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IMPACT OF DISTRIBUTED GENERATION (DG) ON THE DISTRIBUTION SYSTEM NETWORK

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Abstract: Power system quality is a vital issue for electricity companies and consumers of low and medium voltage. In order to reduce the dependency on producing electric energy from fossil fuel, so the distributed renewable energy technologies are becoming increasingly important in the energy supply systems of many countries. Distributed Generator (DG) units can be defined as small units that generate electric power near to the location of customers based on the renewable energy techniques, including wind energy, solar energy, and geothermal energy. Interconnecting DG to an existing distribution system provides various benefits to several entities as for example the owner, utility and the final user. DG provides an enhanced power quality, higher reliability of the distribution system and can peak shaves and fill valleys. However, the integration of DG into existing networks has associated several technical, economic and regulatory questions. This paper investigates the impact of DGs on the power system for enhancing the power system quality by improve the voltage profile and power losses reduction. This paper uses the power system IEEE-12 busses for an example to illustrate the voltage control and decreases the active and reactive power losses by adding the wind generation DGs with the distribution network.
Keywords: Distribution generator, High voltage, Distribution network, Renewable energy and Power quality

1. INTRODUCTION

Distributed Generation (DG) is a generation of electrical energy through alternate energy-producing resources close to load sites. It is connected to utility grid system at the Point of Common Coupling (PCC) to reduce the expansion of present electric transmission system. Power Systems are experiencing huge growth in the field of DG because of economic benefits, environmental concerns, reliability requirement etc. Today there is rapid growth of use of DG at distribution level in restructured power system. This is due to the obvious advantages like increase in reliability of supply, voltage profile improved and reduction in transmission loss. Using of renewable sources of energy has reached greater importance as it promotes sustainable living and with some exceptions (biomass combustion) does not contaminant. Renewable sources can be used in either small-scale applications away from the large sized generation plants or in large-scale applications in locations where the resource is abundant and large conversion systems are used [2]. The power quality issues have been significantly paid attention by researchers and practitioners in recent years. At present, due to the more sensitive electrical devices, side effects of modern equipment's, increasing demand to high quality electricity, producer's tendency to customers' satisfactions, ability of consumers to assess power quality etc. increasing the quality of delivered power has been important for electric companies. Power quality includes different branches such as long and short interruptions, reliability, voltage sag and voltage swell [3]-[4].

Integration and exploitation of Distributed Generation (DG) systems, such as uncontrollable renewable sources, which can maximize green energy penetration in the utility network, increases the concern of voltage and frequency stability. In addition, voltage distortions and fluctuations are also frequently encountered in weak utility network systems. Ripple currents due to the power electronics converters also cause voltage harmonics and, as a result, the utility voltage waveforms may become distorted. Appearance of distributed generation together with its advantages in both transmission and distribution systems has made it is considered to be as ongoing issues in the power system operation and expansion planning. One of these aspects which should be taken into account is considered DGs' impacts issues. In this respect, the impacts of distributed generation on distribution networks reliability are one of the most important issues which should be investigated by network planners as well as researchers [5]. Therefore, distribution network planners need to incorporate DGs' impact into their system planning tasks.

Several researches have been performed in the area of reliability assessment in distribution networks which are equipped with DGs. In the previous works, placement of distributed resources has been studied; in which improvement of voltage profile, reducing the power loss and increasing the system reliability have been mainly considered [6]. In other works, reliability evaluation has been conducted when distribution networks are considered as a market place [5]-[6]. As it is possible to install DGs in various parts of a feeder, it is required to gain analytical approach for evaluating the reliability of a feeder contains DG in several part of the feeder. Renewable energy source (RES) integrated at distribution level is termed as DG. The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues [7]. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ [6],[25-26].

Distributed Generation (DG) is one of the new trends in power systems used to support the increased energy-demand [6]-[8]. There is not a common accepted definition of DG as the concept involves many technologies and applications. Different countries use different notations like "embedded generation", "dispersed generation" or "decentralized generation". DGs is considered as an electrical source connected to the power system, in a point very close to/or at consumer´s site, which is small enough compared with the centralized power plants. The dispersed generation that has been introduced in the radial and mesh system is designed without any electricity production in the distribution system or at local loads. This introduction can play a significant role in improving power flow and voltage profile of the entire system [9]. The implication of this type of generation may be manifested as having negative or positive effects, depending on the distributed generation characteristics and the operating characteristics of the distribution system [10].

Therefore, this paper will summarize the impacts of integrating distributed generation into distribution network including voltage stability and power losses. Based on the literature review discussed above, it has been observed that the different issues in the field of distributed generation are covered which are based on optimal location and sizing of DG, loss minimization, voltage stability enhancement and reconfiguration of distribution network after the integration of DG resources. This paper is mainly focused on voltage control techniques and power losses reduction by using distributed generating units. The impact of DG operating in a voltage regulation mode has been analyzed and simulated in this paper for IEEE-12 bus using for the voltage stability enhancement.

2. RENEWABLE ENERGY SOURCES (RESs)

In distribution systems that use DGs, the active and reactive powers of the DGs are typically scheduled for the purposes of a specific objective, such as loss minimization, and this schedule is based on forecast data. The time intervals of the forecast data are typically tens of minutes or an hour. In this section, we describe the optimization algorithm used to determine the scheduled reactive power of each RES at a given time. Solar photovoltaic modules can be defined as solid-state devices that transform the self-contained energy of photons into DC electricity.

— Photovoltaic renewable energy source

The fundamental principle of PV modules operation dates back up to 150 years ago. However, the significant advancement of PV modules started the subsequent invention of silicon cell by Bell Labs in the mid of the twentieth century [11]. It is worth mentioning that solar technology has numerous advantages such as free emissions, long-life services, and noiseless operation. Not only this, it does not require high maintenance and fuel expenses [12]. Furthermore, solar energy is regarded as redundant and infinite. Conversely, it has some disadvantages including, weather dependency intermittency and unavailability during the night. Also, high penetration level of PV coupled with load demand variations causes power fluctuations along with unpredicted voltage escalation, voltage stability problems, and higher power losses in the power distribution networks. Wind energy is not a novel form; it has been utilized for several decades.

— Wind turbines renewable energy source

Wind turbines comprised of a generator, rotor, blades, drive device, shaft and the nacelle that. Contemporary turbines provide green electricity to wind farms or individuals [13]-[14]. They can be categorized into two kinds such as Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT). This type of energy is characterized by free emissions and no fuel requirements. It is also known that wind power is considered as an endless and redundant source. However, the main issues related to wind generation are intermittency nature, high initial investment costs. Moreover, some problem may occur as a result of extreme wind generation simultaneously with off-demand such as voltage rise, voltage instability, and high-power losses in the power distribution networks [15- 18].

— Hybrid wind solar renewable energy sources

The hybrid wind solar system is the combination of solar photovoltaic and wind, which has the advantage that these two sources complement each other since the peak functioning times take place during different times of the day and year. Evidently, the power generation of such a system is constant and tends to fluctuate less than the two subsystems separately [19]. In this paper, Hybrid wind–solar system is utilized to comprehend the impact of combination between these sources on the voltage stability of IEEE-12 bus system. In this case, power generated from solar and wind energy is injected into the weak buses in this particular system.

3. IMPACT OF DG ON THE POWER SYSTEM VOLTAGE STABILITY

Distributed generation technology is not only clean, environmental protective, economic and efficient, but also can look up the stability and flexibility of the whole power system. In recent years, distributed generation technologies have developed rapidly, and that implement the parallel operation. The segments of electricity generation, transmission, distribution and supply were integrated within individual electric utilities. This made the operation of the grid less complicated because the system operator had full knowledge of the grid status and total control over it. Liberalization and deregulation of the industry led to the introduction of competition in the segments of generation and supply [10]-[20]. In transmission and distribution, the natural monopoly element has been maintained subject to network regulation. Electricity exhibits a combination of attributes that make it distinct from other products: non-storability (in economic terms), real time variations in demand, low demand elasticity, random real time failures of generation and transmission, and the need to meet the physical constraints on reliable network operations. One of the consequences of liberalization is the new way in which the now separated entities interact with each other. In order to ensure instantaneous balancing of supply and demand, real-time markets are run as centralized markets, even in fully deregulated systems. The system operator acts as a single buyer and is responsible for upward and/or downward regulation, which may be done via regulating bids under an exchange or pool approach. Economic decisions are made individually by market participants and system-wide reliability is achieved through coordination among parties belonging to different companies. So, the connection of generators to distribution networks modifies the radial design and structure of these networks, in which the flow is in a single direction, from the substation to the loads. Changing the flows changes the voltage profile [20]. Voltage stability of electrical power system can be defined as the ability of this system to retrieve its normal operating condition after being subjected to severe interruptions such as faults. There are a significant number of approaches that are used to improve the stability of power systems such as using FACTS devices, shunt reactors, and capacitors as well as DG units. Indeed, DG units can play an important role in improving the stability of power system by increasing the maximum load penetration as well as increasing the margins of voltage stability. In addition, DG units inject real power to the electrical grids which support the ability of the loads and the network regarding voltage fluctuation due to sudden changes in load as well as disturbances. Accordingly, DG technologies are grouped in the following manner [20]-[21].

— Type 1: DG capable of injecting both active power (P) and reactive power (Q)

DG units that are based on synchronous machine for small hydro, geothermal, and combined cycles fall in Type 1 category. The DG with the synchronous generators may be modeled either with constant terminal voltage control (voltage control mode) or with constant power factor control (power factor control). The DGs with the voltage control mode are considered as PV nodes and DGs with the power factor control mode are considered as PQ nodes [22]. In this work, the DG with synchronous generator of Type 1 category is modeled as PV nodes.

— Type 2: DG capable of injecting active power (P) only

Photovoltaic (PV), micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters [22]-[24] are the examples of Type 2 category. In this work, it is assumed that DG units in this category neither absorb nor deliver reactive power to system and operate with unity power factor only.

— Type 3: DG capable of injecting reactive power (Q) only

The DG units equipped with synchronous compensator are considered as Type 3 category.

— Type 4: DG capable of injecting active power (P), but consuming reactive power (Q)

Fixed speed squirrel cage induction generator (SQIG) used for wind turbine generating (WTG) system falls under this category. SQIG in super-synchronous mode is capable of injecting real power in the system whereas it demands reactive power from the system. Thus, it is worthwhile to note that the type of DG technology adopted will have a significant bearing on the performance of distribution network [20]-[31]. The installation of synchronous machine-based DG units that are close to the loads can lead to beneficial impact on system voltage stability margin; on another end, the case with an induction generator may have detrimental impact on the system stability margin. Therefore, it is an utmost requirement to analyses the effect of different types of DG technologies on the voltage stability to enjoy the system wide benefits.

4. ACTIVE AND REACTIVE POWER FLOW ANALYSIS

The formulation of the active and reactive power entering a bus, it's needs to define the following quantities. The nodal analysis equations for the power system can be used to driven the OPF basic equations [24-26]. Equation (1) the matrix for N -buses system.

$$\begin{bmatrix} I_1 \\ .. \\ I_N \end{bmatrix} = \begin{bmatrix} Y_{11} & \dots.. & Y_{1N} \\ \dots. & \dots. & \dots \\ Y_{N1} & \dots & Y_{NN} \end{bmatrix} \begin{bmatrix} V_1 \\ .. \\ V_N \end{bmatrix} \tag{1}$$

where: Yij: Elements of the bus admittance matrix; Vi: Buses voltages; Ii: Currents value at each node; So, Equation (2) followed to node at bus i.

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{2}$$

Per-unit value at Bus i for active and reactive power and current injected into the system at that bus:

$$S_i = V_i I_i^* = P_i + JQ_i \tag{3}$$

where: Vi : per-unit voltage at the bus; Ii*: complex conjugate of the per-unit current injected at the bus; Pi and Qi: per-unit real and reactive powers.

$$I_i^* = \frac{(P_i + JQ_i)}{V_i}; I_i = \frac{(P_i - JQ_i)}{V_i^*}$$

$$(P_i - JQ_i) = V_i^* \sum_{j=1}^{n} Y_{ij} V_j = \sum_{j=1}^{n} Y_{ij} V_j V_i^* \tag{4}$$

Can be simulate as:

$$Y_{ij} = |Y_{ij}| \angle \theta_{ij}, \text{ and } V_i = |V_i| \angle \delta_i$$

$$(P_i - JQ_i) = \sum_{j=1}^{n} |Y_{ij}||V_i||V_j| \angle(\theta_{ij} + \delta_j - \delta_i) \tag{5}$$

$$P_i = \sum_{j=1}^{n} |Y_{ij}||V_i||V_j| \cos(\theta_{ij} + \delta_j - \delta_i) \tag{6}$$

$$Q_i = \sum_{j=1}^{n} |Y_{ij}||V_i||V_j| \sin(\theta_{ij} + \delta_j - \delta_i) \tag{7}$$

So, 4 variables are required to compute the power flow parameters P, Q, V.

5. OPTIMUM DG INSTALLATION BASED ON VOLTAGE STABILITY

There are more researcher focusses on the renewable energy especially solar generation and wind generation, that considered friendlier with the environment. Due to considerable costs, the DGs must be allocated suitably with optimal size to improve the system performance such as to reduce the system loss, improve the voltage profile while maintaining the system stability [25]. The problem of DG planning has recently received much attention by power system researchers. Selecting the best places for installing DG units and their preferable sizes in large distribution systems is a complex combinatorial optimization problem. Different formulations have been used based on calculus-based methods, search-based methods and combinations of various approaches [26], such as, gradient and second-order algorithms [27], Hereford Ranch algorithm [28], heuristic iterative search method [29], analytical method [30], hybrid fuzzy- Genetic Algorithm (GA) method [31].

The placement of different types of DG in distribution network greatly affects the voltage profile at the different buses and power flow in feeders, thus alters the active and reactive power losses in a system. The variation in voltage profile and losses in a system also varies with the different types of DG technologies discussed in Section 2. Hence, the attention must be paid not only to decide the location for DG placement but the types of DG technologies need to be considered. In this work, voltage stability enhancement is considered to be the major criteria for the DG placement to ensure the stable operation of the system with acceptable voltage levels at the consumer nodes [32]-[33]. The procedure adopted to find out the optimal locations for DG placement along with selection of different types of DG technologies in a given test system is shown in figure (1).

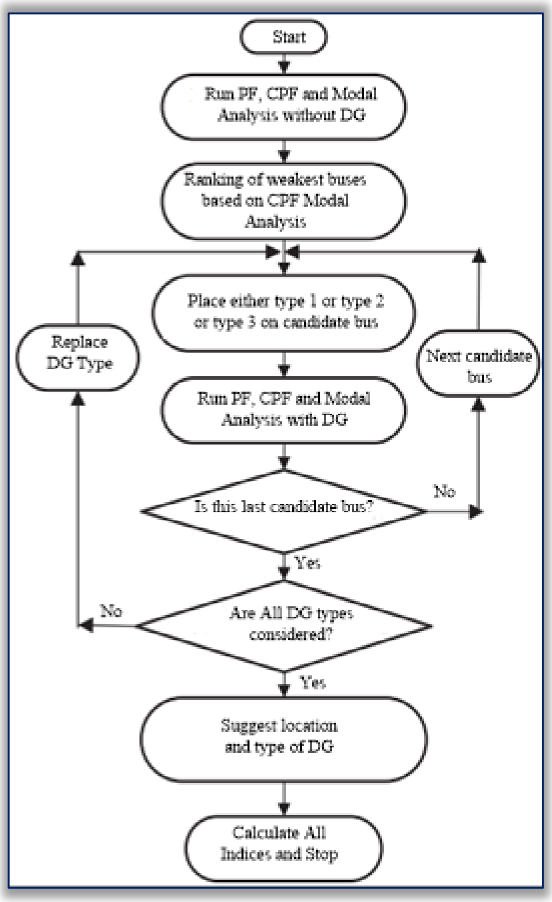

Figure 1. Flowchart for selection of DG type and location for voltage stability

6. SIMULATION AND DISCUSSION

IEEE-12 bus system as shown in figure (2) has been used for voltage stability study. This system comprises five generators including one slack bus and 11 load buses as well as 17 transmission lines, the system full data has been illustrated in table 1. Modal analysis method has applied to the 12-IEEE bus system to evaluate the voltage stability and the losses reduction of the above-mentioned system. All generators values are calculated in order to identify the weakest bus in the system. This study has been implanted based on power world simulator software. After adding the wind generation DG with bus-8, it found the voltage improved as shown in table 2. The comparison between the busses voltage without DG and with DG is illustrated in figure (3). Finally, after adding the DG with the distribution network, the voltage will improve.

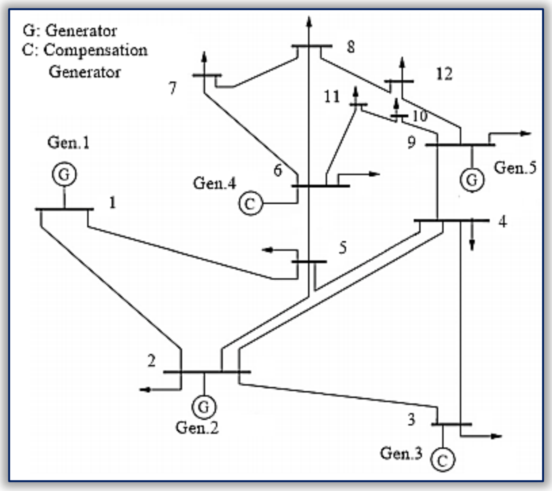

Figure 2. IEEE-12 busses system distribution network

Table 1. Operation system data without DG with distribution network

Bus No.	Nom. Voltage	Voltage (kV)	Nom Kv PU	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	22	22.000	1.00000	-18.16	50.30	18.50	75.16	44.03
2	22	22.000	1.00000	-15.26	18.00	12.58	31.01	77.20
3	22	22.000	1.00000	0.36	37.00	11.00	274.61	21.55
4	22	21.227	0.96485	-19.72	25.00	10.00	-	-
5	22	21.038	0.95625	-24.52	33.25	11.00	-	-
6	22	21.522	0.97826	-37.74	30.31	19.42	20.00	100.00
7	22	20.897	0.94989	-39.01	48.24	26.79	-	-
8	22	20.607	0.93670	-39.74	33.58	19.21	-	-
9	22	22.000	1.00001	-31.23	18.04	5.00	50.00	93.81
10	22	21.006	0.95480	-40.68	59.95	10.00	-	-
11	22	20.894	0.94973	-41.90	44.85	11.59	-	-
12	22	20.747	0.94306	-37.83	35.18	19.76	-	-

Table 2. IEEE-12 busses operation System data after adding the wind energy DG with bus 8

Bus No.	Nom. Voltage (kv)	Voltage (kV)	Nom Kv PU	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	22	22.000	1.00000	-13.35	50.30	18.50	75.16	34.29
2	22	22.000	1.00000	-11.31	18.00	12.58	31.01	51.60
3	22	22.000	1.00000	0.36	37.00	11.00	217.79	11.17
4	22	21.489	0.97679	-14.99	25.00	10.00	-	-
5	22	21.411	0.97323	-18.61	33.25	11.00	-	-
6	22	22.000	1.00000	-28.07	30.31	19.42	20.00	65.85
7	22	21.663	0.98469	-28.95	48.24	26.79	-	-
8	22	22.277	1.01259	-27.58	33.58	19.21	50.00	50.00
9	22	22.000	1.00000	-23.48	18.04	5.00	50.00	54.89
10	22	21.210	0.96407	-32.12	59.95	10.00	-	-
11	22	21.188	0.96308	-32.85	44.85	11.59	-	-
12	22	21.690	0.98592	-27.62	35.18	19.76	-	-

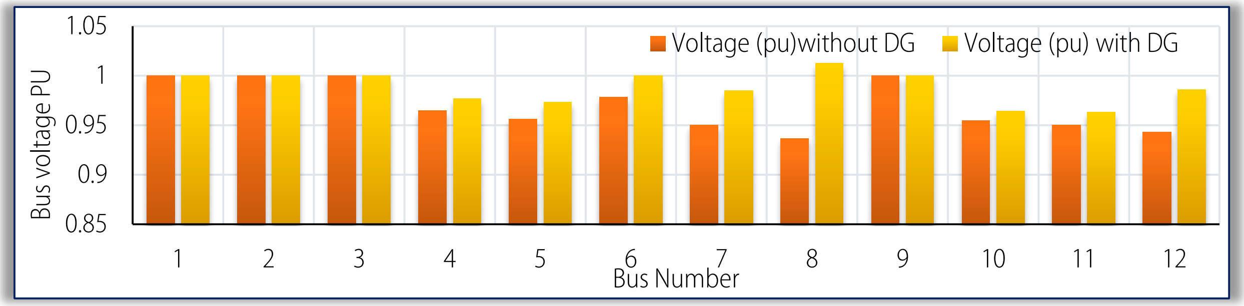

Figure 3. Bus Voltage without and with adding DG with Distribution network

7. CONCLUSIONS

Power quality (PQ) is the most discussed topics in the power industry. It is nothing but the interaction between the electrical power and electrical equipment. If the electrical equipment can operate correctly as well as reliably without damaged or stressed, that means the electrical power is of good quality. There are different types of issues in power quality like Transients, Interruptions, Sag or under-voltage, Swell or Overvoltage, Waveform distortion, Voltage fluctuations, Frequency variations and Harmonics which are more sensitive due to large use of power electronic equipment as well as nonlinear loads. These all issues are almost present in industry, commercial and domestic applications. Smart grid has been emerged as promising technology for enabling bi-directional communication between the power company and its users to facilitate intelligent and robust emerging power grid systems [1][2]. One important challenge for smart grid designers is demand side management, which can lead to avoid peak hours as well as to reduce the cost for the consumers and power quality issues. Renewable distribution generation (DG) such as wind turbine (WT) and photovoltaic (PV) systems presents a cleaner power production. This paper started from the observed renewed interest in large-scale power generation includes existing technology and infrastructure used to give electricity. The proposed approaches are not an iterative algorithm, like power flow programs. The load is not constant throughout the day; it varies from time to time. Distribution System Reliability Indices are calculated for before and after placement of DG. From the study, it found the voltage has been improved to reach 1 pu in bus 6 and bus 8 also its improved in another busses.

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