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Multiple Distributed Generations Optimal Location Choice And Range By Using KFA

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ABSTRACT: The beneficial effects of DG mainly depend on its location and size. The non optimal placement of multiple DGs will lead to increase the losses in the system and also its cost of generation. Therefore, the selection of optimal location and size of the DG plays a key role to maintain the constant voltage profile and reliability of existing system effectively before it is connected to the power grid. In this paper, a method to determine the optimal locations of DG is proposed by considering power loss. Also, their optimal sizes are determined by using kalman filter algorithm. It also analysis the system cost of generation before and after placement of DG. The proposed KFA based approach is to be tested on standard IEEE-30 bus system.
Index Terms: Distributed Generation, Optimal location, Optimal Size, Power loss and Kalman filter algorithm.

I. INTRODUCTION

In response to the recently increased prices of oil and natural gas, it is expected that the electric power industry will undergo considerable and rapid change with respect to its structure, operation, planning, and regulation. Moreover, because of new constraints placed by economical, political, and environmental factors, trends in power system planning and operation are being pushed toward maximum utilization of existing electricity infrastructure with tight operating margins. Therefore, the electric utility companies are striving to achieve this objective via many different ways, one of which is to defer the distributed generation (DG) solution by an independent power producer (IPP) to meet growing customer load demand. In this case, deferral credits received by the IPP depend on the incremental system reliability improvement made by the DG solution. The DG is based on the renewable energy sources such as fuel cell, photovoltaic, and wind power as well as combined heat and power gas turbine, micro-turbine, etc. Distributed generation is an approach that employs small– scale technologies to produce electricity close to the end users of power. DG technologies often consist of modular (and sometimes renewable – energy) generators, and they offer a number of potential benefits. In many cases, distributed generators can provide lower. Cost electricity and higher power reliability and security with fewer environmental consequences than can traditional power generators. In contrast to the use of a few large- scale generating stations located far from load centers- the approach used in the traditional electric power paradigm. DG systems employ numerous, but small plants and can provide power onsite with little reliance on the distribution and transmission grid. DG technologies yield power in capacities that range from a fraction of a kilowatt (kW) to about 100 megawatts (MW). Utility – scale generation units generate power in capacities that often reach beyond 1,000 MW. 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. The non-optimal locations and non-optimal sizes of DG units may lead to stability, reliability, protection coordination, power loss, power quality issues, etc. [1]–[4].

First of all, it is important to determine the optimal location and size of a given DG before it is connected to a power system. Moreover, if multiple DGs are installed, an optimal approach for selection of their placement and sizing is imperative in order to maintain the stability and reliability of an existing power system effectively. This paper proposes a method to select the optimal locations of multiple DGs by considering total power loss in a steady-state operation. Thereafter, their optimal sizes and its costs of generation are determined by using the Kalman filter algorithm.

This paper is organized as follows. How to select the optimal locations of multiple DGs is described in Section 2. Next, the procedure to determine the optimal size of DGs at the selected locations is proposed by using the Kalman filter algorithm in Section 3. Then, the effectiveness of the proposed method is verified with the simulation results in Section 4 and also the estimated cost of generation for all the DGs shown in 5. Finally, the conclusions are given in Section 6.

II. SELECTION OF OPTIMAL LOCATIONS

A. Reduction of Power loss by connecting DG

The IEEE 30-bus system is shown in Fig. 1 [5], where all loads can be classified under one of two classes. The first classification is the directly-connected-bus while the second is the load-concentration-bus. The directly-connected-bus is defined as a bus connected to a reference bus that does not pass through any other buses. For example, buses 12, 14, 18, and 23 in Fig. 1 are the directly-connected-buses if bus 15 is chosen as a reference bus. The load-concentration-bus handles relatively large loads, and is more connected to the other directly connected buses when compared to other nearby buses. In fig. 1, buses 10, 12,27 and 5 can be selected as the representative load concentration buses of Areas 1 through 4, respectively. When the DG is applied to this system, it is not desirable to connect each DG to every load bus to minimize power loss. Instead, the multiple representative DGs can be connected to the load concent-ration-buses. Then, they provide an effect similar to the case where there are all DGs on each load bus, but with added benefit of reduced power loss [6]–[9].

The power loss, P_{loss} between the two buses i and j is computed from the simplified unit circuit shown in fig. 2 by the following equation:

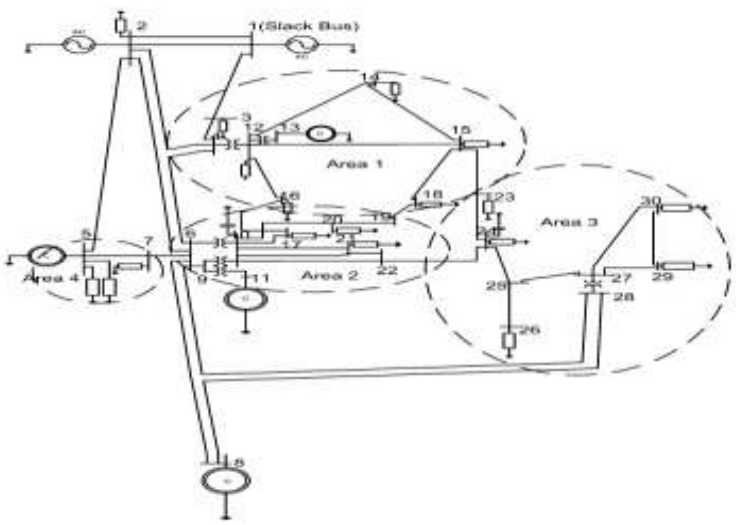

Fig. 1. IEEE 30-bus system

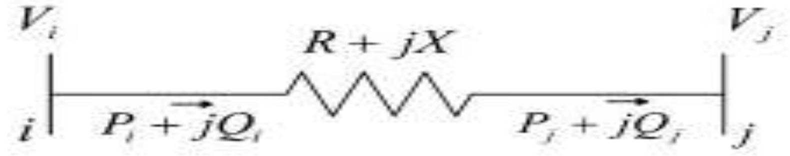

Fig.2. Simplified unit circuit between two buses

$$P_{loss,ij} = P_i - P_j \quad (1)$$

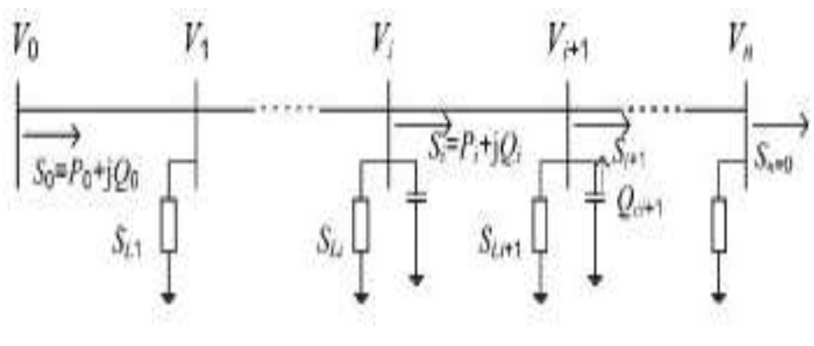

Fig.3. One line diagram of a distribution feeder

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

Also, the one-line diagram of a distribution feeder with a total of *n* unit circuits is shown in Fig. 3. When power flows in one of direction, the value of bus voltage, V_{i+1}, is smaller than that of V_i, and this associated equation can be expressed by (2). In general, the reactive power, Q_i, is reduced by connecting a capacitor bank on bus i in order to decrease the voltage gap between V_{i+1} and V_i . In other words, the capacitor bank at bus *i* makes it possible to reduce power loss and regulate the voltages by adjusting the value of Q_i in equation(2).

If a DG is installed at the location of the capacitor bank, the proper reactive power control of the DG has the same effect on the system as does the capacitor bank. Moreover, the main function of the DG is to supply real supplementary power to the required loads in an effective manner. The variation of power loss is relatively less sensitive to voltage changes when compared to the size of DG. In other words, the amount of real power supplied by the DG strongly influences the minimization of power loss. This means that the DG can control the bus voltage for reactive power compensation independently of its real power control to minimize power loss.

B. Selection of Optimal Location for DGs by Considering Power Loss

Before deriving the equations for the selection of optimal locations of DGs, the following terms are defined. The factor, D shown in the following is called the generalized generation distribution factor [10]:

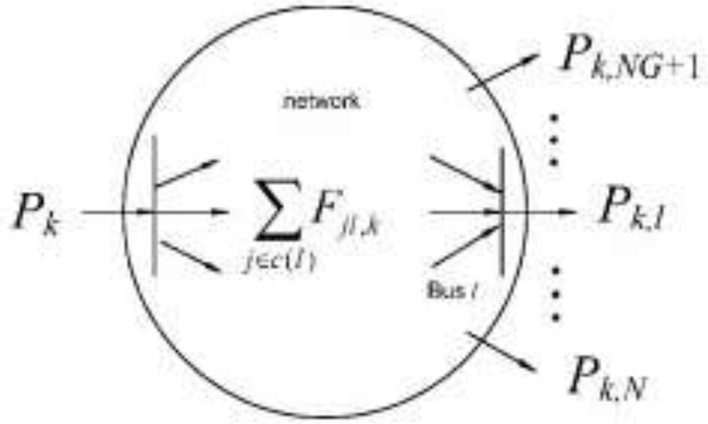

Fig.4. Power flow from the k^{th} generator to the other several loads.

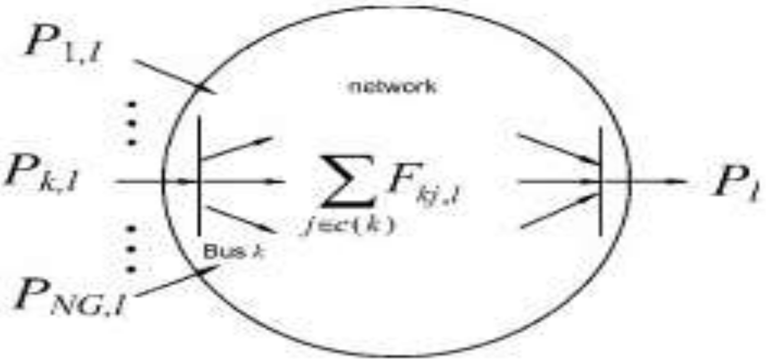

Fig.5. Power flow from the several generators to the l^{th} load

P_k: power supplied by the k^{th} generator in a power network
P_l: power consumed by the l^{th} load in a power network
$P_{k,l}$: power flowing from the k^{th} generator to the l^{th} load
$F_{jl,k}$: power flowing from the k^{th} generator to the l^{th} load through bus j connected to the *l* th load.
$D_{jl,k}$: ratio of $F_{jl,k}$ to the power supplied by the k^{th} generator
$P_{loss,k}$: power loss on transmission line due to the power supplied from the k^{th} generator
$F_{kj,l}$: power flow from the k^{th} generator to the l^{th} load through bus j connected to the k^{th} generator
$D_{kj,l}$: ratio of $F_{kj,l}$ to the power supplied by the k^{th} generator

$P_{loss,l}$: power loss on a transmission line due to power supplied to the l^{th} load
$P_{loss,ij}$: power loss between buses i and j

The IEEE 30-bus system in Fig. 1 is now analyzed for two different cases with respect to generator or load[11]. In other words, the first case is one where power flows from the *k* th generator to numerous loads. The second case is one where power is flowing from several generators to the *l* th load. These two conditions are shown in Figs. 4 and 5, respectively.

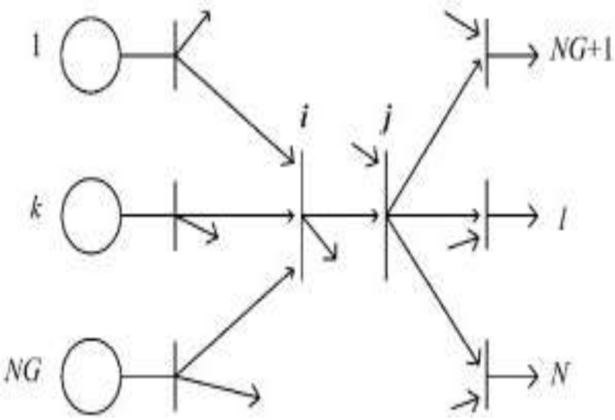

Fig.6. Simplified circuit with only power generations and consumptions.

For the first case (case-1), the power supplied from the *k* th generator to the *l* th load among several loads is calculated by the following:

$$P_{k,l|case-1} = \sum_{j\epsilon c\,(l)} F_{jl,k} = \sum_{j\epsilon c\,(l)} D_{jl,k}\, P_k \quad (3)$$

Where *c(l)* are the buses connected to the *l* th load. Then, the power loss associated with the *k* th generator is computed by the following, which is the difference between the power supplied from the *k* th generator and the sum of powers consumed in loads:

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

In the same manner, the power supplied from the *k* th generator among several generators to the *l* th load is calculated by the following for the second case (case-2):

$$P_{k,l|case-2} = \sum_{j\epsilon c\,(k)} F_{kj,l} = \sum_{j\epsilon c\,(k)} D_{kj,l}\, P_l \quad (5)$$

Where *c(k)* are the buses connected to the *k* th generator. The power loss associated with the *l* th load is computed by the following:

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

Table 1 Buses included in each area I fig.1

Area	Buses	Total amount of power consumption in loads
Area 1	3,4,12,13,14,15,16 and 18	45 MW
Area 2	10, 11, 17, 19, 20, 21, 22	44 MW
Area 3	23, 24, 25, 26, 27, 29, 30	28.4 MW
Area 4	5, 7	117 MW

Table 2 Buses with largest and smallest loads in each area

Area	Largest load bus	Smallest load bus
Area 1	12	16
Area 2	10	22
Area 3	27	26
Area 4	5	7

To minimize the total power loss, the largest load buses in each area, which are buses 12, 10, 27, and 5, can be selected as the optimal locations for the multiple DGs as the representative load-concentration-buses. Assume that the power losses between two adjacent buses in each area are negligible. In this case, the multiple DGs with the same size as the total amount of power consumption at each area might be implicitly used to minimize the power loss. In other words, the total system power loss is 3.452 MW if each DG in Areas 1 through 4 supplies the real power of 45, 44, 28.4, and 117 MW, respectively. The resulting system power loss of 3.452 MW will be compared with the total power loss computed after the optimal size of multiple DGs is systematically determined by using the Kalman filter algotihm.

III. PROCEDURE TO SELECT THE OPTIMAL SIZE OF MULTIPLE DGs USING KALMAN FILTER ALGORITHM

To deal with this problem, the Kalman filter algorithm is applied to select the optimal sizes of multiple DGs by minimizing the total power loss of system. The Kalman filter algorithm [12], [13] has the smoothing properties and the noise rejection capability robust to the process and measurement noises. In practical environments (in which the states are driven by process noise and observation is made in the presence of measurement noise), the estimation problem for the optimal sizes of multiple DGs can be formulated with a linear time-varying state equation. Also, the error from interval of computation can be reduced during the estimation optimization process. In this study, the state model applied for the estimation is given as

$$X(n+1) = \Phi X(n) + \Gamma\omega(n), x(0) = x_0$$
$$y(n) = c\,x(n)$$
$$z(n) = y(n) + v(n) \qquad (7)$$

Where the matrices $\Phi(\epsilon\ R^{n \times n})$ and $\Gamma(\epsilon\ R^{n \times m})$ and the vector, $c(\epsilon\ R^{1 \times n})$, are known deterministic variables, and the identity matrix $I(\epsilon\ R^{n \times n})$ is usually chosen for the matrix Φ. The state vector, $x(\epsilon\ R^{n \times 1})$,, can represent the size of each of the multiple DGs or their coefficients. Also, $(\epsilon\ R^{m \times})$ is the process noise vector, is the measured power loss, and *v* is stationary measurement noise. Then, the estimate of the state vector is updated by using the following steps.

- Measurement update: Acquire the measurements, *z(n)* and compute a *posteriori* quantities:

$$k(n) = P^{-}(n)\, c^{T}\, [cP^{-}(n)c^{T} + r]^{-1}$$
$$\hat{X}(n) = \hat{x}^{-}(n) + k(n)[z(n) - c\hat{x}^{-}(n)$$
$$P(n) = P^{-}(n) - k(n)cP^{-}(n) \qquad (8)$$

Where $k(\epsilon\ R^{n \times 1})$ is the kalman gain, P is a positive definite symmetric matrix, and *r* is a positive number selected to avoid a singular matrix $P^{-}(0)$ is given as $P^{-}(0) = \lambda I (\lambda > 0)$, where I is an identity matrix.

- Time update:

$$\hat{x}^{-}(n+1) = \Phi\hat{x}(n)$$
$$P^{-}(n+1) = \Phi P(n)^{T} + \Gamma Q \Gamma^{T} \qquad (9)$$

Where $Q(\epsilon\ R^{m \times m})$ is a positive definite covariance which is zero in this study because the stationary process and measurement noises are mutually independent.

- Time increment: Increment and repeat.

Thereafter, the estimated output (the total power loss of the system) is calculated as

$$y(n) = c\,\hat{x}(n) \qquad (10)$$

Fig. 7 shows the procedure to obtain data samples for the sizes of multiple DGs and the power loss required before applying the Kalman filter algorithm. In Stage-1 of Fig. 9, the algorithm begins with the zero values for all DGs, and the index denotes the number of given DG. After adding the small amount of power, P_{step} of 10 MW to each DG, the initial power loss is obtained by a power flow computation based on the Newton -Raphson method [5]. Then, the information on the individual power loss, P_{loss}, corresponding to each DG increased by 10 MW is sent to Stage-2, where the values of P_{loss} are substituted with those of P_{temp}. After the minimum value of P_{temp} is selected, its value and the corresponding sizes of multiple DGs are stored in the memory of $P_{losses,n}$ and $DG_{i,n}$ in Fig. 7, respectively. This process is then repeated until the total sum of all DGs is the same as the predefined value, P_{max}, in Stage-3 by increasing n to $n+1$. Finally, the accumulated data of the minimum power loss and sizes of DGs, which are $P_{losses,samples}$ and $DG_{i,samples}$ respectively, are obtained.

The data samples obtained above might be different from the actual values due to the large sampling interval of 10 MW. If this sampling interval is reduced to find more accurate values, the computational requirement will be dramatically increased. To deal with this problem, the steps in Fig. 8 with two phases in application of the Kalman filter algorithm are taken to reduce the error between the estimated and actual values, and then the optimal sizes of multiple DGs are finally estimated. In Phase-1 of Fig. 8, the estimated sizes of multiple DGs, $DG_{i,estimated}$, are determined by applying the Kalman filter algorithm with the data samples obtained from Fig. 7, which are $P_{losses,samples}$ and $DG_{i,samples}$. Its associated parameters are then given in the following:

$$\delta(n) = \sum_{i=1}^{4} DG_{i,samples}(n)/\max \times \left\{\sum_{i=1}^{4} DG_{i,samples}(n)\right\} \qquad (11)$$

$$c_{phase-1}(n) = [\delta(n), \delta^2(n), \delta^3(n), \delta^4(n)] \quad (12)$$

$$z(n)|i = DG_{i,samples}(n) \qquad (13)$$

$$DG_{i,estimated}(n) = \hat{y}(n) = c_{phase-1}(n)\,.\,\hat{x}_{\text{phase 1}}(n_{\max})|_i \quad (i=1, 2, 3, 4) \quad (14)$$

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).

After estimating the optimal sizes of multiple DGs in Phase-1, the total power loss, $P_{loss,estimated}$, is estimated in Phase-2 of Fig. 8 with the power loss data samples, $P_{loss,samples}$. From Fig. 7 and the estimated DG sizes, $DG_{i,estimated}$, in phase-1. The associated parameters required to apply the Kalman filter algorithm are given in the following:

$$\beta_i(n) = DG_{i,estimated}(n) \quad (i = 1, 2, 3, 4) \qquad (15)$$

$$c_{phase-2}(n) = [\beta_1(n), \beta_2(n), \beta_{3,}(n), \beta_4(n)] \quad (16)$$

$$z(n) = P_{loss,samples}(n) \qquad (17)$$

$$P_{loss,estimated}(n) = \hat{y}(n) = c_{phase-2}(n)\,.\,\hat{x}_{\text{phase-2}}(n_{\max}) \qquad (18)$$

Where β is the estimated size for each DG from (14).

IV. COST ANALYSIS

A power system can usually be divided into the subsystems of generation, transmission, and distribution facilities according to their functions. The basic function of the electrical power system is to supply the electricity to consumers with reliability and quality. Basically the consumers are far away from the generating stations, so they are severely effected by the low voltages. In order to improve the voltage levels we can generate the power locally by using the distributed generation(DG). Based upon distributed generation, we can also estimate the cost of generation.

- The annual cost ($) due to the power loss is calculated by

$$C_t = P_{loss,X}.F_{loss}.K_E.8760 \qquad (19)$$

Where K_E is the energy cost ($/kWh) and F_{loss} is the power loss factor which is the ratio between the average power loss and the peak power loss and is given as

$$K_E = 12.2600\$/kWh \qquad (20)$$

$$F_{loss} = \frac{Average\ power\ loss}{Peak\ power\ loss} \qquad (21)$$

To compute F_{loss} , a segment of historical load profile over a certain period is obtained from the metering database, and the power loss at each time point is calculated by running power flow. The peak power loss is the power loss at the peak load point and the average power loss is the average value of all of the time.

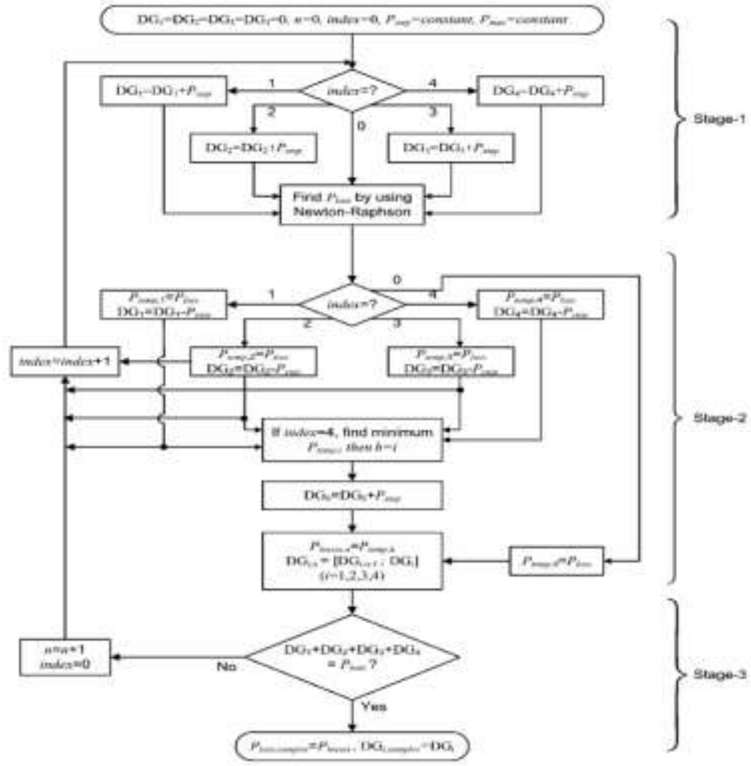

Fig.7. Procedure to obtain data samples of the multiple DGs and power loss required before applying the kalman filter algorithm

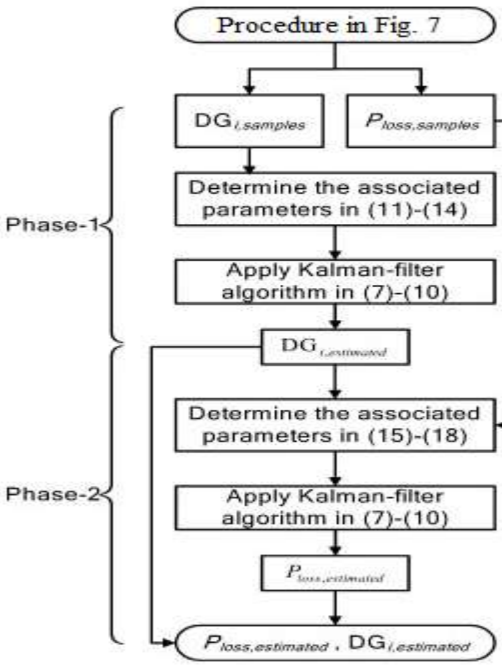

Fig.8. Steps to estimate the optimal size of multiple DGs in two phases by applying the kalman filter algorithm.

V. SIMULATION RESULTS

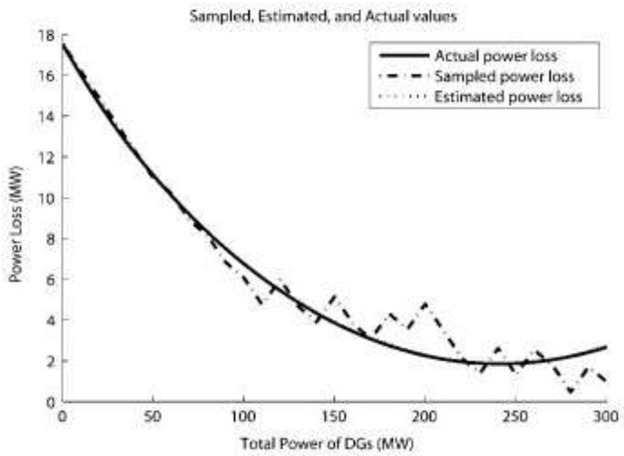

Fig.9. Estimation performance of total power loss

It is clearly observed that from the result shown in fig(9), the minimum value of total power loss is 1.907MW.The corresponding optimal sizes of multiple DGs , which are estimated by the kalman filter algorithm , are 47.2,67.7,27.7,and 91.8MW For the DG1, DG2, DG3 and DG4 respectively as shown in Table 4.The summation of the size of all DGs is 234.4MW. When the initial values of multiple DGs (i.e without optimal location and size) are used, the corresponding total power loss is 3.452MW even though the summation of the initial size of all DGs is same as the above case with 234.4MW.

Finally, the total power loss is effectively reduced by the optimal size selection process. In particular, note that the size in Area 2 is required to increase from 44 to 67.7 MW, of which is a difference of 23.7 MW. In contrast, the size of DG in Area 4 is necessary to decrease significantly from 117 to 91.8 MW, which is a difference of 25.2 MW. The summation of the size of all DGs is 234.4MW.

TABLE 3 Cost analysis

	Without DG and KFA	With DG and KFA
Cost of generation($)	178508.328	25827.018
Profit($)	-	152681.310

	DG_1	DG_2	DG_3	DG_4	Sum of DGs	Total power loss P_{loss}
Total amount of power consumption in loads	45 MW	44 MW	28.4 MW	117 MW	234.4 MW	19.016 MW
With DG and Without KFA	45 MW	44 MW	28.4 MW	117 MW	234.4 MW	3.452 MW
With DG and KFA	47.2 MW	67.7 MW	27.2 MW	91.8 MW	234.7 MW	1.907 MW

TABLE 4 Comparison of total power loss

VI. CONCLUSION

This paper proposed the method for selecting the optimal locations and sizes of multiple distributed generations (DGs) to minimize the total power loss and cost of generation. To deal with this optimization problem, the Kalman filter algorithm was applied. When the optimal sizes of multiple DGs are selected, the computation efforts might be significantly increased with many data samples from a large-scale power system because the entire system must be analyzed for each data sample. The proposed procedure based on the Kalman filter algorithm took the only few samples, and therefore reduced the computational requirement dramatically during the optimization process.

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