OPTIMAL PLACEMENT AND SIZE SELECTION OF MULTIPLE DISTRIBUTED GENERATIONS BY USING KALMAN FILTER ALGORITHM

[1]Shalini V.S & [2]Poornachandra Rao .N
[1]PG student & [2]Associate Professor,
Deptt. of EEE, SVPCET, Puttur, A.P, India

ABSTRACT

The serious stability problems may occur due to increase in power consumption in electric power system if there are no ongoing or impending construction projects of new power plants or transmission lines etc., and also the power losses of the system will be large due to these problems. The distribution generation (DG) has been paid great attention so far as a potential solution to avoid constructing the new infrastructures such as power plant, transmission lines in costly and environmentally effective manner. The beneficial effects of DG mainly depend on its location and size. Therefore, to maintain the stability and reliability of existing system effectively is based on selection of optimal location and size of DG before it is connected to a power grid. In this paper, a method to determine the optimal locations of multiple DGs is proposed by considering power loss. Also, by using kalman filter algorithm the optimal size of DG are determined.

INDEX TERMS*—Distributed generation, grid connection, Kalman filter algorithm, load-concentration-bus, optimal location, optimal size, power loss.*

I. INTRODUCTION

The structure, operation, planning and regulation of electric power industry will undergo considerable and rapid change due to increased prices of oil and natural gas. Therefore, electric utility companies are striving to achieve power from many different ways; one of them is distributed generation solution by an independent power producer (IPP) to meet growing customer load demand. The renewable energy sources such as fuel cell, photovoltaic and wind power are the sources used by the distribution generation. In recent years, it becomes an integral component of modern power system for several reasons.

For example, the DG is a small scale electricity generation, which is connected to customer’s side in a distribution system. The additional requirements such as huge power plant and transmission lines are reduced. So, the capital investments are reduced. Additionally, it has a great ability for responding to peak loads quickly and effectively. Therefore, the reliability of the system is improved. It is not a simple plug and play problem to install DG to an electric power grid. Indeed, the operations of DG require a careful consideration for the interaction with existing power network. A method to select the optimal locations of multiple DGs by considering total power loss in a steady state operation is proposed by this paper. Thereafter, their optimal sizes by using a kalman filter algorithm.

II. SELECTION PROCESS OF OPTIMAL LOCATIONS

A. power loss reduction by connecting DG:

Generally, the power plants are far from the consumption regions, it causes a large amount of power loss. The 30-bus system is shown in figure (1), where all loads are divided into two classes. The first one is directly connected bus while the second is load concentration bus. The directly connected bus is the bus connected to reference bus only but does not pass through any other buses. In the figure (2), the buses 12, 14, 18 and 23 are directly connected buses, if reference bus is chosen as 15th bus. The load concentration bus is the bus which is relatively large loads, and is connected to other directly connected buses. The buses 10, 12, 27 and 5 are load concentration buses of area 1 through 4 respectively.

To minimize power loss, it is not desirable to connect each DG to every load bus. Instead of these, the multiple distribution generation are connected to load concentration buses. The figure (3) shows the distribution feeder one line diagram with a total of n unit circuits.

The simplified unit circuit is shown in figure (1) and the power loss between two buses I and j is calculated as

$$P_{loss,ij} = P_i - P_j = \frac{(P_i^2+Q_i^2)r}{v_i^2} \tag{1}$$

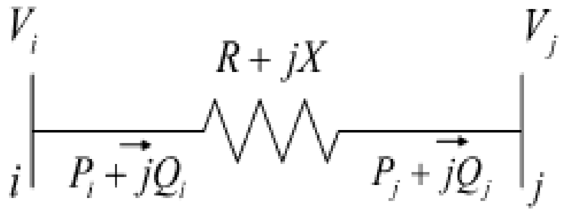

Figure.1: simplified unit circuit between two buses

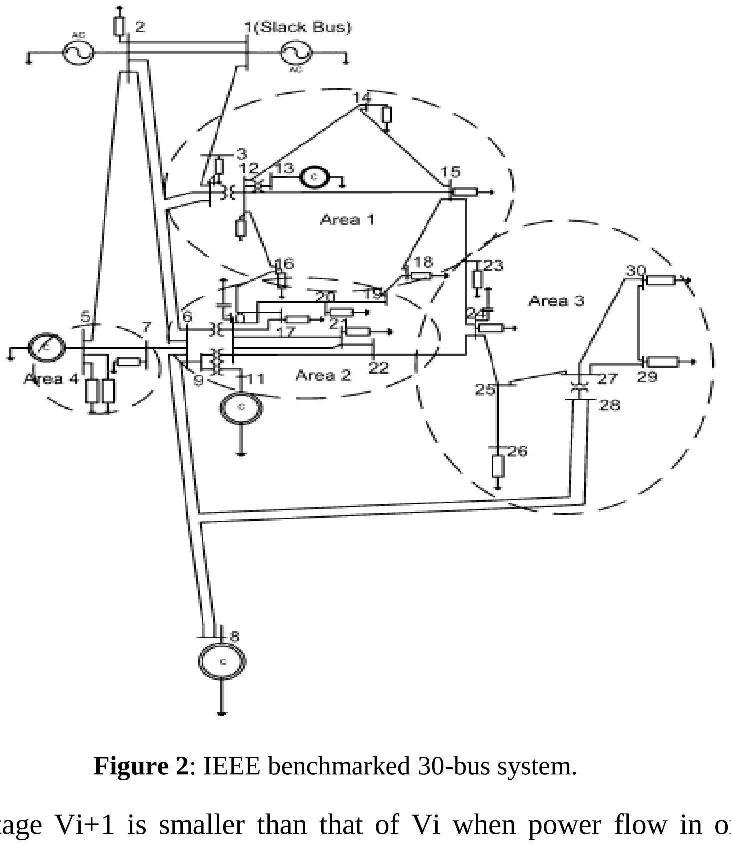

Figure 2: IEEE benchmarked 30-bus system.

The value of bus voltage Vi+1 is smaller than that of Vi when power flow in one direction. The voltage at bus Vi+1 is computed as

$$V_{i+1}^2 = V_i^2 - 2(r_{i+1}P_i + x_{i+1}Q_i + (r_{i+1}^2 + x_{i+1}^2)(P_i^2 + Q_i^2)/V_i^2 \tag{2}$$

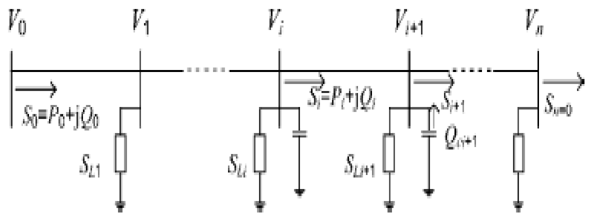

Figure.3: one –line diagram of a distribution feeder

Generally, by connecting a capacitor bank on bus I the reactive power can be reduced in order to decrease voltage gap between Vi+1 and Vi. And also, the capacitor bank at bus I reduce the power loss and regulate the voltages by adjusting reactive power. By locating DG at capacitor bank, the proper reactive power control of DG has same effect as capacitor bank. The main function of DG is to supply real power supplementary power effectively to the required loads.

B. selection of optimal placement for DGs by considering power loss:

In this section the 30 bus system is analyzed for two different cases with respect to generator or load. The first case is one where power flows from the Kth generator to numerous loads. The second case is one where power is flowing from several generators to the lth load. And these two conditions are shown in the following figures.

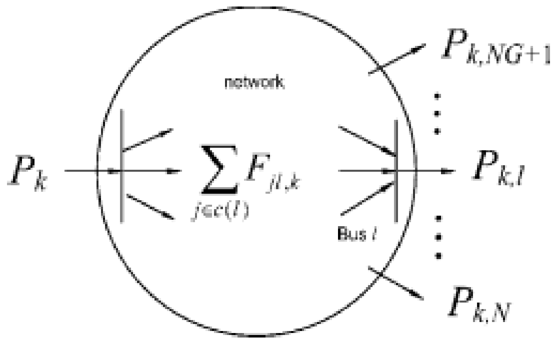

Figure 4: power flow from Kth generator to the other several loads.

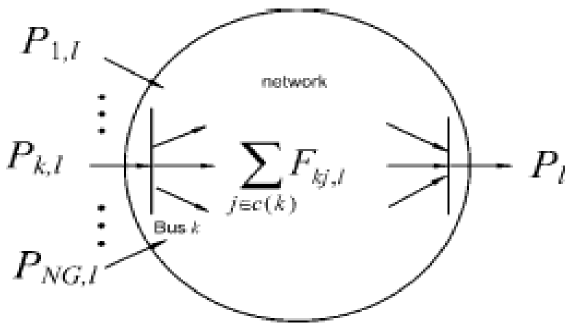

Figure 5: power flow from several generators to the lth load

For the first case, the power supplied from the Kth generator to the lth load among several loads is calculated as

$$P_{k,l} = \sum_{j\in c(l)} F_{jl,k} = \sum_{j\in c(l)} D_{jl,k} P_K \quad (3)$$

Then, the power loss associated with the Kth generator is computed by the following, which is the difference between the power supplied from the Kth generator and sum of powers consumed in loads.

$$P_{loss,k} = P_k - \sum_{l=NG+1}^{N} P_{k,l} \quad (4)$$

Where

C (l): buses connected to lth load;
$P_{k,l}$: Power flowing from Kth generator to lth load;
$F_{jl,k}$: Power flowing from Kth generator to lth load through bus j connected to the lth load;
$D_{jl,k}$: Ratio of $F_{jl,k}$ to the power supplied by the Kth generator;
P_k: Power supplied by the Kth generator in a power network;
In the same manner, the power supplied from the Kth generator among several generators to the lth load is calculated by the following for the second case:

$$\mathrm{P_{k,l}} = \sum_{j\in c(k)} F_{kj,l} = \sum_{\mathrm{j}\in \mathrm{c(k)}} \mathrm{D_{kj,l}}\, \mathrm{P_l} \quad (5)$$

The power loss associated with the lth load is computed by the following:

$$\mathrm{p_{loss,l}} = \sum_{k=1}^{NG} \mathrm{P_{k,l}} - \mathrm{P_l} \quad (6)$$

Where
C (k): buses connected to the Kth generator;
$F_{kj,l}$: Power flow from Kth generator to the lth load through bus j connected to the Kth generator;
$\mathrm{D_{kj,l}}$: Ratio of $F_{kj,l}$ to the power supplied by the Kth generator;
P_l: Power consumed by the lth load in a power network.
In combination of above two cases, the power system in figure (1) can be expressed by simplified circuit shown in figure with consideration of only power generations and consumptions.

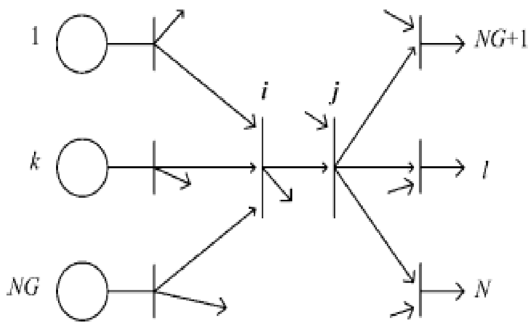

Figure 6: simplified circuit with only power generations and consumptions.

The branch between buses I and j in figure (6) can become an arbitrary branch in figure (1). This means that the total power loss of the system can be calculated by summing the losses of all branches whenever the DG is connected to any bus. Each loss of the branch is thus simply computed by the equation (1).

TABLE 1: Buses with Largest and Smallest Loads in Each Area

Area	Largest load bus	Smallest load bus	Total amount of power consumption in loads
Area 1	12	16	45MW
Area 2	10	22	44MW
Area 3	27	26	28.4MW
Area 4	5	7	117MW

The Table-1 gives the largest and smallest loads and total amount of power consumption in each area. Assume that the power loss between two adjacent buses in each area is negligible.
In this situation, the total amount of power consumption at each area can be considered as size of multiple distributed generation that is 45, 44, 28.4and 117MW respectively. In other words, the total system power loss is 3.452MW will be compared with total power loss computed after the optimal size of multiple DGs is determined by using kalman filter algorithm.

III. SELECTION OF OPTIMAL SIZE OF MULTIPLE DGS USING KALMAN FILTER ALGORITHM

At each area total power consumption can be chosen as size of DGs but these are not optimal values for DGs because power loss in lines connecting two buses is ignored. Due to this problem kalman filter algorithm is applied to select optimal sizes of multiple distribution generation by minimizing total power loss of system. It has smoothing property and noise rejection capability. The estimation problem for optimal sizes of multiple DGs can be formulated with a linear time varying state equation. The estimation state model is given as

$$X(n+1) = \Phi x(n) + \Gamma \omega(n),\ X(0) = X_0 \tag{7}$$

$$Y(n) = C.X(n) \tag{8}$$

$$Z(n) = Y(n) + V(n) \tag{9}$$

Where Φ ,Γ , C are known deterministic variables ,ω is the process noise vector , Z is the measured power loss a ,V is stationary measurement noise ,X can represent the size of each DGs.
Figure 7 shows the flowchart which is used to obtain data samples for size of multiple distribution generation and power loss required before applying kalman filter algorithm. This flowchart undergo three stages ,in stage-1 of figure the algorithm starts with zero values for all DGs and the index represents the number of given DG. By adding the small amount of power Pstep of 10MW to each DG.

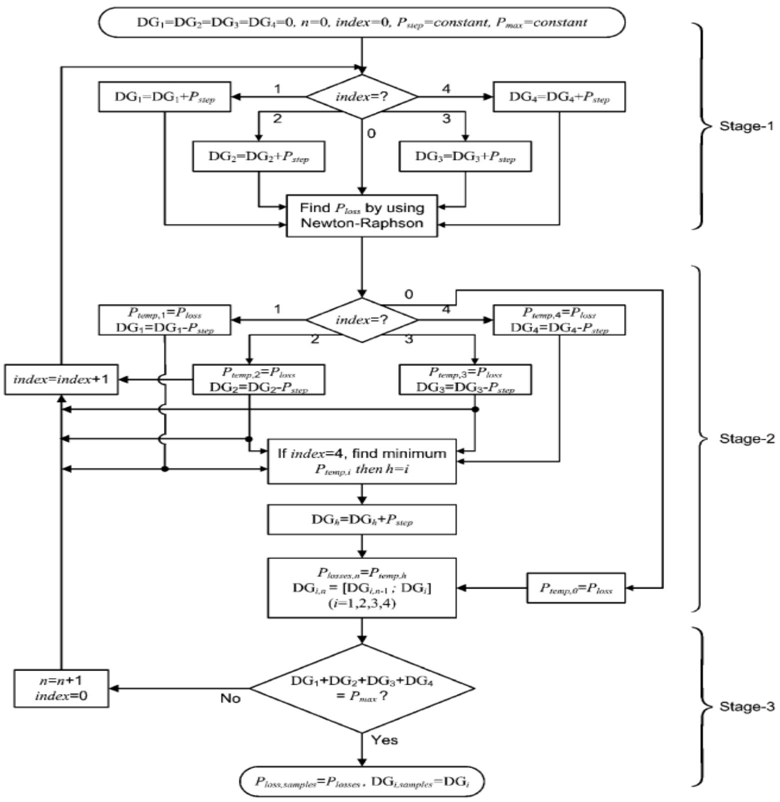

Figure.7: procedure to obtain data samples of the multiple DGs and power loss required before applying the kalman filter algorithm.

By using Newton Raphson method, the initial power loss is obtained. Then obtained individual power loss corresponding to each DG is sent to Stage-2 of flowchart, where the values of Ploss are substituted with those of Ptemp. After selecting minimum value of Ptemp, its value and the corresponding sizes of multiple distributed generation are stored in memory of Ploss, n and DGi, n in flowchart respectively.
Until the total sum of all DGs is same as the predefined value, Pmax, this process is repeated in stage-3 by increasing n to n+1. Finally obtained the accumulated data of minimum power loss and sizes of DGs, which are Ploss, samples and DGi, samples respectively.

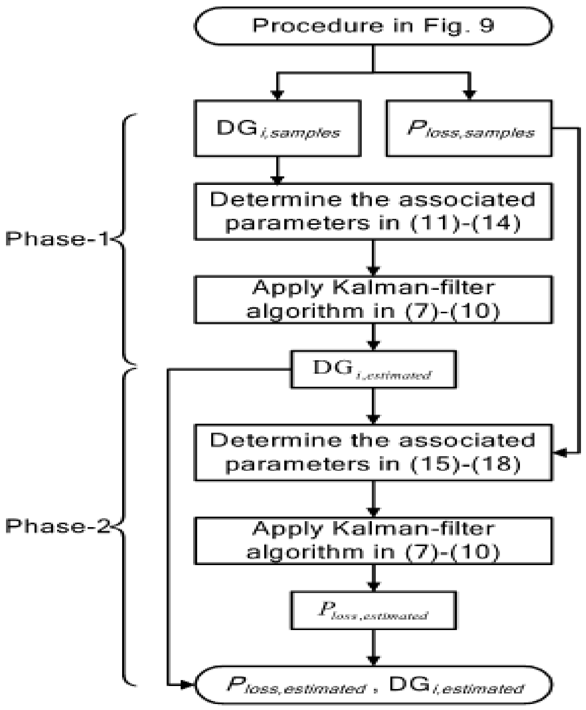

Figure 8: steps to estimate the optimal size of multiple DGs in two phases by applying the kalman filter algorithm.

In figure 7 the obtained data samples might be different from the actual values, due to the large sampling interval of 10MW. Due to this problem, the steps in figure (8) with two phases in application of kalman filter algorithm are taken to reduce the error between estimated and actual values, and then finally optimal sizes of multiple distribution generations are estimated.

Its associated parameters are as follows:

$$\delta(n) = \quad \sum_{i=1}^{4} DG_{i,samples(n)} \, / \max \times \left\{\sum_{i=1}^{4} DG_{i,samples}(n)\right\} \tag{10}$$

$$C_{phase-1}(n) = [\delta(n), \delta^2(n), \delta^3(n), \delta^4(n)] \tag{11}$$

$$Z(n)|_i = DG_{i,samples}(n) \tag{12}$$

$$DG_{i,estimated}(n) = \hat{Y}(n)$$
$$= C_{phase-1}(n).\hat{X}(n_{max}) \tag{13}$$

Where δ is the normalized value, and n_{max} is the number of last samples in $DG_{i,samples}$. To estimate the size of each DG, the Kalman filter algorithm is applied in sequence with different measurements of Z in (13).

The associated parameters required to apply the Kalman filter algorithm are given in the following:

$$\beta_i(n) = DG_{i,estimated}(n),$$
$$(i = 1,2,3,4) \tag{14}$$

$$C_{phase-2}(n) = [\beta_1(n), \beta_2(n), \beta_3(n), \beta_4(n)] \tag{15}$$

$$Z(n) = P_{loss,samples}(n) \tag{16}$$

$$P_{loss,estimated}(n) = \hat{Y}(n) = C_{phase-2}(n).\hat{X}(n_{max}) \tag{17}$$

Where β is the estimated size for each DG

IV. SIMULATION RESULTS

A. Procedure to find actual values:

To verify whether the optimal sizes of multiple DGs estimated by Kalman filter algorithm are acceptable are not to reduce power loss. For these actual values for each DG and total power loss are required.

These values are obtained by the following steps:

(1) Take the steps in figure 4 and 5.
(2) Reduce the value of Pstep by half.
(3) Repeat step (1) until state vector X converges to a constant value.
(4) Obtain total 'n' number of actual power loss and actual sizes of each DG.

B. Estimation performance of kalman filter algorithm:

The estimation performance of kalman filter algorithm is evaluated by root mean square error and is computed with actual measurements as follows

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{m=0}^{n-1} Y_m^{\mathrm{actual}} - Y_m^{\mathrm{estimated}}} \tag{18}$$

Where 'n' is the number of data samples. By applying the kalman filter algorithm, the estimated results for sizes of each DG are shown in figure (9) and Table 2. By observing, the RMSE values calculated with estimated sizes are significantly decreased when compared to the sampled case.

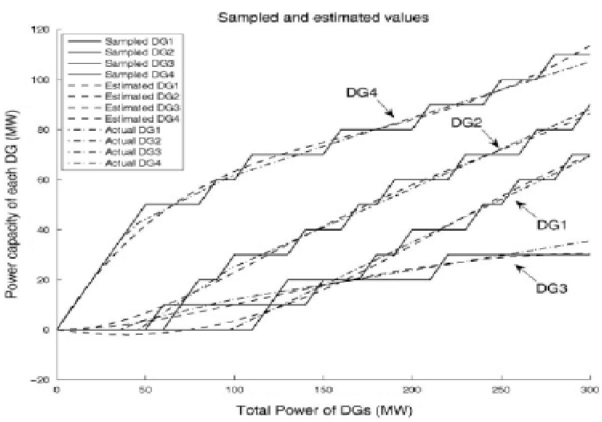

Figure 9: Estimation performance of the kalman filter algorithm for each DG

TABLE 2: Comparison of Rmse Values

RMSE	SAMPLED	ESTIMATED
DG1	2.4662	1.4061
DG2	2.8893	1.6863
DG3	2.9184	1.6363
DG4	3.2082	2.0435

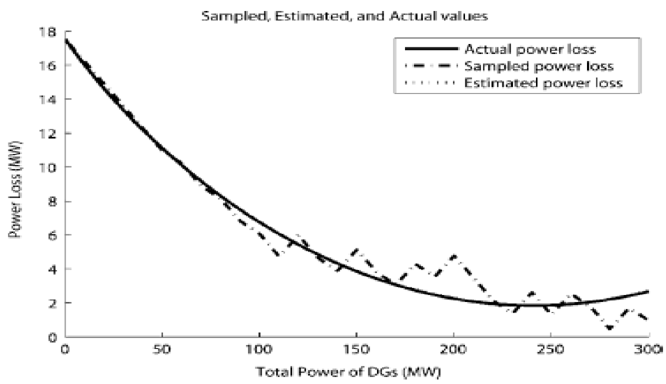

Figure.10: Estimation performance of total power loss.

TABLE-3 Comparison of Rms Values

Power loss	Sampled	Estimated
RMSE	0.9029	0.0272

Figure (10) and **Table 3** shows the estimation results for total power loss. Corresponding, the RMSE value of the estimated power loss is very low. Finally, observed that kalman filter algorithm provides a very accurate estimation performance when RMSE value is very low.

C. Effect by optimal size of multiple distribution generations:

From figure7, the minimum power loss is 1.907MW. The corresponding optimal sizes of MDGs which are estimated by kalman filter algorithm are 47.2, 67.7, 27.7 and 91.8MW for DG1, DG2, and DG3 andDG4respectively as shown in table. When the initial values of multiple DGs are used, the corresponding total power loss is 3.452MW even though the summation of the initial size of all DGs is the same as the above case with 234.4MW.

TABLE4: Comparison of power loss

	DG1	DG2	DG3	DG4	Sum of DGs	Total Ploss
Without DG and KF	45MW	44MW	28.4MW	117MW	234.4MW	19.016MW
With DG and without KF	45MW	44Mw	28.4MW	117MW	234.4Mw	3.452MW
With DG and with KF	47.2Mw	67.7MW	27.2MW	91.8MW	234.4MW	1.907MW

Finally total power loss is effectively reduced by the optimal size selection process. In particular, note that the size of DG2 in Area 2 is required to increase from 44 to 67.7 MW, which is a difference of 23.7 MW. In contrast, the size of DG4 in Area 4 is necessary to decrease significantly from 117 to 91.8 MW, which is a difference of 25.2 MW.

V. CONCLUSION

The method for selecting optimal locations and sizes of multiple distribution generations to minimize the total power loss of system is proposed by this paper. The kalman filter algorithm was applied to deal with this optimization problem. This study can be used as a decision making process in power system operation and planning for selecting optimal locations and size of multiple distributed generations based on renewable energy resources such as fuel cell, photovoltaic, wind turbine, micro turbine, etc.

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Shalini V.S is pursuing PG degree in Electrical Power system at SVPCET, RVS, Nagar, puttur,(AP).

Poornachandra Rao .N is working as Associate Professor in department of EEE, SVPCET, RVS Nagar, puttur, (AP).