Chapter 10
Wind Distributed Generation with the Power Distribution Network for Power Quality Control

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1 Introduction

Nowadays, the power electricity demand is growing fast due to the increase in the world population. Using the fossil fuels for the electrical generation is considered as non-economical way due to the fossil fuel is nonrenewable source, and hence, the searching to utilize the renewable sources is very important for reducing the electric generation cost and the environmental aspects. To appropriately meet the consumer requirements, electricity companies have tried to improve the power quality by using the compensation techniques to overcome the drop voltage or the system disturbance [1]. There are different definitions of power quality for instance: the electricity companies define power quality as reliability that can statistically demonstrate how reliable a network to feed the loads. In contrast, electrical equipment manufacturers define power quality as guaranteeing the performance of devices based on power supply characteristics. Utilizing renewable energy sources has arrived at more important significance as it advances sustainable living and with certain special cases (biomass combustion) does not contaminant. Renewable energy sources can be utilized in either small-scale applications from the enormous estimated generation plants or in large-scope applications in areas which the asset is abundant and large conversion systems [2]. The power quality issues have been significantly paid attention by researchers and practitioners in recent years. At present, related to the highly sensitive electrical equipment, the customers are requiring an excellent stable and

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reliable power system, so the electric companies searching to the ability to satisfying the consumers to assess power system quality. Renewable sources can be utilized in either small-scale applications from the large estimated generation plants or in large scale applications in areas where the resource is the bountiful and enormous electrical generation and types are utilized [3]. The power quality issues have been fundamentally focused by researchers and professionals as of late. At present, related to the increase in the sensitive and critical electrical loads especially at the manufacturing part, reactions of current equipment's, expanding request to top-notch power, maker's inclination agreeable to clients, the capacity of customers to evaluate power quality and so forth expanding the quality of conveyed power has been significant for electric companies. Power quality incorporates various branches, for example, long and short disturbance, dependability, over/under frequency, voltage sag, and voltage swell [4]. Integration and exploitation of distributed generation (DG), for example, wild renewable sources, which can expand the green energy in the utility system, build the worry of voltage and frequency strength. Moreover, voltage disturbance is likewise as often as possible experienced in powerless main grid. Due to the power electronics converters, the current will ripple also cause voltage harmonics and, as a result, the utility voltage waveforms may get contorted. The presence of distributed generation along with its points of interest in both transmission and distribution network has made it is viewed as continuous issues in the power network activity and development arranging. One of these viewpoints which ought to be considered will be viewed as DGs' effects issues. In this respect, the effects of DG on distribution systems designed a quality are one of the most significant issues which ought to be examined by arranging organizers just as researchers [5]. In this manner, dispersion arranges organizers need to join DGs' effect into their grid arranging to the required target. A few sorts of research have been acted in the region of dependability appraisal in conveyance systems which are furnished with DGs. In the past works, the situation of distributed resources has been examined; in which improvement of voltage profile, diminishing the power misfortune and expanding the framework dependability have been for the most part considered [6]. So, unwavering quality assessment has been directed when conveyance systems are considered as a commercial center [5, 6]. As it is conceivable to introduce DGs in different pieces of a feeder, it is required to increase an investigative methodology for assessing the unwavering quality of a feeder contains DG in a few pieces of the feeder [7]. The renewable energy source (RES) incorporated at the circulation level is named as DG. The utility is worried because of the high infiltration level of irregular RES in dispersion frameworks as it might represent a danger to organize as far as steadiness, voltage guideline, and power quality (PQ) issues [8]. In this context, this study presents a complete investigation of DG penetration level influence on system technical aspects such as voltage profile and power losses. The simulation system in this paper has been analyzed and simulated with a sample IEE-12 busses distribution network using the power world simulator software to study the impact of wind DG on the distribution network for power quality enhancement.

2 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. Because of significant costs, the DGs must be assigned reasonably with ideal size to improve the system execution, for example, to diminish the system misfortune, improve the voltage profile while keeping up the system security [9]. The issue of DG arranging has as of late got a lot of consideration by power system researchers. Choosing the best places for introducing DG units and their best sizes in enormous dispersion systems is a complex combinatorial enhancement issue [10]. Various details have been utilized dependent on analytics-based techniques, search-based strategies, and blends of different methodologies [11], for example, gradient and second-order calculations [12], Hereford Ranch calculation [13], heuristic iterative search method [14], analytical method [15], hybrid fuzzy—genetic algorithm (GA) method [16]. The using of different types of DG in the correct allocation with the distribution network can enhance the operation and stability system, improving the voltage profile, which directly decrease the losses power in the system. 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 [17, 18]. 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 (see Fig. 1).

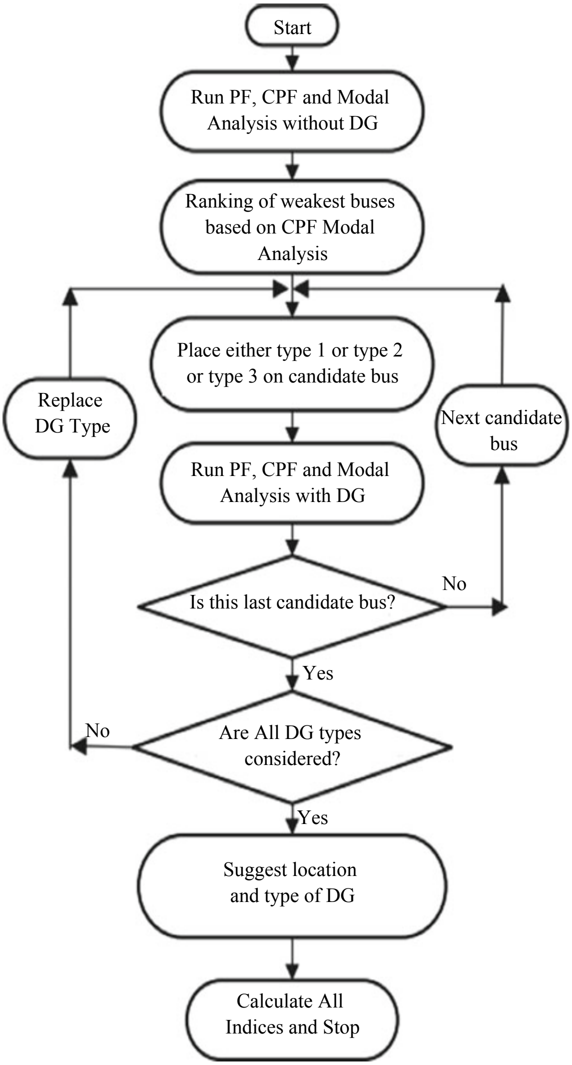
2.1 Analyzing of Active and Reactive Power Flow

The power flow analysis is very important step during the design of the power system to control the direction of power flow depending on the loads areas and the generation parts. Hence, the known of the quantities of the power system is the basic data to analyze the active and reactive power entering to the busbars. The nodal analysis method can to use to find the equations to find the driven the power flow, with considering the busbars by the node part [19]. Equation (1) is the matrix for N—busbars power system.

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

I_i	Currents value at each node
Y_{ij}	Elements of the busbar admittance matrix
V_i	Busses voltages

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



So, Eq. (2) follows to node at busbar *i*.

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

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

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

V_i	Per-unit voltage at the bus
I_i*	Complex conjugate of the per-unit current injected at the bus
P_i and Q_i	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 simulated as:
$Y_{ij} = |Y_{ij}|\angle\theta_{ij}$, and $V_i = |V_i|\angle\delta_i$

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

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

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

Finally, there are four variant components to can uses to find the power flow parameters P, Q, V.

3 Wind Energy Conversion with the Power System

The fundamental parts of a wind turbine system are delineated (see Fig. 2), including a turbine rotor, a gearbox, a generator, a power electronic system, and a transformer for matrix association. Wind turbines catch the power from wind by methods for turbine cutting edges and convert it to mechanical power [20]. During higher wind speeds, it is imperative to add the options to allow for control and breaking point to save the generation power in a stable condition. The power constraint might be done either by slow down control, dynamic slow down, or throw control whose power curveballs are appeared (see Fig. 3). With a note that, the power might be easily restricted by turning the cutting edges either by pitch or dynamic slow down control while the power from a slowdown-controlled turbine shows a small overshoot and a lower power yield for

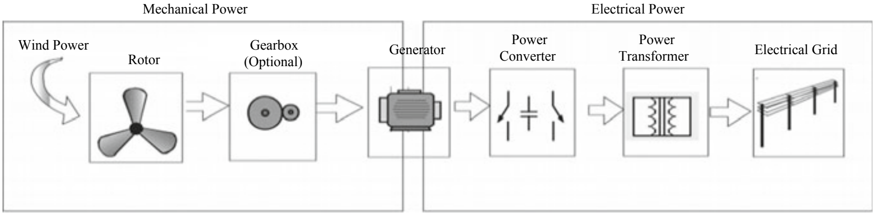


Fig. 2 Main components of a wind turbine system

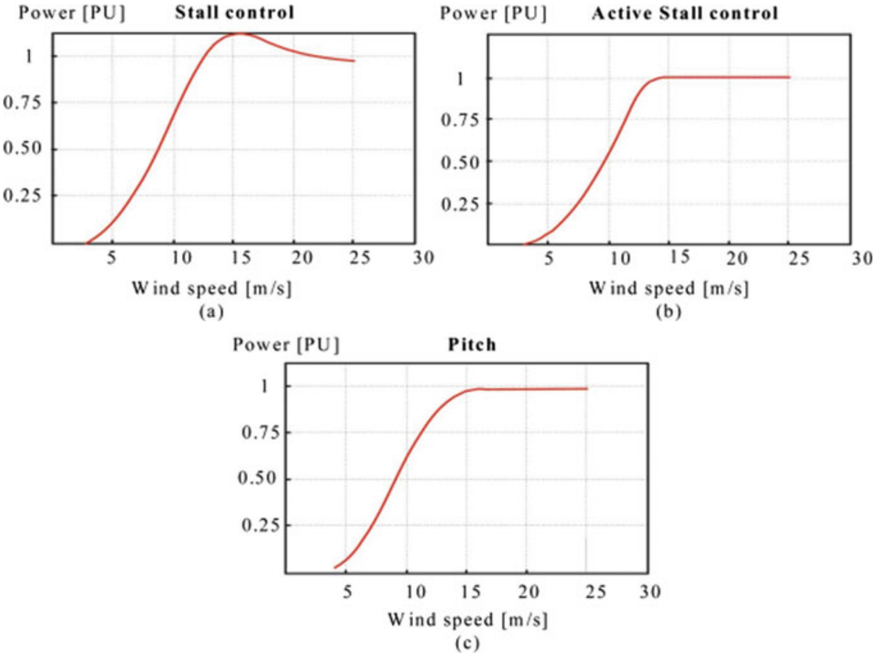


Fig. 3 Power characteristics of fixed speed wind turbines. **a** Stall control. **b** Active stall control. **c** Pitch control

higher wind speed [21–23]. The basic method to change over the low-speed, high-force mechanical power to electrical power is utilizing a gearbox and a generator with the standard speed. The gearbox adjusts the low speed of the turbine rotor to the rapid of the generator; however, the gearbox may not be essential for multipole generator systems. The generator changes over the mechanical power into electrical power, which is taken care of into a matrix perhaps through power electronic converters, and a transformer with circuit breakers and power meters. The two most normal kinds of electrical machines utilized in wind turbines are induction generators and synchronous generators. Induction generators with confine rotor can be utilized in the fixed speed wind turbines because of the damping impact. The receptive power important to empower the attractive circuits must be provided from the system or equal capacitor banks at the machine terminal that may have the risk of self-excitation when the association with the system is lost. A wound-rotor induction machine has a rotor with copper windings, which can be associated with an outer resistor or to air-conditioning systems by means of power electronic systems. Such a system furnishes an incomplete variable speed activity with a small power electronic converter and along these lines expanding energy catch and diminished mechanical burden to the system. This kind of system is a practical method to flexibly receptive power and acquires variable speed for expanded energy yield at wind speeds underneath the evaluated speed. Synchronous generators are energized by a remotely applied DC or by changeless magnets (PMs). There is extensive interest in the use of the various post synchronous generators (either with PM excitation or with an electromagnet) driven by a wind turbine rotor without a gearbox or with a low proportion gearbox. Synchronous machines powered by wind turbines may not be legitimately associated with the air conditioner framework on account of the prerequisite for critical damping in the drive train. The utilization of a synchronous generator prompts the prerequisite for a full appraised power electronic transformation system to decouple the generator from the system. While the greater part of the turbines is these days associated with the medium-voltage system, enormous seaward wind homesteads might be associated with the high-voltage and extra-high-voltage systems. The transformer is typically found near the wind turbines to maintain a strategic distance from high current streaming in long low-voltage links. The electrical assurance system of a wind turbine system ensures the wind turbine just as secures the sheltered activity of the system [21–23]. As the power yield of the wind turbine differs in a nonlinear relationship with respect to the wind speed, the point of maximum power point tracking (MPPT) control is to persistently modify the wind turbine rotor speed in such a manner to remove maximum power from the wind resource for each wind speed, it very well can be seen from Fig. 2 (see Fig. 4). Thus, in this control plot, the wind speed is taken as a boundary, while the rotor speed of the turbine or generator is a variable [24].

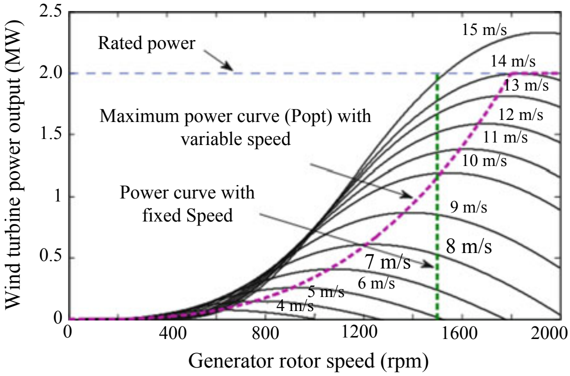


Fig. 4 Fixed and variable speed wind DGs output power

3.1 Output Power and Compensation of Wind Generation

The wind generator is the synchronous machine without the own excitation; consequently, it relies upon the input receptive power compensation by the electric network. In this way, the wind generation not considered PQ or PV in the power stream contemplates [25]. The asynchronous generator identical circuit is presented in this study (see Fig. 5), where, U is the yield machine voltage, R is the rotor resistance, X_1 is the stator reactance, X_2 is the rotor reactance, and X_m is the excitation reactance. With disregarding the stator resistance.

The total reactance rotor and stator is shown as:

$$X_\sigma = X_1 + X_2 \tag{8}$$

Th active output power can be calculated as:

$$P = \frac{SRU^2}{S^2X_\sigma^2 + R^2} \tag{9}$$

where S is the generator slip, which can be defined as shown in Eq. (10). And by using Eqs. (8) and (9) can obtain the reactive power as shown in Eq. (11).

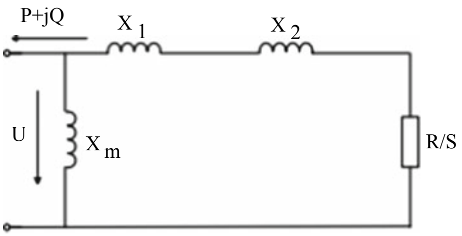
$$S = R\left(U^2 - \sqrt{U^4 - 4X_\sigma^2 P^2}\right)/2PX_\sigma^2 \tag{10}$$

$$Q = \left[R^2 + X_\sigma(X_m + X_\sigma)S^2\right]/SRX_m \tag{11}$$

In the wind system, it is imperative to remunerate the responsive power by introducing the receptive compensation hardware, that additionally, to lessen the system misfortunes. Additionally, the power factor compensation can spare the steady power stream, which utilizes the equal shunt capacitors with the wind power circuit [26]. The power factor compensation condition can be appeared as:

$$\text{Cos}(\emptyset) = P/\sqrt{P^2(Q_C - Q)^2} \tag{12}$$

Fig. 5 A simplified wind turbine equivalent circuit



With considering the parallel capacitor group simulated by Q_C which can be demonstrate from Eq. (13).

$$Q = P\left[\sqrt{\frac{1}{(\mathrm{Cos}(\emptyset 1))^2} - 1} - \sqrt{\frac{1}{(\mathrm{Cos}(\emptyset 2))^2} - 1}\right] \tag{13}$$

At assuming the actual capacitor investment group is [n], and the reactive power capacitor compensation capacity is $Q_{N\text{-Unit}}$, that simulates at the rated voltage.

$$[n] = Q_C / Q_{N\text{-}Unit} \tag{14}$$

And, the wind generation reactive power is shown as:

$$Q' = Q_C - Q \tag{15}$$

3.2 Wind Generation Control

Using wind speed is considered as one of the principle difficulties to structure the wind dissemination system. By control the MPPT with the wind speeds, Fig. 4 shows an example of the output power with the variable wind speed [24].

The proportion between the wind speed and the rotor speed can be characterized as the tip-speed (λ) as shown in Eq. (16):

$$\lambda = \frac{R_p w}{v_m} \tag{16}$$

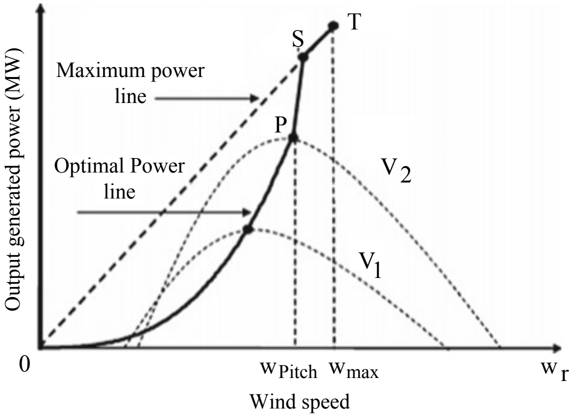
where w is the wind turbine rotational speed and v_w is the wind speed [27]. The mechanical power that extracts by the wind at constant pitch can be defined as:

$$P_m = \frac{1}{2} \cdot \rho A_r v_w^3 \cdot C_p(\lambda) \tag{17}$$

where ρ is the air density, A_r is the area swept by the blades and C_p is the turbine power coefficient. To depict the wind speed power, Fig. 6 shows the Wind turbine power control bend, which mimics the wind speed as $V1$ and $V2$. Where, every speed has one maximum power catch point at the turbine works at the ideal power coefficient (Cz_p max) [28]. There is an individual ideal power can be identified with the genera-peak speed by Eq. (18).

$$P_{\mathrm{opt}} = k_{\mathrm{opt}} w_T^3 \tag{18}$$

Fig. 6 Wind turbine power control curve



where k_{opt} is the unique parameter optimal power and w_t is the rotational speed.

4 Simulation and Discussion

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 [29]. Figure 7 shows the 12-busses sample distribution system, and it has been used for voltage stability study. This system comprises five generators including one slack busbar and 11 load busses as well as 17 transmission lines, and the system full data has been illustrated in Tables 1 and 2. Modal analysis method has applied to the 12 busses 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 busbar in the system. This study has been implanted based on power world simulator software. Table 3 shows the active and reactive power losses in the branches. After adding the wind generation DG with busbar-8, it found the voltage improved as shown in Table 4. The comparison between the bus's voltage without DG and with DG is illustrated (see Fig. 8). Also, the branches losses have been decreased as shown in Table 5. Figures 9 and 10 show the comparison between active power and reactive power losses, respectively, without adding the DG and with adding the wind generation DG. Finally, after adding the DG with the distribution network, the voltage will improve and the losses will reduce.

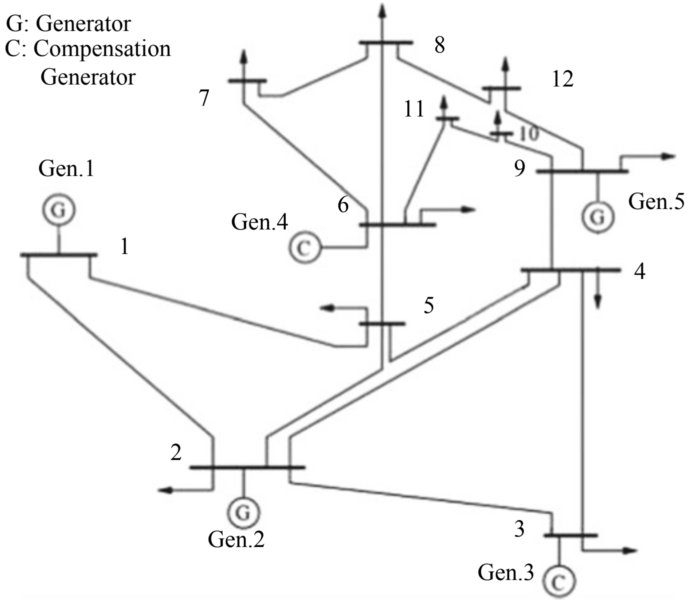


Fig. 7 IEEE-12 busses system distribution network

Table 1 Operation system data without DG with distribution network

Busbar 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	100.0
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	–	–

5 Conclusion

The integration of embedded power generation systems to existing power systems influences the power quality and causes voltage quality, over-voltage, reactive power,

Table 2 Initial data for the branches to link the system

Link No.	Branch from bus	Branch to bus	Branch *R*	Branch *X*	Branch Lim MVA
1	1	2	0.00000	0.18000	120.0
2	1	5	0.00000	0.20000	120.0
3	2	3	0.05000	0.21000	180.0
4	2	4	0.00000	0.20000	120.0
5	5	2	0.08000	0.24000	120.0
6	3	4	0.02000	0.30000	190.0
7	5	4	0.01000	0.30000	120.0
8	9	4	0.01000	0.20000	150.0
9	5	6	0.00000	0.20000	150.0
10	7	6	0.02000	0.05000	120.0
11	8	6	0.02000	0.30000	120.0
12	6	11	0.02000	0.23000	120.0
13	8	7	0.02000	0.22000	120.0
14	8	12	0.01100	0.18000	120.0
15	10	9	0.00200	0.21000	120.0
16	9	12	0.00100	0.21000	120.0
17	11	10	0.00100	0.13000	120.0

and safety issues. The widely popular generation resources are the wind and photovoltaic systems. Due to the penetration of renewable energy, the poor power quality arises which creates problems on electric systems. DGs are considered as a small generator that can operate stand-alone or in connection with the distribution networks and can be installed at or near the loads, unlike large central power plants. Renewable distribution generation (DG), wind turbine (WT) and photovoltaic (PV) systems present a cleaner power creation. This study introduced the using of the renewable wind DG with the distribution power network for power quality control. This works out in a good way in close relationship with the general public's normal development, where responses to a lot of pickles are respected by minute scale arrangements and nearness. In this paper, a conversation has been proposed for examining effects of the DG which centers around the wind generation on appropriation organize dependability. From the examination, it found the voltage has been improved to arrive at 1 pu in busbar 6 and busbar 8 also it is improved in another busbars. Likewise, the absolute dynamic power misfortunes have been diminished to arrive at 10.25 MW which is 17.11 MW before including the DG and the receptive power has been diminished to arrive at 92.92 MVAR which is 161.73 MVAR. At long last, from this paper, it is imperative to prescribe to the power system planner to consider the wind DGs for upgrading the power system quality.

Table 3 Active and reactive power losses through the 17 branches system without DG

Link No.	Branch from bus	Branch to bus	Branch MW loss	Branch Mvar loss	Branch % of MVA limit (max)
1	1	2	0.00	1.42	23.4
2	1	5	0.00	6.85	48.8
3	2	3	7.93	33.29	35.0
4	2	4	0.00	3.54	69.9
5	5	2	3.36	5.29	60.3
6	3	4	3.21	37.40	21.7
7	5	4	0.17	2.09	72.9
8	9	4	1.00	19.98	54.0
9	5	6	0.00	25.01	26.7
10	7	6	0.96	1.99	53.8
11	8	6	0.06	0.85	13.9
12	6	11	0.21	2.45	6.4
13	8	7	0.01	0.05	14.4
14	8	12	0.03	0.57	66.6
15	10	9	0.13	13.22	49.8
16	9	12	0.04	7.49	66.3
17	11	10	0.0	0.24	12.8

Table 4 IEEE-12 busbars operation system data after adding the wind DG with busbar 8

Busbar No.	Nom. voltage (kv)	Voltage (kV)	Nom Kv PU	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	22	22.000	1.000	−13.35	50.30	18.50	75.16	34.29
2	22	22.000	1.000	−11.31	18.00	12.58	31.01	51.60
3	22	22.000	1.000	0.36	37.00	11.00	217.79	11.17
4	22	21.489	0.9767	−14.99	25.00	10.00	–	–
5	22	21.411	0.9732	−18.61	33.25	11.00	–	–
6	22	22.000	1.0000	−28.07	30.31	19.42	20.00	65.85
7	22	21.663	0.9846	−28.95	48.24	26.79	–	–
8	22	22.277	1.0125	−27.58	33.58	19.21	50.00	50.00
9	22	22.000	1.000	−23.48	18.04	5.00	50.00	54.89
10	22	21.210	0.9640	−32.12	59.95	10.00	–	–
11	22	21.188	0.963	−32.85	44.85	11.59	–	–
12	22	21.690	0.9859	−27.62	35.18	19.76	–	–

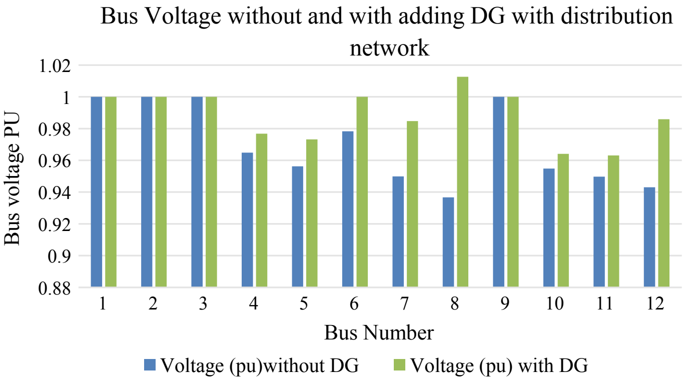


Fig. 8 Busbar voltage without and with adding DG with distribution network

Table 5 Branch losses after adding DG with the distribution network

Link No.	Branch from bus	Branch to bus	Branch MW loss	Branch Mvar loss	Branch % of MVA limit (max)
1	1	2	0.00	0.70	16.5
2	1	5	0.00	4.46	39.4
3	2	3	0.00	2.29	28.2
4	2	4	4.43	18.62	52.3
5	5	2	2.15	21.37	46.5
6	3	4	0.14	1.17	16.8
7	5	4	0.00	13.60	55.0
8	9	4	2.06	1.32	42.5
9	5	6	0.30	3.46	32.4
10	7	6	0.42	0.61	33.5
11	8	6	0.02	0.39	12.5
12	6	11	0.06	0.51	14.0
13	8	7	0.01	-0.02	4.3
14	8	12	0.55	10.95	49.3
15	10	9	0.01	2.54	29.0
16	9	12	0.10	10.93	60.4
17	11	10	0.00	0.02	7.6

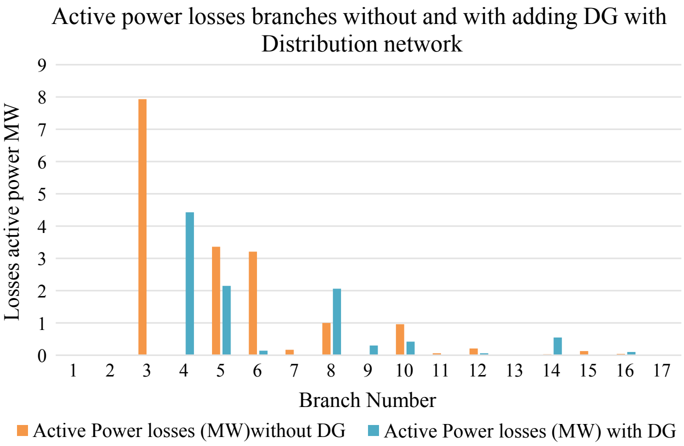


Fig. 9 Active power losses without and with adding DG with distribution network

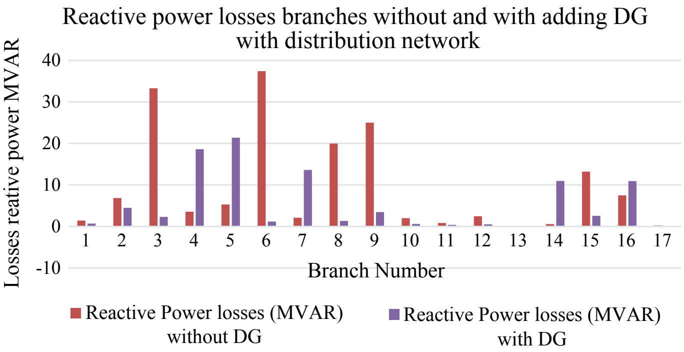


Fig. 10 Reactive power losses branches without and with adding DG with distribution network

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