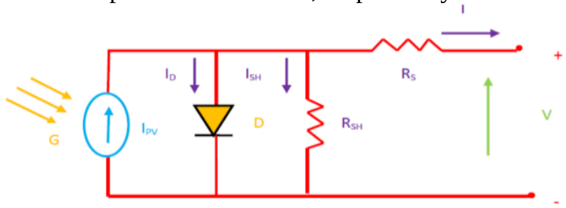

Fig. 1. Practical equivalent model of a photovoltaic cell with single diode

The output power in photovoltaic cells depends on the light intensity received on the solar panel surface and the temperature of the panel. Therefore, in order to maximize the efficiency of the renewable energy system, it is necessary to optimize these two parameters. Because, higher intensity of solar light on the panel, lead to temperature enhancement of the of the panel surface.

3. IEEE 30-Bus Network With Large-Scale PV

In this paper, IEEE 30-bus system is considered as a standard case study, integrating a large-scale photovoltaic power plant. The configuration of this grid is shown in Fig. 2, which is consists of 30 buses, six synchronous generating units, four transformers and 24 load points. The first generator is in the swing mode at slack bus and other generators are in voltage control mode. Generators G1 and G2 are rated at 135 kV, and have a four-pole engine with a speed of 1800 rpm. The generator parameters of the IEEE 30-bus system are shown in Table 1 which can be used for simulation with ETAP All loads used in the test system are three phased and voltage is rated at 135 kV. The system's total real power is 283.4 MW, and the total reactive power is 126.2 MVar.

The total real power losses are 17.563 MW and total reactive power is 33.045 MVar. The penetration of large-scale photovoltaic power plant is set at 154 MW. The standard Newton-Raphson method was used for solving the power flow analysis, by increasing the number of iterations from two to eight. In addition, the parameters and values of the photovoltaic system are shown in Table 2.

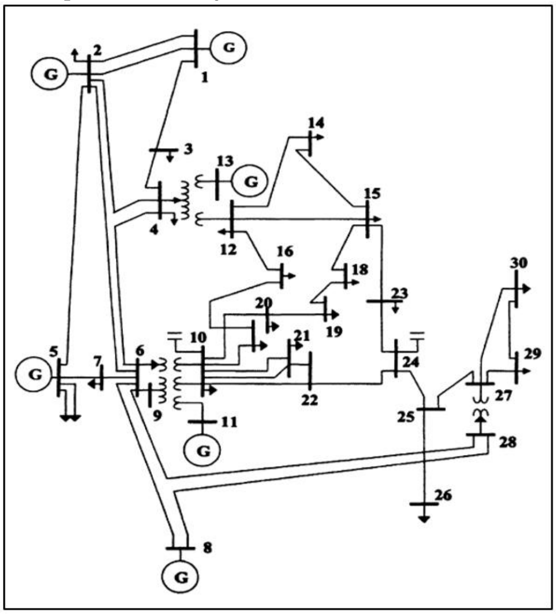

Fig. 2. Single-line diagram of IEEE 30-bus network with a large-scale PV

4. Simulation Results and Discussion

In order to provide a comprehensive operational model of a power grid, ETAP is adopted as a power system analysis software platform. It's performed as a simulation study based on the observed voltage and voltage angle of the buses to analyze the impact of the large-scale photovoltaic system on the voltage stability of the power system. In this study, due to minimizing the table sizes only the results of the weakest buses (26, 29 and 30) are illustrated to investigate the impact of photovoltaic penetration level.

Table.1.
Generator parameters of IEEE 30-bus system [6]

		MODEL		Subtransient
Generator 1	imp/ Model	Rating	MVA	260.2
			KV	132
		Positive sequence impedence(%)	Xd''	19
			Xd'	28
			Xd	155
			Xq''	19
			Xq'	65
			Xq	155
		Zero seq.Z(%)	R0	0.668361
			X0	7
	Mechanical parameters	Gen.	WR2	1044964
			RPM	1800
			H	3
		Coupling	WR2	1044964
			RPM	1800
			H	3
		Prime Mover/Load	WR2	1044964
			RPM	1800
			H	3
Generator 2	imp/ Model	Rating	MVA	40
			KV	132
		Positive sequence impedence(%)	Xd''	19
			Xd'	28
			Xd	155
			Xq''	19
			Xq'	65
			Xq	155
		Zero seq.Z(%)	R0	2.721172
			X0	7
	Mechanical parameters	Gen.	WR2	256659
			RPM	1800
			H	3
		Coupling	WR2	256659
			RPM	1800
			H	3
		Prime Mover/Load	WR2	256659
			RPM	1800
			H	3

Table.2.
Parameters of PV array

PV Array	Output	300
	No. of modules	1400
	No. of series modules in one array	100
	No. of arrays in parallel	14
	Maximum power rating of one module	300 W
	Rated Current of module	7.9 A
	Rated Voltage of module	30 V
	Short Circuit Current of module	8.33
	Open Circuit Voltage of module	32.97 V
Inverter	Number of unit	1
	Rated Capacity	300 KW
	Input DC Voltage	120 V
	Output Voltage	230 V
	Frequency	50 HZ

A) The 30-bus System Without any Photovoltaic

In this case, the voltage magnitude and angle of the weakest buses are investigated without any photovoltaic unit. The load flow result of a 30-buses system is shown in Table 3. The initial results show that the voltage magnitude of bus 30 has dropped more than the permitted range ($\Delta V > 5\%$). This is because of the weakness of the bus 30 in comparison with the other buses. In the next case, the photovoltaic system is connected to the 30-bus system, with various levels of penetration and the results are investigated for the impact on voltage stability.

B) The 30-bus system with various levels of large-scale photovoltaic systems

In this case, a photovoltaic system with a maximum capacity of 154 MW is considered. Its penetration level is divided into various steps (10%, 30%, 60% and 100%), in order to investigate its impact on voltage stability. Then we examine the voltage magnitude and the voltage angle of the desired buses. Note that, the photovoltaic system and a 40 MW synchronous generator are located at bus 2. The results for different penetration levels of photovoltaic system are illustrated in the Tables 4.
According to the simulation results, it is found that increasing the penetration level of the photovoltaic system improves the bus's voltage magnitude and decreases the voltage angle compare to the reference bus; thus, the voltage profile and the voltage stability are improved due to lower voltage drop and higher stability margin, respectively. It should be noticed that, in order to allocate a photovoltaic system at a weak bus such as 26, the transfer capacity of the transmission lines should be considered as well, thus allocating is not considered in this paper. Moreover, the voltages of other buses (26, 29 and 30) are increased and moved into the permitted range. Higher penetration level of photovoltaic system also increases the voltage magnitude and decreases the voltage angle of other buses, thus the voltage stability improves.

Table.3.
Load flow results of IEEE 30-bus without a large-scale photovoltaic system

Bus number	*Magnitude of voltage bus (PU)*	*Angle of voltage bus (degree)*
26	0.9613	-16.56
29	0.9590	-16.86
30	0.9471	-17.8

Table.4.
Load flow results with penetration of 10%

Bus number	*Magnitude of voltage bus (PU)*	*Angle of voltage bus (degree)*
26	0.9713	-15.96
29	0.9688	-16.25
30	0.9570	-17.18

Table.5.
Load flow results with penetration of 30%

Bus number	*Magnitude of voltage bus (PU)*	*Angle of voltage bus (degree)*
26	0.9748	-15.52
29	0.9623	-15.79
30	0.9605	-16.72

Table.6.
Load flow results with penetration of 60%

Bus number	*Magnitude of voltage bus (PU)*	*Angle of voltage bus (degree)*
26	0.9826	-14.39
29	0.9800	-14.66
30	0.9683	-15.56

Table.7.
Load flow results with penetration of 100%

Bus number	***Magnitude of voltage bus (PU)***	***Angle of voltage bus (degree)***
26	0.9404	-13
29	0.9900	-13.25
30	0.9790	-14.15

5. Conclusion

In this paper, IEEE 30-bus grid has been considered as a standard system test. The results are achieved in ETAP software. As the penetration level of photovoltaic system increased the voltage magnitude of the buses improved, voltage angle decreased so and therefore, the stability margin of the power system increased. Hence, the simulation results indicate that the penetration of photovoltaic systems helps the grid improve voltage stability of the power system and increase its reliability. However, excessive penetration of photovoltaic systems will also increase the voltage which can be undesirable for a power system and cannot be justified financially.

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