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Research Article

Role of Distributed Generation in Voltage Stability Enhancement

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Abstract

Distributed generation (DG) is estimated to become more important in the future generation system. This paper discusses the incorporate of DG units into distribution systems can have an impact on voltage stability. In general, DG can be defined as electric power generation within distribution networks or on the customer side of the network. In addition, the terms distributed resources; distributed capacity and distributed utility are discussed. This has been carried out on IEEE-6, IEEE-9 bus test system and PSAT software results are presented.

Keywords: *Distributed Generation(DG); Voltage Stability.*

1. Introduction

The electrical power system was usually designed and operated to transport large amounts of active and reactive power one way from the generation through transmission and distribution networks to the electric energy consumes. The distribution systems were normally passive and designed to operate with unidirectional energy flow. When planning and operating, the distribution system was assumed that electric power always flew from the secondary winding of the transformers in substations to the end of feeders.[1,2]With newly introduced distributed generation (DG), the distribution system becomes an active system with both energy generation and consumption. Bidirectional power flows should now be incorporated the hierarchical network design and its operation criteria. Distributed generation is a concept of installing and operating small electric generators connected directly to the distribution network or at the customer site of the meter, typically less than 15 MW, but sometimes up to 100 MW. DG technologies include photovoltaics, wind turbines, fuel cells, small and micro sized turbines; Stirling-engine based driver generators, and internal combustion engine-generators[3,6]. These technologies are entering an era of rapid expansion andCommercialization. The premise of distributed generation is to provide electricity to a customer at a reduced cost and more efficiently with reduced losses than the traditional utility central generating plant with transmission and distribution wires. Additionally, local resources including renewable energies can be used. On the other hand, the distributed generation has significant impact on the power flow, voltage profile and power quality for customers and electricity suppliers. This impact may manifest itself either positively or negatively, depending on the distribution system operating and Distributed generator characteristics[4].This paper aims at investigating the impacts of DG on the voltage stability of a distribution system. The modeling, distributed generators and load characteristics are also discussed. The distribution system and distributed generators are modelled using the PSAT. Different distributed generation technologies are taken into consideration voltage stability with different distributed generators and different load characteristics are analyzed.

2. Distributed generation

Distributed Generation seems to be an electric power generation source that is connected directly to the distribution network or on the customer side of the meter. Distributed Generation is also called as On-site Generation or**Dispersed Generation** OR **Embedded Generation**or **Decentralized Generation**.

Types of Distributed generation

Wind turbines

Wind energy is the most widely used DG source in the world. A wind turbine is a rotating machine that converts the kinetic energy of wind into mechanical energy, and then into electrical energy, using ac generators such as induction and synchronous types. These generators are attached to the wind turbine. The wind turbine consists of turbine blades, a rotor, a shaft, a coupling device, a gear box and a nacelle. A cluster of wind turbines installed in a specific location is called a wind farm.farm should be installed in a windy place, because its electric capacity is limited by the amount of wind. The overall efficiency of

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the wind turbine is between 20-40%, and its power rating varies between 0.3 to 7 MW.

Photovoltaic

Solar cells represent the basic component of a photovoltaic system, and are made from semiconductor materials such as monocrystalline and polycrystalline silicon. Solar cells have much in common with other solid-state electronics devices such as diodes, transistors, and integrated circuits Solar cells are assembled to form a panel or module. Solar cells are assembled to form a panel or module. A typical PV module is made up of about 36 or 72 cells. The modules are then connected in series/parallel configurations to form a solar array that is used to generate electrical energy from the sunlight. The photovoltaic rating can be found in small solar cells of 0.3 kW and all the way up to multi-megawatt in large system. Photovoltaic DG units are interfaced to the power system by using power electronic converters with Maximum Power Point Tracking (MPPT).

Fuel cells

A fuel cell is one of the existing DG technologies. It is an electrochemical device that can be used to convert chemical energy to electrical and thermal energy, without combustion. A fuel cell is considered similar to a battery: it is made of two electrodes with an ion-conductive electrolyte sandwiched between them. However, it is unlike a battery in that it does not need to be charged for the consumed materials during the electrochemical process since these materials are continuously supplied to the cell. Fuel cells are considered as a dispatchable DG source because they are fueled by a variety of hydrogen-rich fuel sources such as natural gas, gasoline, or propane. Since the output voltage of fuel cells is low dc voltage, these cells require a power electronic interface (dc-dc 'boost converter', then dc-ac inverter) in order to condition their output.

Voltage stability

Voltage stability refers to the ability of a power system to maintain steady and acceptable voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition.The main factor causing voltage instability is inability to meet the reactive power demand. Voltage stability can be classified as small or large based on the disturbance type. Small voltage stability refers to the ability of the system to control the voltage when small perturbations occur, such as changes in the loads. Large voltage stability refers to the ability of the system to control the voltage after being subjected to large disturbances such as load outages, faults, and large-step changes in the loads.Voltage stability can be evaluated by two different methods of analysis: static and dynamic[13]

Static analysis

This method examines the viability of the equilibrium point represented by a specified operating condition of the power system. This method allows the examination of a wide range of system conditions. The electric utility industry depends on P-V and Q-V curves in order to determine stability at selected buses. The static method is evaluated by means of a variety of techniques

P-V Curve

The P-V curves, active power-voltage curve, are the most widely used method of predicting voltage security. They are used to determine the mw distance from the operating point to the critical voltage. A typical p-v curve is shown in Figure 1. Consider a single, constant power load connected through a transmission line to an infinite-bus. Let us consider the solutions to the power flow equations, where p, the real power of the load, is taken as parameter that is slowly varied, and v is the voltage of the load bus. It is obvious that three regions can be related to the parameter p. in the first region, the power flow has two distinct solutions for each choice of p one is the desired stable voltage and the other is the unstable voltage. As p is increased, the system enters the second region, where the tow solutions intersect to form one solution for p, which is the maximum. If p is further increased, the power flow equations fail to have a solution. This process can be viewed as a bifurcation of the power flow problem; in a large-scale power system the conventional parametric studies are computationally prohibitive. The method of maximum power transfer determines critical limits on the load bus voltages, above which the system maintains steady-state operation.

The most famous P-V curve shown in Figure 2.each value of the transmissible power corresponds a value of the voltage at the bus until V=Vcrit after which further increase in power results in deterioration of bus voltage. The top portion of the curve is acceptable operation whereas the bottom half is considered to be the worsening operation. The risk of voltage collapse is much lower if the bus voltage is further away, by an upper value, from the critical voltage corresponding to pmax.

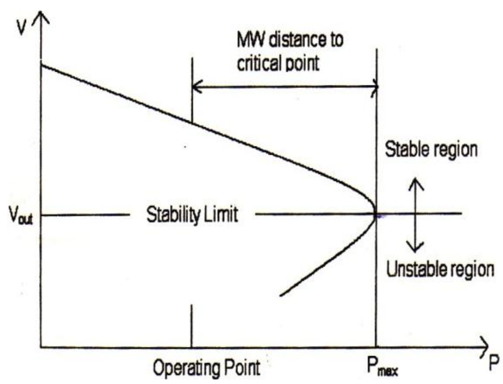

Fig.1 Typical P-V curve

V Curve

Q-V curve technique is a general method of evaluating voltage stability. It mainly presents the sensitivity and variation of bus voltages with respect to the reactive power injection Q-V curves can be used by many utilities for determining proximity to voltage collapse so that operators can make a good decision to avoid loosing system stability. In other words, by using Q-V curves, it is possible for the operators and the planners to know, the maximum voltage limit or voltage limit or voltage instability. Furthermore, the calculated MVAR margins could relate to the size on shunt capacitor or static VAR compensation in the load area.

V-Q or voltage- reactive power curves are generated by series of power flow simulation. They plot the voltage at a test bus or critical bus versus reactive power at the same bus. Most of the time these curves are termed Q-V curves rather than V-Q curves. Scheduling reactive load rather than voltage produces Q-Curves. These curves are a more general method of assessing voltage stability. They are used by utilities as a workhorse for voltage stability analysis to determine the proximity to voltage collapse and to establish system design criteria based on Q and V margins determined from the curves. Operators may use the curves to check whether the voltage stability of the system can be maintained or not and take suitable control actions. The sensitivity and variation of bus voltages with respect to the reactive power injection can be observed clearly. The main drawback with Q-V curves is that is generally not know previously at which buses the curves should be generated.

As a traditional solution is system planning and operation, the voltage level is used as index of system voltage instability. If it exceeds the limit, reactive support is installed to improve voltage profiles. With such action, voltage level can be maintained within acceptable limits under a wide range of MW loadings. In reality voltage level may never decline below that limit as the system approaches its steady state stability limits. Consequently, voltage levels should not be used as a voltage collapse warning index. Figure 3 shows a typical Q-V curve.

The Q axis shows the reactive power that needs to be added or removed from the bus to maintain a given voltage at a given load. The reactive power margin is the MVAR distance from the operating point to the bottom of the curve., the curve can be used as an index for voltage instability (PQ/PV goes negative). Near the nose of a Q-V curve, sensitivities get very large and then reverse sing. Also, it can be seen that the curve shown two possible values of voltage for the same value of power.

The power system operated at lower voltage value would require very high current to produce the power. That is why the bottom portion of the curve is classified as an unstable region the system cannot be operated in steady state in this region. The steady state voltage problem analysis will be focused on the practical range of an operating system the top portion of the curve. Hence, the top portion of the curve represents the stability region while the bottom portion from the stability limit indicates the unstable operating region.

It is preferred to keep the operator will attempt to correct the low voltage condition by increasing the terminal voltage. However, if the system is operating on the lower. Portion of the curve, the unstable region, increasing the terminal voltage will cause an even further drop in the load voltage.

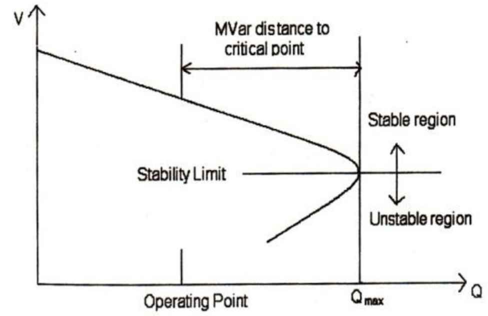

Fig.2 Typical Q-V curve

Dynamic voltage stability analysis

The mathematical model for the dynamic voltage stability study of a power system comprises a set of first order differential equations and a set of algebraic equations:

$$x = f(x,y) \quad (1)$$
$$0 = g(x,y) \quad (2)$$

Wherex- is the state vector of the system, y- vector containing bus voltages

Equations (1) and (2) are usually solved in the time domain by means of the numerical integration and power flow analysis methods .

The steady state equilibrium values (x0 y0) of the dynamicsystem can be evaluated by setting the derivative in Equation (1) to zero. Through linearization about (x0 y0), Equations (1) and (2) are expressed as follows:

$$\frac{d\Delta x}{dt} = A\Delta x + B\Delta y \quad (3)$$
$$0 = C\Delta x + D\Delta y \quad (4)$$

Further, by eliminating Δy, the linearized state equation can be written as :

$$\frac{d\Delta X}{dt} = (A - BD^{-1}C)\Delta X = A\Delta X \quad (5)$$

The static bifurcation will occur when det (D) = 0.For the dynamic bifurcation phenomenon, it is always assumed that det (D) ≠ 0 and that D-1 exists .By analyzing the eigenvalues of A , dynamic voltage stability analysis can be performed.

3. *IEEE*-6 Bus Test System

Table1 Power Flow Results-without DG

Bus	V [p.u.]	phase[rad]	Pgen [p.u]	Q gen [p.u]	Pload[p.u]	Q load[p.u]
Bus1	1.05	0.08871	2.9662	3.2364	0	0
Bus2	1.05	0	5.3812	5.9814	0	0
Bus3	1.05	-0.05074	2.6662	3.3982	0	0
Bus4	0.5252	-0.25974	0	0	3.483	2.6217
Bus5	0.72985	-0.20372	0	0	2.033	1.4232

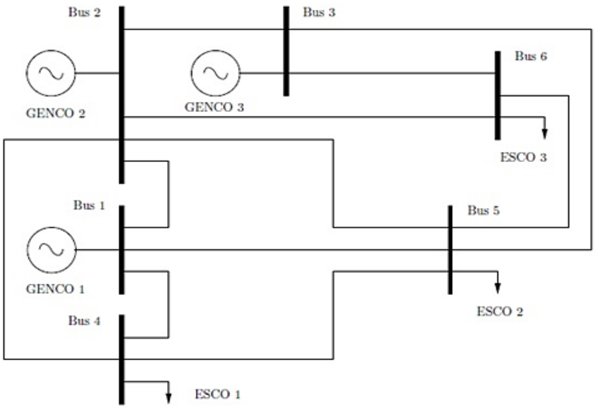

Fig. 3 *IEEE*-6Bus Test System

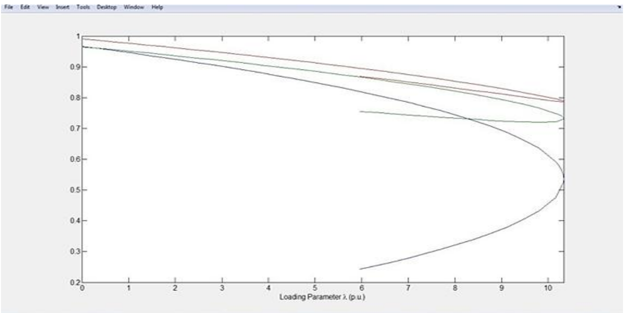

Fig. 4 PV Curve without DG

Table 2 Power Flow Results with DG

Bus	V [p.u.]	phase[rad]	Pgen [p.u]	Q gen[p.u]	Pload[p.u]	Q load[p.u]
Bus1	1.05	0.10513	1.1786	0.4592	0	0
Bus2	1.05	0	-0.045	1.9585	0	0
Bus3	1.05	-0.0151	0.8785	0.9608	0	0
Bus4	0.95	0.09773	17786	-0.8762	1.248	0.8321
Bus5	0.94461	-0.03951	0	0	1.139	0.7975
Bus6	0.97115	-0.07032	0	0	1.179	0.7857

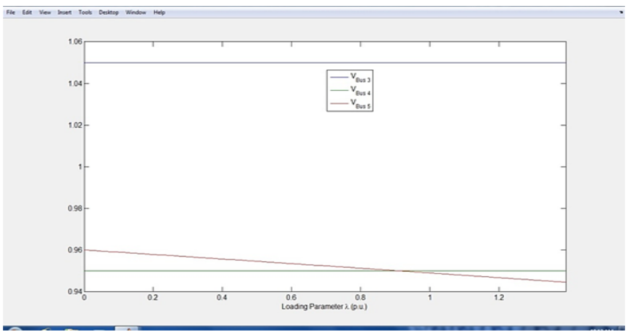

Fig. 5 PV Curve with DG

CPF analysis is applied for the *IEEE* -6 Bus test system in PSAT environment. The magnitude of voltage(p.u), phase angles(p.u), real power(p.u),and reactive power(p.u) at each buses are tabulated in table 1.the voltage profiles of the load buses i.e., bus-4 ,5and 6 are plotted w.r.t loading parameter (λ) are shown in the figure 4.from the table 1, the voltage profiles at bus-4 is below the acceptable limit so the bus 4 is considered as weak bus. In order to improve the voltage profiles, Distributed generation (DG) systems are placed at weak bus 4. CPF analysis is again applied for the same system then the voltage profiles are improved as mentioned in table 2. The improved voltage profiles of the load buses i.e., bus-4 ,5and 6 are plotted w.r.t loading parameter (λ) are shown in the figure 5.

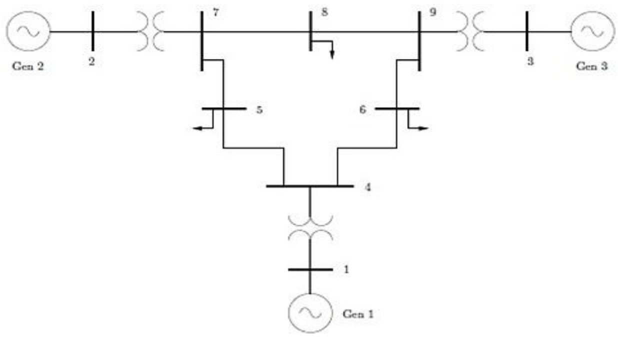

Fig. 5 *IEEE*-9 Bus Test System

Table 3 Power Flow Results withoutDG

Bus	V [p.u.]	phase[rad]	Pgen [p.u]	Q gen[p.u]	Pload[p.u]	Q load[p.u]
Bus1	1.0389	0	1.3031	2.119	0	0
Bus2	0.85802	0.49662	2.9648	0.8364	0	0
Bus3	0.96042	0.22499	1.5461	0.8904	0	0
Bus4	0.9242	-0.07825	0	0	0	0
Bus5	0.78969	-0.15218	-2.2058	-0.8823	2.206	0.8823
Bus6	0.86217	-0.12509	-1.5882	-0.5294	1.588	0.5294
Bus7	0.82583	0.23204	0	0	0	0
Bus8	0.81938	0.08137	-1.7647	-0.6176	1.765	0.6176
Bus9	0.91099	0.12125	0	0	0	0

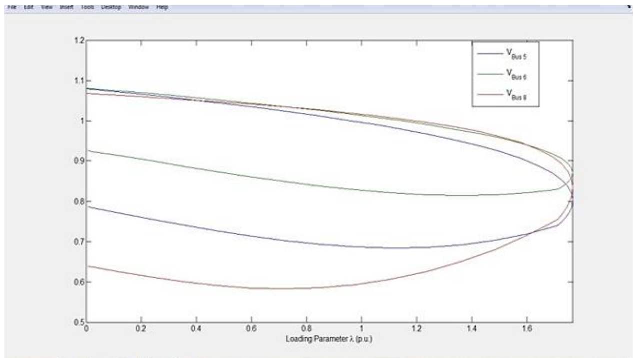

Fig. 6 PV Curve without DG

CPF analysis is applied for the *IEEE* -9 Bus test system in PSAT environment. The magnitude of voltage(p.u), phase angles(p.u), real power(p.u),and reactive power(p.u) at each buses are tabulated in table 1.the voltage profiles of the load buses i.e., bus-5 ,6and 8 are plotted w.r.t loading parameter (λ) are shown in the figure 6.from the table 3, the voltage profiles at bus-5 is below the acceptable limit so the bus 4 is considered as weak bus. In order to improve the voltage profiles, Distributed generation (DG) systems are placed at weak bus 4. CPF analysis is again applied for the same system then the voltage profiles are improved as mentioned in table 4. The improved voltage profiles of the load buses i.e., bus-5 ,6and 8 are plotted w.r.t loading parameter (λ) are shown in the figure 7.

Table 4 Power Flow Results with DG

Bus	V [p.u.]	phase[rad]	Pgen [p.u]	Q gen[p.u]	Pload[p.u]	Q load[p.u]
Bus1	1.0396	0	-1.5001	1.4076	0	0
Bus2	0.85514	0.83654	3.1871	0.3644	0	0
Bus3	0.96141	0.5057	1.662	0.7684	0	0
Bus4	0.96515	0.08622	0	0	0	0
Bus5	0.95	0.25557	2.7715	1.5094	2.31	0.9238
Bus6	0.884	0.07473	0	0	1.663	0.5542
Bus7	0.86063	0.56246	0	0	0	0
Bus8	0.84102	0.38887	0	0	1.848	0.6466
Bus9	0.92017	0.39538	0	0	0	0

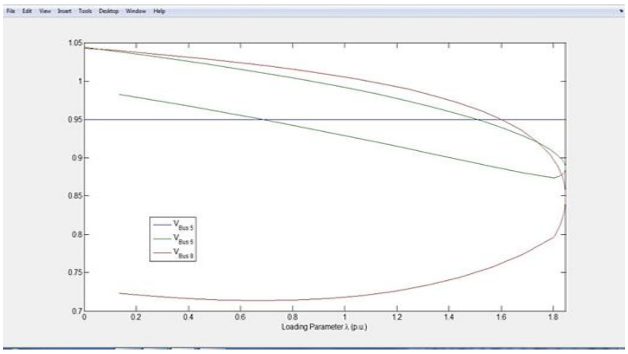

Fig. 7 PV Curve with DG

Conclusions

This paper discusses the incorporate of DG units into distribution systems can have an impact on voltage stability. PSAT tool is used to analyze *IEEE*-6,*IEEE*-9 bus test system for CPF analysis in order to identify the weak bus. Distributed generation (DG) systems are placed at weak bus to improve the voltage stability margins

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