Power flow study of a power system with distributed generators

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Abstract

9001

Distributed Generators (DGs) play an important role to balance load requirements, power loss and voltage drop in power systems. Researchers normally perform load flow analysis to conclude the system under study to place DG. The inappropriate placement of DG would put the system operations at risk. This paper intends to create an interest among Engineering students about load flow studies to incorporate DG. Also it highlights about the characteristics of DG, challenges faced to size and sit DGs in distribution networks.

Key words—Distributed Generators(DG), loss minimization, Newton-Raphson method, load flow study, optimal placement.

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1.Introduction

The increased energy demand leads a search of alternative solutions through pollution free natural energy sources that are not depleted. Luckily based on the geographical locations, earth part can catch wind, solar, geothermal and tidal powers that can be converted as electrical power for useful purposes. The conversions of energy in a pollution free environment shift the generation plants nearer to the consumers. Thus by availing on spot renewable sources, DGs may serve a certain percentage of its nearby demand. The main reason of DG placement nearer to load centre is to minimize transmission losses. In power systems, power loss minimization is important for economic operation to reduce energy cost [1].The common loss reduction techniques in distribution systems are network reconfiguration, optimal placing of DG and sizing, reactive power compensation, usage of high-efficient transformer and automatic voltage booster. There are different terminologies used for DGs in different countries, such as isolated generation, embedded generation, decentralized generation [2].The range of generated power is 3 kW to 10 MW from renewable sources like solar, wind, fuel cells,bio-mass, bagasse etc., which are environment friendly and connected closer to the customers [3-5].It has benefits like increased efficiency, improved reliability, reduction of peak power requirements, reducing SO_2, CO_2 gas emissions. The optimal allocation of DGs in the radial distribution systems will resolve environmental and economic challenges [6]. Also, DGs are used as a standalone, a grid interrelated, a reserve, a co-generation etc., [3-9].

In U.S., to control the levels of SO_2, CO, NO, and O_3 in ground level, a measure of air pollution is done with the Clean Air Act. Even though the downsides of non-renewable energy sources stimulate for the clean energy production, the constant power supply from renewable energy sources is difficult due to the climatic conditions. The future Engineering professionals can give solution for this with less control times by grid hook-ups, inverters, and storage batteries. This promotes Universities around world to introduce programs in renewable engineering, public health and environmental engineering [10].

The Hurricane Sandy in USA and Cyclones Hudhud, Thane and Gaja in India made people forsaken to receive power supply for many days, due to the damage of transmission lines from main grid. This facilitates the establishmentof sufficient DGs in the distribution systems to manage important loads [11].

The different characteristics of DGs are, i) injecting real power only, e.g photovoltaic and fuel cells [2, 12-16], ii) injecting reactive power for voltage profile improvement, e.g. kvar compensator, synchronous compensator, capacitors, iii) injecting real and reactive power, e.g. synchronous machines, iv) injecting real power and consuming reactive power, e.g. induction generators in wind farms [8].

The professional activities of engineering students gain popularity, if they support for the welfare of the global resources. The electrical engineering education may provide possible solutions with its interested students. In this paper, a detailed step-by-step calculation is performed for a 3 bus system and its results are verified in MATLAB environment. The power losses are reduced by including wind and solar DGs separately.

2. Challenges with DGs

The DGs are small sources that have no connection with power grid. Thus, their generated power at any instant is unknown to grid. These sources are mostly weather dependent (e.g. solar or wind) and at any instant it can stop their energy production. Even if the DG is optimally fixed, inappropriate sizing would increase the losses when compared to the case without DG. The type of DG depends on optimal sizing and location [2].Moreover, small generators frequently break down. In addition to that, power variation caused by distributed sources appears as a real problem. Power electronic converters used in DG considerably contribute to the overall cost of investment. Its construction for a significant amount of distributed generation can be a real challenge. The standard grid connected inverters designed for operation with network, face different operating conditions when surrounded by a preponderance of similar systems. When disconnected from the grid, operating DG in islanded mode even be a greater challenge. The overly conservative inverters often disconnect throughout standard working conditions. Inverters are like a key enabling technology of distributed generation and particularly for renewable their failure is relied on its profound setback [17].

The interconnection of DGs with network causes bidirectional power flow in the feeders. Also, the unpredictability of renewable resources is likely to violate the power-quality chains and needs. These impacts may be positive or negative. The negative impacts are estimated and reduced for normal power system operation. The connection of DG may degrade the power quality to some extent. Voltage dips are inevitable when power is transmitted over a long distance.The connection of DGs to the distribution network has an active impact and helps voltage to maintain in an acceptable range. This active impact is dependent on the capacity of DG connected to the host distribution network. It is essential to maintain a balance between DG penetration level and real power losses to achieve better result [18].If the penetration of DG exceeds a certain threshold, it might have a negative impact on the network due to voltage rise [19].

3. Formulation of Load flow equations for optimization problems

In power systems nearly 13% of the generated power is exhausted as I^2R losses. Transmission and sub transmission lines constitute about 30% of total losses and nearly 70% of these losses occur in the primary and secondary distribution systems. Even though the target level of distribution losses is 7.5% of the generation capacity, presently the losses constitutes 15.5% [12].The transmission line losses mainly depend upon conductor property, current flow, temperature, capacitance and inductance value that affects power factor, skin effect, and etc., that cannot be avoided. This promotes researchers to work out for loss minimization with nearby located DGs using optimization methods.

Load flow studies are numerical analysis offering solutions with nonlinear power flow equations for complex power systems. It is performed for a system with many branches and nodes that is assumed as a balanced one. Even though several methods are used to form network equations, nodal voltage method is used to form network equations in terms of nodal admittance. Figure 1 represent the basic bus arrangement in a radial distribution system. The set of equations may be solved easily for nodal voltage for particular nodal currents.

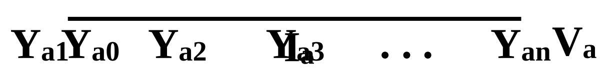

Fig. 1; Representation of a Power system bus

In a power system bus shown in above figure, π model equivalent transmission lines are composed with its impedance in per unit admittance with common MVA base. If Kirchhoff's Current Law is applied then current is,

$$I_a = Y_{a0}V_a + Y_{a1}(V_a - V_1) + Y_{a2}(V_a - V_2) + Y_{a3}(V_a - V_3) + \cdots + Y_{an}(V_a - V_{1n})$$
$$= (Y_{a0} + Y_{a1} + Y_{a2} + \cdots + Y_{an})V_a - Y_{a1}V_1 - Y_{a2}V_2 + Y_{a3}V_3 - \cdots - Y_{an}V_n \qquad (1)$$

$$I_a = \sum_{b=0}^{n} Y_{ab} - \sum_{b=1}^{n} Y_{ab}\, V_b \quad ; \quad a \neq b \qquad (2)$$

$$P_a + jQ_a = V_a {I_a}^* \qquad (3)$$

Where P is real power at bus and Q is reactive power at bus.

$$I_a = \frac{P_a - jQ_a}{{V_a}^*} \qquad (4)$$

By substituting this in (2),

$$\frac{P_a - jQ_a}{{V_a}^*} = V_a \sum_{b=0}^{n} Y_{ab} - \sum_{b=1}^{n} Y_{ab}\, V_b \quad ; \quad a \neq b \qquad (5)$$

The iterative techniques gives optimal solution for this mathematically formulated nonlinear algebraic power flow equations.

Objective Function for Optimal location and Sizing

Minimization of power loss

$$Min\, P_{Loss} = Min \sum_{i}^{n} \sum_{j}^{n} \frac{(V_i)^2 + (V_j)^2 - 2(V_i)(V_j)\cos\theta_{ij}}{Z_{ij}} = 0 \quad ; \; i \neq j \;\; \& \, i,j \in b \quad (6)$$

Where b is number of branches; i, j are the nodes of a branch

V_i, V_j voltages at i, j nodes of a branch

Z_{ij} impedance between two nodes i and j.

9003

Equality power flow constraints are,
Active and reactive power output of DG at n^{th} bus is given by [20],

$$P_{DG} = V_n \sum_{j=1}^{TB} V_j Y_{nj} \cos(\delta_n - \delta_j - \theta_{nj}) \qquad (7)$$

$$Q_{DG} = -V_n \sum_{j=1}^{TB} V_j Y_{nj}\, sin(\delta_n - \delta_j - \theta_{nj}) \qquad (8)$$

Where, P_{DG} & Q_{DG} are DG active and reactive power outputs at n^{th} bus
V_n is n^{th} bus voltage
δ_n , δ_j are phase angles of voltages at n^{th} and j^{th} bus
Y_{nj} is admittance between n^{th} and j^{th} bus
θ_{ij} is line admittance angle between buses i and j
TB Number of buses in the test system
Inequality voltage constraint is
$Vmin \leq Vi \leq Vmax$ (9)
The voltage must be controlled in between acceptable maximum and minimum limits of the system. The tolerance level is taken as ±10%.
The inequality constraint of voltage angles is
$\delta min \leq \delta \leq \delta min$ (10)

The power losses at various buses with their own operational loads are calculated by load flow analysis. By performing this, the researcher can come to a conclusion about the inclusion of certain capacity of DG in a particular bus may lower power losses. The load flow studies are considered as a heart of the power system analysis for stable operation. The powerful method for load flow studies is Newton-Raphson (NR) method and today it dominates the field. The difficulties in conventional NR method to apply for a complex power distribution systems can be modified by some algorithms. The students should be aware that for two or three (less no. of) bus system the power flow calculations can be carried out manually. But for the more numbers of bus system it can be done only with the help of MATLAB, ETAP, etc.,

Unless the location and size of DG units are well planned with load flow studies, the techno-economic performance of the system gets affected. Thus to minimize the losses, optimal placement and sizing plays a significant role which can be achieved by optimization techniques [13].Substantial research has been conducted for optimal DG allocation.

4. Load flow study of a 3-Bus system by Newton-Raphson method

The students under power systems engineering study normally know the importance of the load flow analysis. In this paper, load flow study is elaborated by Newton-Raphson method for a simple 3 bus system and the results are verified by MATLAB. In Newton-Raphson method, the solution converges with more accuracy in less number of iterations [20].

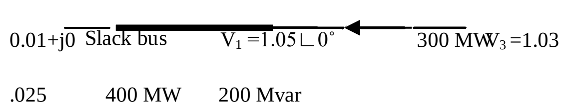

Fig.2 Single-line diagram of a 3-bus system with pu impedances (100-MVA base)

In the Figure.2, bus 1 voltage magnitude is adjusted to 1.05 pu and bus 3 has fixed magnitude of 1.03 pu. Bus 1 and 3 have generators. Bus 3 has 300 MW real power generation. Bus 2 is subjected to carry a load of 400 MW and 200 Mvar. All the impedances are represented in a common 100 MVA base. The steps involved to calculate line losses by Newton-Raphson method is performed below.

Step:1 Formation of Y_{bus}matrix

Z_{12}=0.01+j0.025 ; $y_{12} = \frac{1}{Z_{12}} = 13.8 - j34.5$

Z_{13}=0.02+j0.05 ; $y_{13} = \frac{1}{Z_{13}} = 6.9 - j17.2$

Z_{22}=0.012+j0.025 ; $y_{23} = \frac{1}{Z_{23}} = 15.6 - j32.5$

$$Y_{bus} = \begin{bmatrix} 20.7 - j51.7 & -13.8 + j34.5 & -6.9 + j17.2 \\ -13.8 + j34.5 & 29.4 - j67 & -15.6 + j32.5 \\ -6.9 + j17.2 & -15.6 + j32.5 & 22.5 - j49.7 \end{bmatrix} \text{ -------- (1)}$$

By converting into polar form, the bus admittance matrix becomes

$$Y_{bus} = \begin{bmatrix} 55.69004\llcorner - 1.19 & 37.15764\llcorner 1.9513 & 18.5324\llcorner 1.9523 \\ 37.15764\llcorner 1.9513 & 73.16666\llcorner - 1.1573 & 36.0501\llcorner 2.0183 \\ 18.5324\llcorner 1.9523 & 36.0501\llcorner 2.0183 & 54.5558\llcorner - 1.1457 \end{bmatrix} \text{ -------- (2)}$$

In the above Y_{bus} matrix the angles are represented in radian.

Step: 2 Formation of Jacobian matrix (Iteration-I)

The system has known real, reactive power consumption at bus 2 and known real power generation at bus 3. So the expressions for P_2, Q_2 and P_3 are written and their derivatives are taken with respect to, δ_2, δ_3 and $|V|$.

In Newton-Raphson method,

$$P_a = \sum_{b=1}^{n} |V_a||V_b|\,|Y_{ab}|\cos(\theta_{ab} - \delta_a + \delta_b) \text{ -------- (3)}$$

$$Q_a = \sum_{b=1}^{n} |V_a||V_b|\,|Y_{ab}|\sin(\theta_{ab} - \delta_a + \delta_b) \text{ -------- (4)}$$

$$P_2 = |V_2||V_1||Y_{21}|\cos(\theta_{21} - \delta_2 + \delta_1) + |V_2{}^2||Y_{22}|\cos\theta_{22} + \cos(\theta_{23} - \delta_2 + \delta_3) \text{ -------- (5)}$$

9005

$$P_3 = |V_3||V_1||Y_{31}|\cos(\theta_{31} - \delta_3 + \delta_1) + |V_3||V_2||Y_{32}|\cos(\theta_{32} - \delta_3 + \delta_2) + |V_3{}^2||Y_{33}|\cos\theta_{33} \text{ -------- (6)}$$

$$Q_2 = -|V_2||V_1||Y_{21}|\sin(\theta_{21} - \delta_2 + \delta_1) - |V_2{}^2||Y_{22}|\sin\theta_{22} - |V_2||V_3||Y_{23}|\sin(\theta_{23} - \delta_2 + \delta_3) \text{ ------ (7)}$$

The load at bus 2 is represented in 100 MVA base as,

$$S_2(Scheduled) = -\frac{(400 + j200)}{100} = -4.0 - j2.0\,pu$$

The generation at bus 3 is represented in 100 MVA base as,

$$P_3(Scheduled) = \frac{300}{100} = 3.0\,pu$$

The voltage at bus 1 (reference bus) is 1.05∟0˚ pu ($|V_1|$). The magnitude of voltage at bus 3 is $|V_3| = 1.03\,pu$.

By taking initial values as, $|V_2{}^{(0)}| = 1.0$; $\delta_2{}^{(0)} = 0$ & $\delta_3{}^{(0)} = 0$

The real and reactive power residuals are,

$\delta P_2{}^{(0)} = P_2{}^{Scheduled} - P_2{}^{(0)}$

By substituting initial values in eqns (5, 6 & 7)

$P_2{}^{(0)} = -1.1578$; $P_3{}^{(0)} = 0.3398$; $Q_2{}^{(0)} = -2.7001$

$\delta P_2{}^{(0)} = -4.0 - (-1.1578) = -2.8422$

$\delta P_3{}^{(0)} = 3.0 - (0.3398) = 2.66024$

$\delta Q_2{}^{(0)} = -2.0 - (-2.7001) = 0.7001$

$$\frac{\partial P_2}{\partial \delta_2} = |V_2||V_1||Y_{21}|\sin(\theta_{21} - \delta_2 + \delta_1) + |V_2||V_3||Y_{23}|\sin(\theta_{23} - \delta_2 + \delta_3)$$

= ((1.0)(1.05)(37.15764)sin(111.801+0+0))+((1.0)1.03)(36.0501)sin(115.64) =69.70038

Here $|V_2|$, $|V_1|$, δ_1, δ_2, δ_3 are the initial values. The values of θ_{21}&θ_{23} are from Y_{bus} matrix in degrees.

Similarly the following values are calculated ,

$\frac{\partial P_2}{\partial \delta_3} = -33.47528$; $\frac{\partial P_2}{\partial |V_2|} = 28.24155$; $\frac{\partial P_3}{\partial \delta_2} = -33.47528$; $\frac{\partial P_3}{\partial \delta_3} = 52.07710$

$\frac{\partial P_3}{\partial |V_2|} = -16.06741$; $\frac{\partial Q_2}{\partial \delta_2} = -30.55715$; $\frac{\partial Q_2}{\partial \delta_3} = 16.06741$; $\frac{\partial Q_2}{\partial |V_2|} = 64.30019$

The first iterative linear equations are,

$$\begin{bmatrix} \delta P_2^{(0)} \\ \delta P_3^{(0)} \\ \delta Q_2^{(0)} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial |V_2|} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} & \frac{\partial P_3}{\partial |V_2|} \\ \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial |V_2|} \end{bmatrix} \begin{bmatrix} \delta\delta_2^{(0)} \\ \delta\delta_3^{(0)} \\ \delta\left||V_2|^{(0)}\right| \end{bmatrix}$$

$$\begin{bmatrix} -2.8422 \\ 2.66024 \\ 0.7001 \end{bmatrix} = \begin{bmatrix} 69.70038 & -33.47528 & 28.24155 \\ -33.47528 & 52.07710 & -16.06741 \\ -30.55715 & 16.06741 & 64.30019 \end{bmatrix} \left[\begin{bmatrix} \delta\delta_2^{(0)} \\ \delta\delta_3^{(0)} \\ \delta\left||V_2|^{(0)}\right| \end{bmatrix}\right]$$

Δ = 192651.989 ; Δ_1 = -3970.940853 ; Δ_2 = 6827.248407 ; Δ_3 = -1495.50378

$\delta\delta_2^{(0)} = \frac{\Delta_1}{\Delta} = -0.02061$; $\delta\delta_3^{(0)} = \frac{\Delta_2}{\Delta} = 0.03544$; $\delta\left||V_2|^{(0)}\right| = \frac{\Delta_3}{\Delta} = -0.00776$

$\delta_2^{(1)}$ = 0+(-0.02061) = -0.02061 ; $\delta_3^{(1)}$ = 0+(0.03544) = 0.03544

$V_2^{(1)}$ = 1+(-0.00776) = 0.99224

$\delta_2^{(1)}$ = -1.1809 (in degree) ; $\delta_3^{(1)}$ = 2.03056 (in degree)

Step: 3 Formation of Jacobian matrix (Iteration-II)

By substituting new values get from iteration 1 in eqns (5,6,7)

$P_2^{(1)} = -3.94868$; $P_3^{(1)} = 3.0141$; $Q_2^{(1)} = -1.9458$

$\delta P_2^{(1)} = P_2^{Scheduled} - P_2^{(1)}$ = -4 - (-3.94868) = -0.05132

$\delta P_3^{(1)} = P_3^{Scheduled} - P_3^{(1)}$ = 3.0 – 3.0141 = -0.0141

$\delta Q_2^{(1)} = Q_2^{Scheduled} - Q_2^{(1)}$ = -2 – (-1.9458) = 0.0542

The computed new values for the Jacobian matrix are

$\frac{\partial P_2}{\partial \delta_2} = 67.9103$; $\frac{\partial P_2}{\partial \delta_3} = -32.2702$; $\frac{\partial P_2}{\partial |V_2|} = 25.19173$; $\frac{\partial P_3}{\partial \delta_2} = -34.0565$;

$\frac{\partial P_3}{\partial \delta_3} = 52.91103$; $\frac{\partial P_3}{\partial |V_2|} = -14.1669$; $\frac{\partial Q_2}{\partial \delta_2} = -32.89348$; $\frac{\partial Q_2}{\partial \delta_3} = 17.7784$;

$$\frac{\partial Q_2}{\partial |V_2|} = 64.5193$$

$$\begin{bmatrix} -0.05132 \\ -0.0141 \\ -0.0542 \end{bmatrix} = \begin{bmatrix} 67.9103 & -32.2702 & 25.19173 \\ -34.0565 & 52.91103 & -14.1669 \\ -32.89348 & 17.7784 & 64.5193 \end{bmatrix} \left[\begin{bmatrix} \delta\delta_2^{(1)} \\ \delta\delta_3^{(1)} \\ \delta\left||V_2|^{(1)}\right| \end{bmatrix}\right]$$

Δ = 191581.5385 ; Δ_1 = -176.327148 ; Δ_2 = -215.78813 ; Δ_3 = -191.3747

$\delta\delta_2^{(1)} = \frac{\Delta_1}{\Delta} = -0.000920377$; $\delta\delta_3^{(1)} = \frac{\Delta_2}{\Delta} = -0.0126351$

$$\delta\left||V_2|^{(1)}\right| = \frac{\Delta_3}{\Delta} = -0.00099892$$

$\delta_2^{(2)}$ = -0.02061+(-0.000920377) = -0.02153038

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$\delta_3^{(2)}$ = 0.03544+(-0.00126351) = 0.0341764

$|V_2|^{(2)}$= 0.99224+(-0.00099892) = 0.99124108

$\delta_2^{(2)}$ = -1.2336 (in degree) ; $\delta_3^{(2)}$ = 1.958163 (in degree)

Step: 4 Formation of Jacobian matrix (Iteration-III)

By substituting new values get from iteration 2 in eqns (5,6,7)

$P_2^{(2)} = -3.995433$; $P_3^{(2)} = 2.992699$; $Q_2^{(2)} = -2.002387$

$\delta P_2^{(2)} = P_2^{Scheduled} - P_2^{(2)}$ = -4 - (-3.995433) = -0.004567

$\delta P_3^{(2)} = P_3^{Scheduled} - P_3^{(2)}$ = 3.0 – 2.992699 = 0.00730007

$\delta Q_2^{(2)} = Q_2^{Scheduled} - Q_2^{(2)}$ = -2 – (-2.002387) = 0.002387

The computed new values for the Jacobian matrix are

$\frac{\partial P_2}{\partial \delta_2} = 67.834111$; $\frac{\partial P_2}{\partial \delta_3} = -32.24383$; $\frac{\partial P_2}{\partial |V_2|} = 25.11111$; $\frac{\partial P_3}{\partial \delta_2} = -34.017363$; $\frac{\partial P_3}{\partial \delta_3} = 52.86331$; $\frac{\partial P_3}{\partial |V_2|} = -14.17865$; $\frac{\partial Q_2}{\partial \delta_2} = -32.882031$; $\frac{\partial Q_2}{\partial \delta_3} = 17.74948$

$$\frac{\partial Q_2}{\partial |V_2|} = 64.39336$$

$$\begin{bmatrix} -0.004567 \\ 0.0073006 \\ 0.002387 \end{bmatrix} = \begin{bmatrix} 67.834111 & -32.24383 & 25.1111 \\ -34.01736 & 52.86331 & -14.17865 \\ -32.88203 & 17.74948 & 64.39336 \end{bmatrix} \begin{bmatrix} \begin{bmatrix} \delta\delta_2^{(2)} \\ \delta\delta_3^{(2)} \\ \delta\left||V_2|^{(2)}\right| \end{bmatrix} \end{bmatrix}$$

Δ = 190806.7629 ; Δ_1 = -0.3608945 ; Δ_2 = 26.041222 ; Δ_3 = -0.28930556

$\delta\delta_2^{(2)} = \frac{\Delta_1}{\Delta} = -0.00000189141$; $\delta\delta_3^{(2)} = \frac{\Delta_2}{\Delta} = 0.00013648$;

$$\delta\left||V_2|^{(2)}\right| = \frac{\Delta_3}{\Delta} = -0.000001516223$$

$\delta_2^{(3)}$ = -0.02153038 + (-0.00000189141) = -0.02153

$\delta_3^{(3)}$ = 0.0341764 + 0.00013648 = 0.0343

$|V_2|^{(3)}$= 0.99124108 + (-0.000001516223) = 0.99124

After 3 iterations, the solution converges.

$V_2 = 0.99124\angle -1.234^{\circ}$; $V_3 = 1.03\angle 1.965^{\circ}$ (Angles are in degrees)

Step: 5 Calculation of Q_3, P_1, Q_1

Reactive power at bus 3

$Q_3 = -|V_3||V_1||Y_{31}|\sin(\theta_{31} - \delta_3 + \delta_1) - |V_3||V_2||Y_{32}|\sin(\theta_{32} - \delta_3 + \delta_2) - |V_3|^2|Y_{33}|\sin(\theta_{33})$

= -18.8468-34.0191+52.727 = -0.13886 pu

The real and reactive powers in reference bus are,

$P_1 = |V_1|^2|Y_{11}|\cos\theta_{11} + |V_1||V_2||Y_{12}|\cos(\theta_{12} - \delta_1 + \delta_2) + |V_1||V_3||Y_{13}|\cos(\theta_{13} - \delta_1 + \delta_3)$

= 1.13737 pu

$Q_1 = -|V_1|^2|Y_{11}|\sin\theta_{11} - |V_1||V_2||Y_{12}|\sin(\theta_{12} - \delta_1 + \delta_2) - |V_1||V_3||Y_{13}|\sin(\theta_{13} - \delta_1 + \delta_3)$

= 2.4588 pu

Step: 6 Estimation of Line flows

$I_{12} = y_{12}(V_1-V_2)$ = (13.8-j34.5)[(1.05+j0.0)-(0.991+j0.213)] = 1.549-j1.742

$I_{21} = -I_{12}$= -1.549+j1.742 ; $I_{13} = y_{13}(V_1-V_3)$ = -0.4623-j0.60477

$I_{31} = -I_{13}$ = 0.4623+j0.60477 ; $I_{23} = y_{23}(V_2-V_3)$ = -2.439+j0.365 ;

$I_{32} = -I_{23}$ = 2.439-j0.365

The line flows are,

$S_{12} = V_1I_{12}^*$ = (1.05+j0.0)(1.549+j1.742) = 1.626+j1.829 = 162.6 MW + j182.9 Mvar

$S_{21} = V_2I_{21}^*$ = -1.572 – j1.693 = -157.2 MW - j169.3 Mvar

$S_{13} = V_1I_{13}^*$ = -0.485 +j0.635 = -48.5 MW + j63.5 Mvar

$S_{31} = V_3I_{31}^*$ = 0.497-j0.6064 = 49.7 MW – j60.6 Mvar

$S_{23} = V_2 I_{23}^* = -2.425\text{-}j0.309 = -242.5$ MW - j30.9 Mvar

$S_{32} = V_3 I_{32}^* = 2.497+j0.461 = 249.7$ MW + j46.1 Mvar

The line losses are,

At line 1-2 = $S_{12} + S_{21}$ = 4.8 MW + j13.6 Mvar ; At line 1-3 = $S_{13} + S_{31}$= 1.2 MW + j2.9 Mvar

At line 2-3 = $S_{23} + S_{32}$ = 7.2 MW + j15.2 Mvar

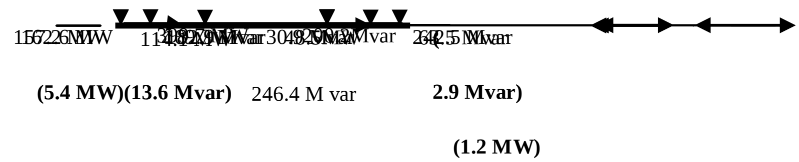

Fig. 3; Power flow diagram with power losses mentioned in brackets

TABLE 1 Real and reactive power at buses - Summary

Bus Number	1		2		3	
Real Power (MW)	114.1	Injection	399.7	Consumption	299.4	Injection
Reactive power (Mvar)	246.4	Injection	200.2	Consumption	14.5	Consumption

The power flow at buses are marked in the figure 3. The table 1 shows about the real and reactive power injections. The load flow solution is presented in the figure 4.

```
iter =     1
DC =
   -2.8420
    2.6601
    0.7000
J =
   69.7000  -33.4750   28.2420
  -33.4750   52.0768  -16.0680
  -30.5580   16.0680   64.3000
DX =
   -0.0206
    0.0354
   -0.0078
V =
    1.0500
    0.9922
    1.0300
d =
         0
   -0.0206
    0.0354
```

```
iter =     2
DC =
   -0.0512
   -0.0140
   -0.0540
J =
   67.9097  -32.2699   25.1921
  -34.0561   52.9106  -14.1676
  -32.8940   17.7788   64.5186
DX =
   -0.0009
   -0.0011
   -0.0010
V =
    1.0500
    0.9912
    1.0300
d =
         0
   -0.0215
    0.0343
```

```
iter =     3
DC =
   1.0e-04 *
   -0.6219
   -0.1159
   -0.7192
J =
   67.8313  -32.2411   25.1072
  -34.0190   52.8659  -14.1746
  -32.8871   17.7544   64.3955
DX =
   1.0e-05 *
   -0.1017
   -0.1222
   -0.1299
V =
    1.0500
    0.9912
    1.0300
d =
         0
   -0.0215
    0.0343
```

```
P1 =
    1.1389
Q1 =
    2.4559
Q3 =
   -0.1391
```

Fig. 4; Load flow solution in MATLAB environment

5. Minimization of loss with DG

In this simple 3-bus system, it is identified that the total real and reactive power losses are 13.8 Mw and 31.7 MVAr respectively. Normally for the power system with more number of buses the total power loss may be reduced with single or multiple DGs included in buses. Researchers normally allocate DGs with proper size in correct location with optimization techniques. Load flow study is carried out in a simple 3 bus system with NR method without implementing any algorithm. The available wind or solar DG is considered for the calculation of losses in the lines. In this study, DG is included in the bus with loads or in bus with no generation.

The maximum power output of a wind DG is $P_{max}(wind) = 0.2963\rho A v^3$

The wind DG output depends on air density (ρ), rotor area (A) and wind velocity (v). Also the values of cut-in, cut-out and rated speed of the wind turbine influence power generation[21].

The maximum power output of a solar DG is $P_{max}(solar) = A\beta\mu$

This solar DG output power depends upon area(A), efficiency(β) of the solar panel and irradiance(μ) from Sun [22].

MATPOWER package is used to add available wind turbine of 0.471 p.u average generation capacity with 10% reactive power consumption and solar plant of average 1.191 p.u power generation capacity separately in bus 3. The wind DG study is carried out with GE 1.5sle turbine. The solar DG work is carried out for available solar irradiance with a PV solar panel of 250731.33 m^2 area having 16% efficiency. DG inclusion reduces real, reactive power losses and improves voltage profile. The solar DG saves more power. It is because wind DG requires reactive power for operation.

6. Benefits of Renewable Energy studies

Presently students know the importance about the energy that is replenished automatically within a short span of time without environmental hazards. The researchers can offer solutions by holding up renewable energy to save the environment. Due to this many educational organizations with their own talented enthusiastic students and research scholars try to produce a certain amount of power by installing DG from universally available renewable energy sources. They normally prefer small wind or solar plants or both which are basic, and easy to install. The wide learning objectives of electrical education convert the knowledge, interest of the scholars practically for DG installation in institutions. These enable the scholars to train with installation and operational procedures which can't be known simply by visiting installed DG plants. The students and research scholars know about the effects of major nuclear accidents, Fukushima Dai-ichi in Japan, Chernobyl in Ukraine and Three Mile Island in USA. These incidents also insist them for the need of power generation from renewable sources.

7. Simulation Results

The tables 2, 3 and 4 brief about the power loss, per unit bus voltages and maximum, minimum voltages in the test system respectively. The bus voltages are plotted in the figure 5.

9009

TABLE 2 Real and reactive power losses

S.No	Type of DG at bus 3	Average power generated by DG (p.u)	Power loss	
			Real power (MW)	Reactive power (Mvar)
1.	Without DG	--	13.887	31.67
2.	Wind	1.191	12.746	29.12
3.	Solar	0.471	11.433	26.52

TABLE 3 Bus voltages in p.u

Bus number	Without DG	With wind DG	With Solar DG
1	1.05	1.05	1.05
2	0.9912	0.9934	0.9981
3	1.03	1.03	1.03

TABLE 4 Maximum, minimum values of voltage magnitude and angle

	Minimum values			Maximum values		
	Without DG	Wind DG	Solar DG	Without DG	Wind DG	Solar DG
Voltage magnitude	0.991 p.u at bus 2	0.993 p.uat bus 2	0.998 p.u at bus 2	1.050 p.u at bus 1	1.050 p.u at bus 1	1.050 p.u at bus 1
Voltage angle	-1.24˚ at bus 2	-0.71˚ at bus 2	0˚ at bus 2	1.96˚ at bus 3	2.33˚ at bus 3	2.90˚ at bus 3

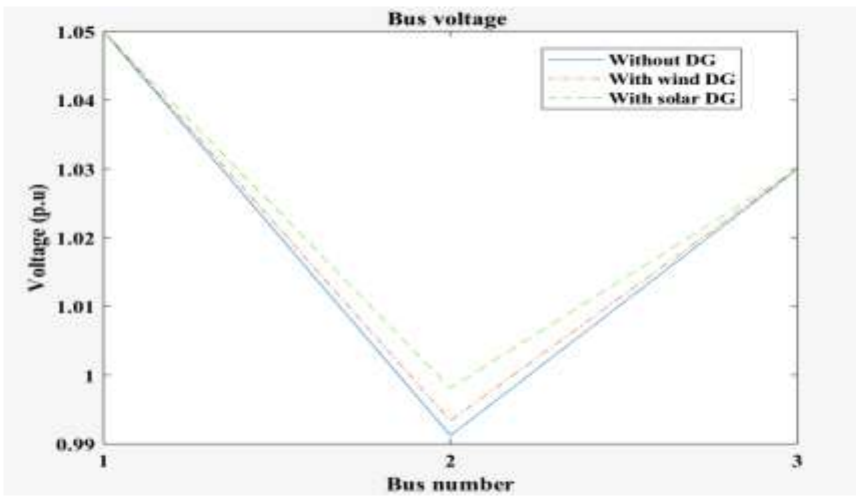

Fig. 5; Voltage profile of a 3-bus system (without and with DGs)

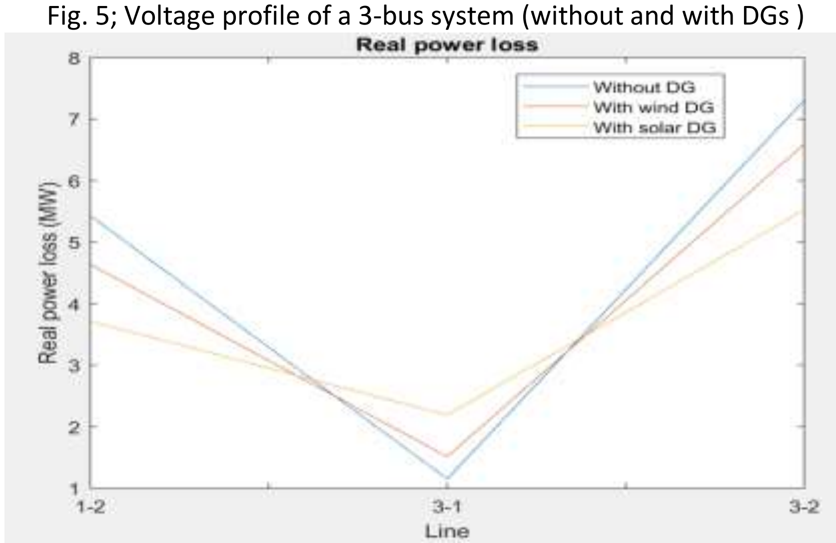

Fig. 6; Real power loss in a 3-bus system (without and with DGs)

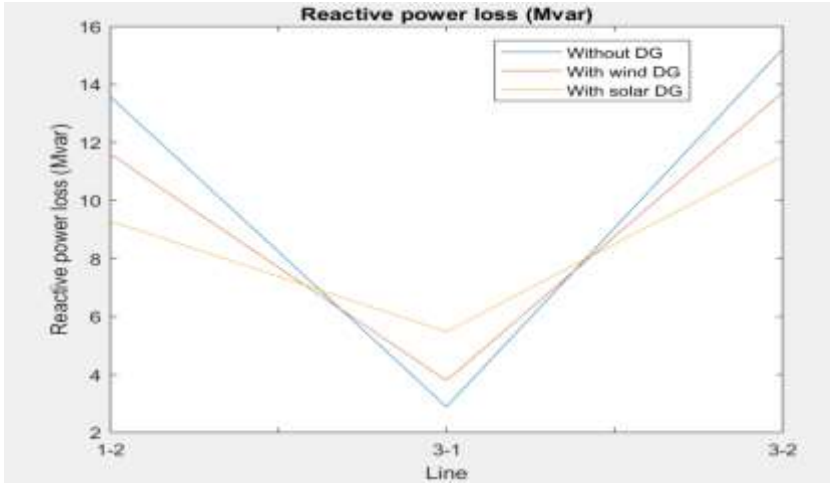

Fig. 7; Reactive power loss in a 3-bus system (without and with DGs)

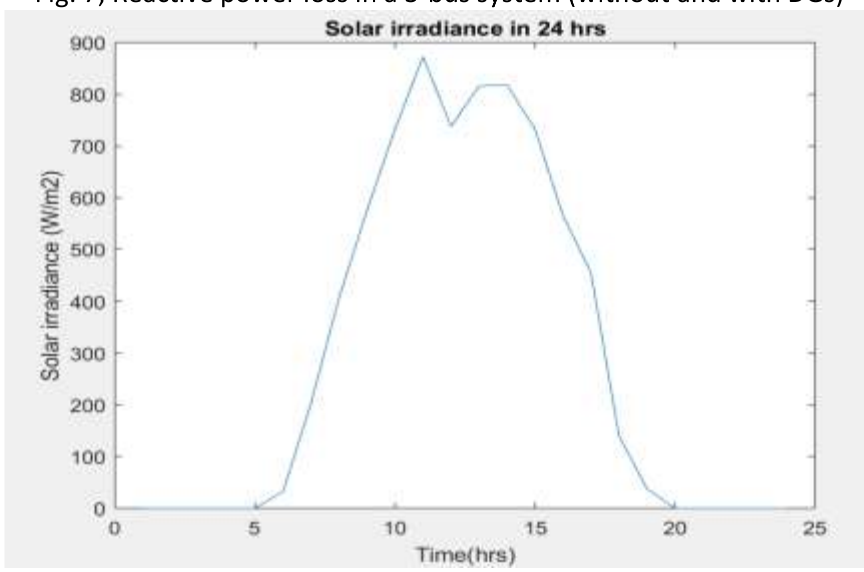

Fig. 8; Solar irradiance received by PV solar panel

8. Conclusion

Due to features like lofty R/X ratio and radial structure, conventional load flow methods does not find good outcome for distribution system analysis. Methods based on forward/backward sweep processes using Kirchhoff's laws have attractiveness in load flow analysis due to its compact memory requirements, computational competence and strong convergence characteristics. Normally the power system is considered as a balanced one and single phase modeled load flow equations are solved by iterative techniques for optimal solution.The wind speed and solar irradiance also decide the power output from wind and solar DGs respectively. Power flow assessment helps professionals to place DGs in the appropriate location. The load flow study procedure and DG insertion given in this paper is useful for the students to carry out research to include DGs in distribution systems. The existing challenges in power sector can be resolved by the electrical and power engineering students with DGs in future.

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