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OPTIMUM LOCATION OF DISTRIBUTED ENERGY RESOURCES IN DISTRIBUTED NETWORK

BY

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Abstract

With ever increasing energy consumption, rising public awareness of environmental protection, steady progress in power deregulation and revolution of environment, transmission line obstruction is quite regular. For maximum benefit and improvement of obstruction, proper position of distributed generators is very necessary. This proposed work identifies the optimum location to connect distribution energy resources in distributed network to minimize the total reactive power loss. Here use a simple conventional iterative search technique by matlab software. Gauss-Seidel method of load flow study is implemented on IEEE 6 bus and IEEE 30 bus systems.

***Keywords*:** Distributed generation(DG), Gauss-Seidel(GS),Objective function(OF).

1. INTRODUCTION

In revolution of environment electric power utilities are now seeking upcoming new technologies to provide acceptable power quality and higher reliability. Now non-conventional generation is growing rapidly around the world, for its low size, low cost and less environmental impact with high potentiality. System efficiency, environmental benefits and transmission congestion management have created a new arena which operate several DG(distributed generation) units. DG means distributed generation (DG). DG may come from a variety of sources and technologies. DG refers to small sources ranging between 1 kW and 50MW electrical power generations.[2] DG (Distribution Generator) is penetrating in power system in a significant numbers and capacity. Distribution networks are presently attracting increasing interest by all electrical market stakeholders. In the recent years, due to economical, Modern electric power system is very complex and undergoes unexpected rapid changes in terms of demand/generation patterns and trading activities that hamper the system security. Modern power systems are becoming weaker to operating limit violation and voltage instability problems due to large transmission networks, deregulation of the electricity industry and utilization of various renewable energy sources as well as different load patterns. The power system, at this stage, can become insecure and prone to voltage collapse due to lack of reactive power support. The bulk of electricity is generated at central station generations, and transmitted through high voltage transmission line to distribution network before supply to consumers. The traditional power system, characterized by centralized bulk power production and wide/long transmission networks, is increasingly supported also by energy-resources connected to the distribution grid, commonly denoted as *distributed generation* (DG). In the recent years DG penetration in the distribution systems has become faster and tangible in a way that in several countries the maximum limit of allowed connections that can be managed with the traditional passive networks approach has been reached. Over the coming years, networks structure, design and operation will have to be radically modified in a way in which generation must be viewed as an integral part of the distribution network system. Important investments and research are then needed to repair the electrical distribution segment in order to achieve a sort of "self healing" distribution system, which allows not only managing large clusters of energy resources, but also the increase of the service quality level. DG supplies better power quality to distribution network, reduce the congestion on transmission and power losses in the network, increase the reliability, and delay the need of transmission and distribution Upgrade. DG also creates some issues such as protection, reactive power, power conditioning, power quality and tariff. This paper presents a simple search approach determining for optimal placement of DG using Gauss-Seidel method of load flow study. Optimal bus location is determined to obtain the best objective. The multi objective optimization covers optimization of both cost and loss simultaneously. The IEEE 6 bus and IEEE 30 bus data is used here. Further, using DGs at various buses the systems are modified and employed for load flow study.

2. METHODOLOGY

As mentioned, this paper focuses on a simple conventional G-S method to solve a system of non-linear algebraic equation of theform f (x) = 0. Here, G-S method is applied to solve power flowequation in polar form. Bus data have been changed to incorporatethe effect of DG.[2]

2.1 LINE FLOWS AND LOSSES

After the iterative solution of bus voltages, the next step is the computation of line flows and line losses. Consider the line connecting the two buses i and j in the fig 2. The line current I_{ij}, measured at bus i and defined positive in the direction

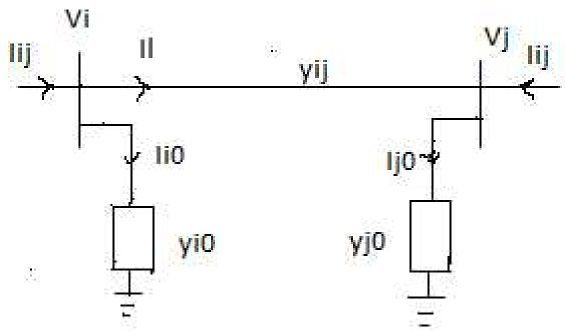


Fig:2 Transmission line model for calculating line flows

$i \rightarrow j$is given by

$$I_{ij} = I_l + I_{i0} = y_{ij}(V_i - V_j) + y_{i0}V_i \quad (1)$$

Similarly, the line current I_{ji} measured at bus j and defined positive in the direction $j \rightarrow i$ is given by

$$I_{ji} = -I_l + I_{j0} = y_{ij}(V_j - V_i) + y_{j0}V_j \quad (2)$$

The complex powers S_{ij} from bus i to j and S_{ij} from bus j to i are

$$S_{ij} = V_i I_{ij}^* \quad (3)$$

$$S_{ij} = V_j I_{ij}^* \quad (4)$$

The power loss in line $i - j$ is the algebraic sum of power flows determined from (3) and (4), i.e.,

$$S_{Lij} = S_{ij} + S_{ji} \quad (5)$$

The power flow solution solved by Gauss-Seidel method.

2.2 POWER FLOW EQUATION

Consider a typical bus of a power system network as shown in fig 3. Transmission lines are represented by their equivalent π models where impedances have been converted to per unit admittances on a common MVA base.

Application of KCL to this bus results in

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + \cdots + \;\; y_{in}(V_i - V_n)$$
$$= (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 \cdots - y_{in}V_n \qquad (6)$$

Or

$$I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij}V_j \qquad j \neq i \qquad (7)$$

The real and reactive power at bus I is

$$P_i + jQ_i = V_i I_i^* \qquad (8)$$

Or

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad (9)$$

Substituting for I_i in (7) yields

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij}V_j \qquad j \neq i \qquad (10)$$

From the above relation, the mathematical formulation of the power flow problem results in a system of algebraic nonlinear equations which must be solved by iterative techniques.

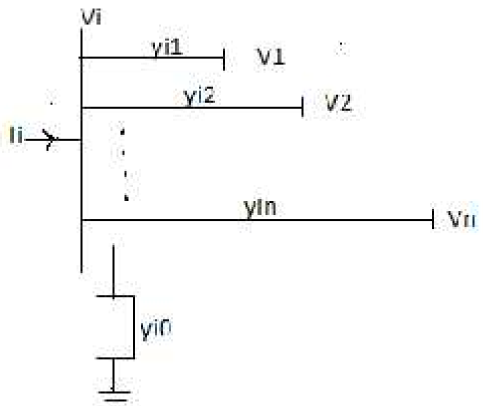


Fig:3 A typical bus of the power system

2.3 GAUSS-SEIDEL POWER FLOW SOLUTION

In the power flow study, it is necessary to solve the set of nonlinear equations represented by (5) for two unknown variables at each node. In the Gauss-Seidel method (5) is solved for V_i, and the iterative sequence becomes

$$V_i^{(k+1)} = \frac{\frac{P_i^{sch} - jQ_i^{sch}}{V_i^{*(k)}} + \sum y_{ij} V_j^{(k)}}{\sum y_{ij}}$$

$j \neq i$ (11)

Where y_{ij} shown in lowercase letters is the actual admittance in per unit. P_i^{sch} and Q_i^{sch} are the net real and reactive powers expressed in per unit. In writing the KCL, current entering bus i was assumed positive. Thus, for buses where real and reactive powers are injected into the bus, such as generator buses, P_i^{sch} and Q_i^{sch} have positive values.For load buses where real and reactive powers are flowing away from the bus, P_i^{sch} and Q_i^{sch} have negative values. If (5) is solved for P_i and Q_i, we have

$$P_i^{(k+1)} = \Re\left\{V_i^{*(k)}\left[V_i^{(k)} \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j^{(k)}\right]\right\}$$

$j \neq i$ (12)

$$Q_i^{(k+1)} = -\Im\{V_i^{*(k)}[V_i^{(k)} \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j^{(k)}]]$$

$j \neq i$ (13)

The power flow equation is usually expressed in terms of elements of the bus admittance matrix. Since the off-diagonal elements of the bus admittance matrix Y_{bus}, shown by uppercase letters, are $Y_{ij} = -y_{ji}$, and the diagonal elements are $Y_{ii} = \sum y_{ij}$, (6) becomes

$$V_i^{(k+1)} = \frac{\frac{P_i^{sch} - jQ_i^{sch}}{V_i^{*(k)}} - \sum_{j \neq i} Y_{ij} V_j^{(k)}}{Y_{ii}} \quad (14)$$

And

$$P_i^{(k+1)} = \Re\{V_i^{*(k)}[V_i^{(k)} Y_{ii} + \sum_{\substack{j=1 \\ j \neq i}}^{n} Y_{ij} V_j^{(k)}]\}$$

$j \neq i$

$$Q_i^{(k+1)} = -\Im\{V_i^{*(k)}[V_i^{(k)} Y_{ii} + \sum_{\substack{j=1 \\ j \neq i}}^{n} Y_{ij} V_j^{(k)}]]$$

$j \neq i$ (15)

Y_{ii} includes the admittance to ground of line charging susceptance and any other fixed admittance to ground.

Since both components of voltage are specified for the slack bus, there are 2(n-1) equations which must be solved by an iterative method. Under normal operating conditions, the voltage magnitude of buses are in the neighborhood of 1.0 per unit or close to the voltage magnitude of the slack bus. Voltage magnitude at load buses are somewhat lower than the slack bus value, depending on the reactive power demand, where as the scheduled voltage at the generator buses are somewhat higher. Also, phase angle of the load buses are below the reference angle in accordance to the real power demand, whereas the phase angle of the generator buses may be above reference value depending on the amount of real power flowing into the bus. Thus, for the Gauss-Seidel method, an initial voltage estimate of 1.0+j0.0 for unknown voltage is satisfactory, and the converged solution correlates with the actual operating states.

For P-Q buses, the real and reactive powers P_i^{sch} and Q_i^{sch} are known. Starting with an initial estimate, (9) is solved for the real and imaginary components of voltage. For voltage-controlled buses where P_i^{sch} and $|V_i|$ are specified, first (11) is solved for $Q_i^{(k+1)}$, and then used in (9) to solved for $V_i^{(k+1)}$. However, since $|V_i|$ is specified, only the imaginary part of $V_i^{(k+1)}$ is retained, and its real part is selected in order to satisfy

$$(e_i^{(k+1)})^2 + (f_i^{(k+1)})^2 = |V_i|^2 \tag{16}$$

Or

$$e_i^{(k+1)} = \sqrt{|V_i|^2 - (f_i^{(k+1)})^2} \tag{17}$$

Where $e_i^{(k+1)}$ and $f_i^{(k+1)}$ are the real and imaginary components of the voltage $V_i^{(k+1)}$ in the iterative sequence.

The rate of convergence is increased by applying an acceleration factor to the approximate solution obtained from each iteration.

$$V_i^{(k+1)} = V_i^{(k)} + \alpha(V_{ical}^{(k)} - V_i^{(k)}) \tag{18}$$

Where α is the acceleration factor. Its value depends upon the system. The range of 1.3 to 1.7 is found to be satisfactory for typical systems.

2.4 Optimal Placement of DG in Networked Systems

Consider the system shown in Fig 4. The system has N buses and loads, and assumed the fault is bus j. The mainexternal power is injected into bus 1, which is taken as slack bus. The objective is to find the bus to connect the DG so that the total system power loss is minimized and the voltage level at each bus is held in the acceptable range.

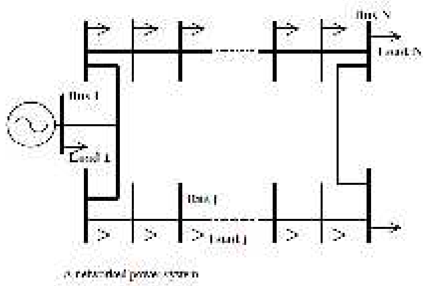


Fig:4 A network power system

The bus admittance matrix is

$$Y_{bus}=\begin{bmatrix} Y_{11}Y_{12}\ldots Y_{1k} & \cdots & Y_{1(N-1)} \\ \cdots & \cdots & \cdots \\ Y_{(N-1)1} \quad Y_{(N-1)2}\ldots Y_{(N-1)k} & \cdots & Y_{(N-1)(N-1)} \end{bmatrix} \tag{19}$$

The bus impedance matrix Z_{bus} is

$$Z_{bus}=Y_{bus}^{-1}=\begin{bmatrix} Z_{11}Z_{12}\cdots Z_{1k} & \cdots & Z_{1(N-1)} \\ \cdots & \cdots & \cdots \\ Z_{(N-1)1}Z_{(N-1)2}\cdots Z_{(N-1)k} & \cdots & Z_{(N-1)(N-1)} \end{bmatrix} \tag{20}$$

Suppose the complex load and generated power of the original system are:

$S_L = [S_{L1}, S_{L2}, \ldots, S_{Li}, \ldots S_{LN}]$, and (21)

$S_G = [S_{G1}, S_{G2}, \ldots, S_{Gi}, \ldots S_{GN}]$,

$= 1,2, \ldots, N$, (22)

Where

$S_{Li} = P_{Li} + jQ_{Li}$ and $S_{Gi} = P_{Gi} + jQ_{Gi}$.

And $S_{Li} = 0$, for $i = 1$ (slack bus);

$$S_{Li} = \begin{cases} P_{Li} - P_{Gi} + j0 & P_{Li} > P_{Gi} \\ 0 & P_{Li} \le P_{Gi} \end{cases}$$

, for i=P-V buses.

Note that at the slack bus (bus 1) $S_{L1} = 0$; it is assumed that the real and reactive power consumed by the load are supplied directly by the external generation at that bus. Also, at a voltage controlled (P-V) bus, $Q_{Li} = 0$; it is assumed that the load reactive power can be supplied by the external power source at the P-V bus.

To find the optimal point to place the DG, we set up an objective function for DG at each bus j as follows:

$$f_j = \sum_{i=1}^{j-1} R_{1i}(j)|S_{Li}|^2 + \sum_{i=j+1}^{N} R_{1i}|S_{Li}|^2, \quad j = 2, \ldots\ldots N \tag{23}$$

where $R_{1i}(j)$ is the equivalent resistance between bus 1 and bus i when DG is located at bus j, $j \neq 1$.

$$R_{1i}(j) = \begin{cases} Real(Z_{11} + Z_{ii} - 2Z_{1i}) i < j \\ Real(Z_{11} + Z_{(i-1)(i-1)} - 2Z_{1(i-1)}) i > j \end{cases} \tag{24}$$

When the DG is located at bus 1 (j=1), the objective function will be

$$f_1 = \sum_{i=1}^{N} R_{1i}|S_{Li}|^2 \tag{25}$$

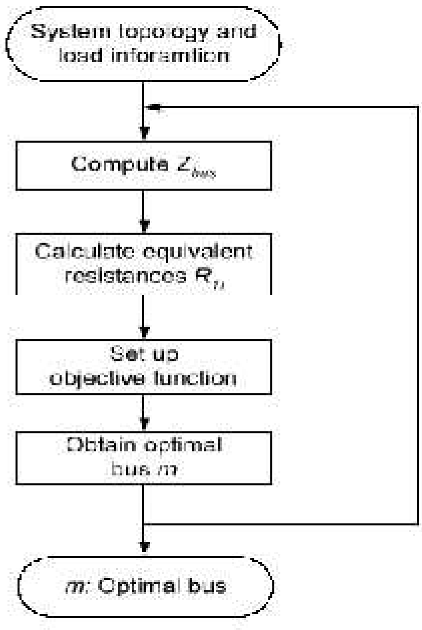
The goal is to find the optimal bus m where the objective function reaches its minimum value.

$$f_m = Min(f_j), \; j = 1, 2, \ldots..N$$

The theoretical procedure to find the optimal bus to place DG in a networked system

1) Find the matrix Y_{bus} and set up the load vector S_L.
2) Compute Y_{bus} and the corresponding Z_{bus} for different DG locations.
3) Calculate the equivalent resistances according to (6).
4) Use (5) and (7) to calculate objective function values for DG at different buses and find the optimal bus m.
5) If all the voltages are in the acceptable range when the DG is located at bus m, then bus m is the optimal site.
6) If there is no bus that can satisfy the above equation and repeat step 5).

The procedure is summarized in the flow chart shown in Figure:



Flow chart to find fm

3. Results and discussion

3.1 Result for IEEE 6 bus system.

TABLE 1

Bus no	V	I	Fm
1	1.0500	0.0711-0.3198i	61.9017
2	1.0524+0.0061i	0.3997-0.5818i	62.0206
3	1.0748+0.0189i	0.5607-0.8977i	118.1903
4	1.0700	0.3172+0.7005i	26.9634
5	1.06400	0.2816+0.6612i	32.8540
6	1.0500	0.4347+0.9715i	86.1245

TABLE 2

Line No	Qij	Pij	Sij
2-1	0.2324	3.0717	3.0717-0.2324i
4-1	23.5294	5.8824	5.8824+23.5294i
5-1	15.5602	4.1494	4.1494+15.5602i
1-2	0.2495	3.0631	3.0631-0.2495i
3-2	8.2842	7.0201	7.0201+8.2842i
4-2	39.5247	25.8344	25.8344+39.5247i
5-2	15.1254	7.0658	7.0658+15.1254i
6-2	22.4128	10.8805	10.8805+22.4128i
2-3	8.0291	6.9691	6.9691+8.0291i
5-3	20.9297	16.9448	16.9448+20.9297i
6-3	68.2336	32.5875	32.5875+68.2336i
1-4	24.7059	6.1765	6.1765+24.7059i
2-4	41.7543	26.9493	26.9493+41.7543i
1-5	16.3382	4.3568	4.3568+16.3382i
2-5	15.9615	7.3445	7.3445+15.9615i
3-5	22.8152	17.8150	17.8150+22.8152i
2-6	23.6542	11.3150	11.3150+23.6542i
3-6	73.9514	33.7311	33.7311+73.9514i

Case study (1)

From the table (1) , the minimum value of objective function is observed. The bus with the minimum objective function means the bus with more losses(more load demand). This bus shall be connected with DG. This has been discussed earlier. Here the objective function is minimum in bus no 4. So DG is connected in bus no 2.

Result for IEEE 30 bus system

TABLE 1

BUS no	V	I	Fm
1	1.0600	0.1813-0.5543i	0.2492
2	1.0430	0.0078-0.0649i	0.1456
3	1.0600	0.5842-1.7744i	1.0838
4	1.0600	0.9055-3.0445i	1.9928
5	1.0100	0.0079-0.1144i	0.0165
6	1.0700	0.5202-1.8800i	0.9443
7	1.0100	0.0295-0.0932i	0.0029
8	1.0100	0.0773-0.2394i	0.1423
9	1.0300	0.0000+0.3942i	0.0667
10	1.0700	0.0000+0.0000i	0.0667
11	1.0820	0.0000-0.3942i	0.1542
12	1.0000	0.0000+0.7415i	0.1092
13	1.0710	0.0000-0.5071i	0.0047
14	1.0000	0.0000+0.0000i	
15	1.0300	0.0000+0.0000i	
16	1.0400	0.0000+0.0000i	
17	1.0000	0.0000+0.0000i	
18	1.0100	0.0000+0.0000i	
19	1.0000	0.0144+0.1318i	

TABLE 2

Line No	Qij	Pij	Sij
2-1	27.7432	9.2638	0.0926 - 0.2774i
3-1	33.7900	9.2452	0.0925 - 0.3379i
1-2	28.1954	9.4148	0.0941 + 0.2820i
4-2	9.3657	3.0734	0.0307 + 0.0937i
5-2	15.9067	3.7862	0.0379 - 0.1591i
6-2	22.0009	7.2504	0.0725 - 0.2200i
1-3	35.8175	9.7999	0.0980 + 0.3582i
4-3	149.6563	52.1231	0.5212 + 1.4966i
2-4	9.2155	3.0241	0.0302 - 0.0922i
3-4	141.1852	49.1727	0.4917 - 1.4119i
6-4	133.8672	38.4787	0.3848 - 1.3387i
12-4	23.4375	3.9099	0 - 0.2344i
2-5	16.4264	2.9540	0.0391 + 0.1643i
7-5	7.4493	7.5622	0.0391 + 0.1643i
2-6	22.9469	40.7875	0.0756 + 0.2295i
4-6	141.8993	6.3522	0.4079 + 1.4190i
8-6	22.2327	2.9836	0.0635 + 0.2223i
5-7	7.5238	6.2893	0.0298 + 0.0752i
6-8	22.0126	1.4440	0.0629 - 0.2201i
28-8	4.5408	1.4584	0.0144 - 0.0454i
11-9	42.6558		0 + 0.4266i
9-11	39.4231		0 - 0.3942i
4-12	24.8438		0 + 0.2484i
13-12	54.3150		0 + 0.5431i
12-13	50.7143		0 - 0.5071i
8-28	4.5862		0.0146+0.0459i

Case study (2)

From the table (1) , the minimum value of objective function is observed. The bus with the minimum objective function means the bus with more losses(more load demand). This bus shall be connected with DG. This has been discussed earlier. Here the objective function is minimum in bus no 4. So DG is connected in bus no 7.

3. CONCLUSION

The idea is to locate and analyze the fault in a IEEE bus by calculating the loss and voltage drop in a given distribution system. If loss is increased and voltage is decreased in any bus in IEEE 6 bus, 30 bus or IEEE any bus system, a DG will connect to that bus. DG will increase the voltage and manage the load demand. By this process of compensation the bus system will be restored of its normal operation and also maintain the system stability.

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