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DISTRIBUTED GENERATION (DG) PLACEMENT FOR REDUCING POWER LOSSES ON RADIAL DISTRIBUTION SYSTEM USING K-MEANS CLUSTERING METHOD

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ABSTRACT

To solve power losses problem appeared on distribution system is to put distributed generation (DG). The use of DG can be the solution improving network ability from decreasing power loss, voltage profile improvements, power quality, also reliability operation. But, research shows that missing precision on DG placement can make the system get bigger loss than the system without DG. So, we need a research and planning before integrating DG to the distribution network. This paper will be using K-means Clustering method which is grouping each bus from loss sensitivity factor (LSF) characteristic operational sight and voltage deviation (dV). Using this method, DG placement for single and multi DG will be the solution repairing value of power loss. The B1 case which became the base case have total 39.2436 kW power loss. After placing single DG until multi DG based on K-means Clustering, the result shows best power loss decreasing for B case become 6.050 kW at 3 DG placing.

Keywords: loss sensitivity factor, K-means clustering, radial distribution system, distributed generation, negative PQ load model.

INTRODUCTION

Growing developed radial distribution system become bigger and more complex, caused power loss increase and worst voltage profile. Research shows that almost 10-13% of thetotal power produced disappear as line losses which caused energy cost increase and worst voltage profile along distribution line [1]. Currently, a lot of solutions have been offered like a capacitor and Distributed Generation (DG) settings. Distributed Generation becomes an interesting alternative to planning a power system and it has a significant contribution to increasing efficiency and system performance. Research shows the use of DG at electric power distribution system can be the solution to increase network ability from voltage power improvement, decreasing power loss, power quality, and reliability operation [2].

Recently, plenty DG topics is being researched due to global issue about conventional generation damaging the environment. At the implementation, the using of DG in a distribution system has some parameters which should be considered, like the maximum capacity of DG usage and its placement. Research shows that missing precision on DG placement can make the system get bigger loss than a system without DG [3]. So, we need a research and planning before integrating DG to the distribution network. This paper proposed research about DG placement using K-means Clustering method. This method classifying every system nodes based on LSF (loss sensitivity factor) characteristic operation and dV (voltage deviation) which has been normalized. The result of classifying each bus with K-means Clustering will be the basic on the installation of DG placement at distribution line IEEE 33, 34 and 69 buses. Using this method, DG placement will be the solution to improve distribution network power loss either putting single DG or Multi DG distributed.

POWER FLOW METHOD

Calculation method to power flow analysis plenty backward forward has used especially at distribution system that has radial topological and a high ratio of R/X. A lot of development has been done for the backward forward method. Development used to accelerate calculation process and accommodating unbalanced three phase calculation. This paper the method that used to solve power flow problem is backward forward sweep method. The step of backward forward sweep method as follows:

a) The first step is backward sweep to calculate a current value that flows from the line by BIBC (Bus Injection to Branch Current) matrix formed. The current line value can be expressed in the equation:

$$I_k = \left(\frac{P_k + jQ_k}{V_k}\right)^* \quad (1)$$

Where I_k, P_k, jQ_k, V_k is the value of current, active power, reactive power, and voltage at the bus k.

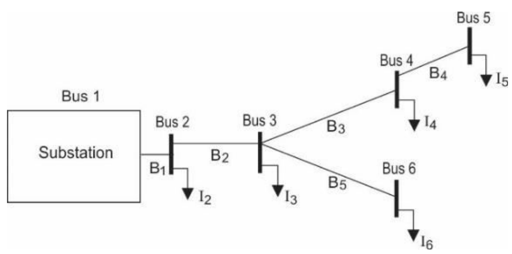

Figure-1. Sample of distribution system.

A simple distribution system at picture 1 supplying distributed load with a specific line. So, to get BIBC matrix, based on Kirchhoff current law the equation as follows:

VOL. 13, NO. 5, MARCH 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

$$B_5 = I_6 \quad (2)$$

$$B_4 = I_5 \quad (3)$$

$$B_3 = I_4 + I_5 \quad (4)$$

$$B_2 = I_3 + I_4 + I_5 + I_6 \quad (5)$$

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \quad (6)$$

Current injection to bus equation above can be simplified for the next calculation using matrix.

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (7)$$

Matrix equation above can be formulated to an equation with BIBC (Bus Injection to Branch Current) matrix components.

$$[B] = [BIBC][I] \quad (8)$$

b) The second step is forward to sweep to calculate voltage drop value at every bus initiated with BCBV (Brunch Current to Brunch Voltage) matrix formed. The connection between current branch and voltage bus can be determined based on Kirchhoff voltage law. For example, to connect to current branch and voltage bus at Figure-1 equation that can be formed:

$$V_2 = V_1 - B_1.Z_{12} \quad (9)$$

$$V_3 = V_2 - B_2.Z_{23} \quad (10)$$

$$V_4 = V_3 - B_3.Z_{34} \quad (11)$$

$$V_5 = V_4 - B_4.Z_{45} \quad (12)$$

$$V_6 = V_3 - B_5.Z_{26} \quad (13)$$

Distributing the equation above, we can get the equation as follows:

$$V_2 = V_1 - B_1.Z_{12}(14)$$

$$V_3 = V_1 - B_1.Z_{12} - B_2.Z_{23} \quad (15)$$

$$V_4 = V_1 - B_1.Z_{12} - B_2.Z_{23} - B_3.Z_{34} \quad (16)$$

$$V_5 = V_1 - B_1.Z_{12} - B_2.Z_{23} - B_3.Z_{34} - B_4.Z_{45} \quad (17)$$

$$V_6 = V_1 - B_1.Z_{12} - B_2.Z_{23} - B_5.Z_{26} \quad (18)$$

So voltage drop can be calculated become:

$$V_1 - V_2 = B_1.Z_{12}(19)$$

$$V_1 - V_3 = B_1.Z_{12} - B_2.Z_{23} \quad (20)$$

$$V_1 - V_4 = B_1.Z_{12} - B_2.Z_{23} - B_3.Z_{34} \quad (21)$$

$$V_1 - V_5 = B_1.Z_{12} - B_2.Z_{23} - B_3.Z_{34} - B_4.Z_{45} \quad (22)$$

$$V_1 - V_6 = B_1.Z_{12} - B_2.Z_{23} - B_3.Z_{34} - B_4.Z_{45} - B_5.Z_{26} \quad (23)$$

The equation above can be formed and done using BCBV (Branch Current to Branch Voltage) matrix components.

$$\begin{bmatrix} V_1 - V_2 \\ V_1 - V_3 \\ V_1 - V_4 \\ V_1 - V_5 \\ V_1 - V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (24)$$

So that, to get ΔV value obtained the last equation as follows:

$$[\Delta V] = [BCBV][BIBC][I] \quad (25)$$

$$[\Delta V] = [DLF][I] \quad (26)$$

DETERMINATION OF DG LOCATION BASED ON K-MEANS CLUSTERING METHOD

A. Loss sensitivity factors

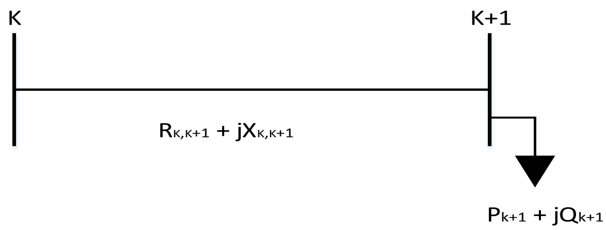

Figure-2. Simple distribution channel.

Loss Sensitivity Factors (LSF) Method has been used to solve some of the problems occurring in the distribution network system, for examples such as determining the location of the installation of the capacitor and the DG [3]. To be able to calculate the value of each node of LSF in a distribution system, we need to know the value of the load and voltage on each bus. Current and power flowing on each line and losses occur on each line obtained by analysis of power flow calculation. Figure-2 shows a simple distribution line which has the impedance Rk, k+1 + jXk, k+1 from the bus k to the bus k+1. On the bus k + 1 there is a load Pk + 1 + 1 + JQK. Active power losses in the line between the bus k and k + 1 formulated in the following (2) until (39) equation [3].

$$P_{Loss\_k,k+1} = (I_{k,k+1})^2 * (R_{k.k+1}) \quad (27)$$

$$P_{Loss\_k,k+1} = \left(\frac{(P_{k+1})^2 + (Q_{k+1})^2}{|V_{k+1}|^2}\right) * (R_{k.k+1}) \quad (28)$$

VOL. 13, NO. 5, MARCH 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

LSF value can be expressed by derivative of the equation 30 toP_{k+1}

$$\frac{\partial P_{loss_{k,k+1}}}{\partial P_{k+1}} = \frac{2*P_{k+1}*R_{k,k+1}}{|V_{k+1}|^2} \quad (29)$$

$$LSF = \frac{2*P_{k+1}*R_{k,k+1}}{|V_{k+1}|^2} \quad (30)$$

After the settlement of power flow, the value at each bus searched using the equation. LSF value then normalized in the range of 0-1 with the definition that 1 is the greatest sensitivity and 0 is the smallest sensitivity value. LSF normalization process is performed after obtaining all the LSF value from each node in the system, after that the value of LSF determined to LSF_{max} as the largest LSF value and LSF_{min} as the smallest LSF value. LSF normalization (l) is calculated using the following equation 31 [13].

$$l = \frac{LSF - LSF_{min}}{LSF_{max} - LSF_{min}} \quad (31)$$

Value of voltage deviation normalization (dU) of each bus in the system is obtained from the comparison between the value of voltage deviation of each bus (dV) with the system voltage (V_n), voltage deviation is the difference between the value of system voltage (V_n) with value of voltage on a bus (V_k) is defined in equation 32 below:

$$dV = V_n - V_k \quad (32)$$

$$dU = \frac{dV}{V_n} \quad (33)$$

This LSF normalization value (l) and voltage deviation normalization (v) of each node/bus in the distribution network system will be used as input for K-means Clustering method.

B. K-means clustering method

In the early stage of this method, the number of K cluster is defined first. Then specify the value of the center (centroid) of each cluster. Object data used for this method is the value of LSF normalization and dV. Furthermore, K-means test each LSF and dV of each bus and classify it into one of the predetermined centroid based on the minimum distance between data object with each existing centroid. The value of each centroid will be recalculated by calculating the average value of data object that goes into its cluster. This iteration will continue until the convergent condition, where the value of centroid is no longer changed, or the same as before. In more detail, the K-means Clustering algorithm is as follows:

a) Define the number of K cluster

The number of clusters is determined by the following equation 34 [14].

$$K \approx \sqrt{\frac{n}{2}} \quad (34)$$

K = number of cluster
n = number of data

b) Initiation of the center value (centroid) of each cluster. Centroid value can be determined by a random value or selected from first K data object [13].

c) Calculate the distance of each data with the centroid of each cluster. The distance used is Euclidean Distance according to the following equation

$$d(x_j, C_j) = \sqrt{\sum_{j=1}^{n} \sum_{i=1}^{m} (x_j - C_i)^2} \quad (35)$$

d) Classify each data into one of the clusters with the closest distance.
e) Recalculate the value of the centroid from the cluster as the average value of all data within each cluster.
f) Check the value of centroid

If the value of centroid shifted/changed from the previous centroid value, then go back to step 3. However, if the value of the centroid of each cluster has not changed (Convergent), then the K-means process has been completed [15].

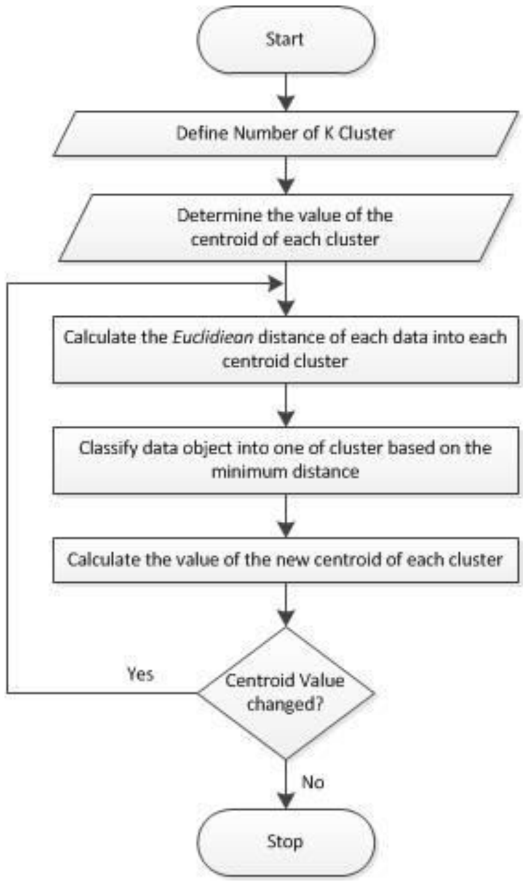

Figure-3. K-means clustering flowchart.

VOL. 13, NO. 5, MARCH 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

C. Determining candidates bus installation of DG

From the results of the clustering that has been done in the previous step, the candidate bus for the DG installation can be determined from each cluster [13]. After getting the results of clustering for each bus in the system, each cluster will be ranked based on the average value of LSF normalization and voltage deviation from each member of the cluster. Then this value is called cluster ranking index. After getting the cluster ranking then every bus in each cluster also ranked based on the value of LSF normalization and voltage deviation (clustering index).

Each bus that has the highest clustering index value from each cluster will be a candidate for the installation of DG on the distribution network system. The order of candidate is determined based on the rankings of each cluster. If bus A is the bus with the largest clustering index profile of cluster 1 which is also the cluster with the largest profile of cluster index rank of all existing cluster, then bus A will be the first candidate of the DG installation.

RESULTS AND VERIFICATION

In this paper used test distribution feeder system IEEE 34. This follows Single line diagram, the network and loaddata from IEEE 34 bus system:

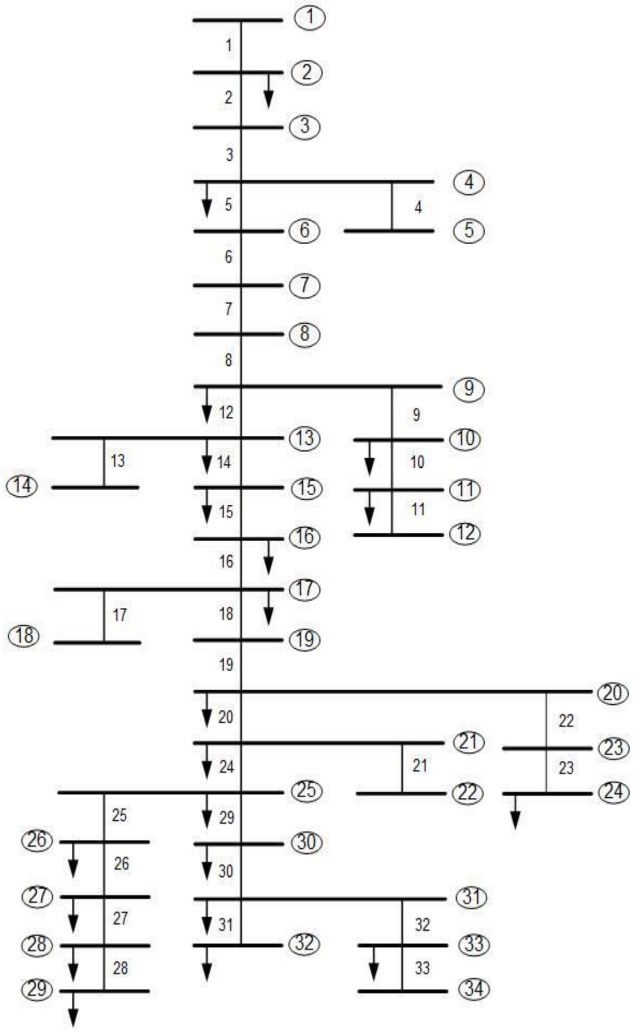

Figure-4. Single line diagram system IEEE 34 bus.

Table-1 and Table-2 are the network and loading data of IEEE 34 Bus System

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Table-1. Network data of IEEE 34 BusSystem.

Network		Impedance		Network		Impedance	
Bus	Bus	R (Ω)	X (Ω)	Bus	Bus	R (Ω)	X (Ω)
1	2	0.64988	0.65775	17	19	13.4104	9.9062
2	3	0.43577	0.44105	19	20	0.00364	0.00269
3	4	8.11854	8.21681	20	21	1.78416	1.31795
4	5	1.02577	0.5443	21	22	0.28631	0.15192
4	6	9.44602	9.56036	20	23	3.936	8.452
6	7	7.4888	7.57946	23	24	2.66	2.6922
7	8	0.00364	0.00269	21	25	2.12279	1.5681
8	9	0.11287	0.08338	25	26	0.10195	0.07531
9	10	0.30221	0.16036	26	27	0.49155	0.36311
10	11	8.50984	4.51558	27	28	1.32538	0.97905
11	12	2.42835	1.28855	28	29	0.19298	0.14255
9	13	3.71762	2.74619	25	30	0.73551	0.54332
13	14	0.53551	0.28415	30	31	0.97583	0.72084
13	15	0.30585	0.22593	31	32	0.3131	0.23131
15	16	7.4425	5.49776	31	33	0.10195	0.07531
16	17	0.1893	0.13986	33	34	0.5896	0.43605
17	18	4.1232	2.18792				

Table-2. Load data IEEE 34 Bus System.

Bus	P (kW)	Q (kVAR)	Bus	P (kW)	Q (kVAR)
2	0.0180	0.1000	18	0.0000	0.0000
3	0.0000	0.0000	19	0.0000	0.0000
4	0.0050	0.0030	20	0.0050	0.0020
5	0.0000	0.0000	21	0.0110	0.0060
6	0.0000	0.0000	22	0.0000	0.0000
7	0.0000	0.0000	23	0.0000	0.0000
8	0.0000	0.0000	24	0.1500	0.0750
9	0.0200	0.0010	25	0.0490	0.0240
10	0.0110	0.0060	26	0.0030	0.0020
11	0.0450	0.0230	27	0.1500	0.1130
12	0.0000	0.0000	28	0.0080	0.0040
13	0.0150	0.0070	29	0.0200	0.0160
14	0.0000	0.0000	30	0.0470	0.0300
15	0.0020	0.0010	31	0.0130	0.0070
16	0.0150	0.0070	32	0.0090	0.0070
17	0.0010	0.0010	33	0.0090	0.0050

In this research, DG placement analysis based on the K-means clustering using MATLAB 2014a and the results of running the program will be validated by 12.6 ETAP software. The analysis is passed to each feeder tested in this study by looking at the improvement of

ARPN Journal of Engineering and Applied Sciences

power loss value with a single to multi DG placement in accordance with the results of K-means clustering method.

A. The Results of clustering and sizing DG

Network distribution system IEEE 34 bus has a number of 34 objects data. In accordance with the 34^{th}equation, the total number of K-cluster set for this system is 4. After calculating the power flow analysis and then carried grouping bus using K-means clustering. Total iteration calculation for the clustering is 5 times. Then each cluster is sorted and shown in Table-3. The selected candidates for clustering analysis are buses 24, 25, 30 and 4.

Table-3. Results of clustering and candidates of Bus IEEE 34 Bus System.

Bus	LSF normalisation	D V normalisation	Index clustering	Cluster
1	0.0000	0.0000	0.0000	2
2	0.0251	0.0012	0.0131	2
3	0.0000	0.0019	0.0009	2
4	0.0895	0.0151	0.0523	2
5	0.0000	0.0151	0.0075	2
6	0.0000	0.0303	0.0151	2
7	0.0000	0.0423	0.0211	4
8	0.0000	0.0423	0.0211	4
9	0.0053	0.0424	0.0239	4
10	0.0078	0.0425	0.0251	4
11	0.8946	0.0433	0.4689	3
12	0.0000	0.0433	0.0217	4
13	0.1313	0.0472	0.0893	1
14	0.0000	0.0472	0.0236	4
15	0.0014	0.0476	0.0245	4
16	0.2683	0.0568	0.1626	1
17	0.0005	0.0570	0.0288	4
18	0.0000	0.0570	0.0285	4
19	0.0000	0.0732	0.0366	4
20	0.0000	0.0732	0.0366	4
21	0.0490	0.0747	0.0618	4
22	0.0000	0.0747	0.0373	4
23	0.0000	0.0753	0.0377	4
24	1.0000	0.0764	0.5382	3
25	0.2607	0.0764	0.1685	1
26	0.0008	0.0764	0.0386	4
27	0.1849	0.0767	0.1308	1
28	0.0266	0.0768	0.0517	4
29	0.0097	0.0768	0.0432	4
30	0.0867	0.0765	0.0816	4
31	0.0318	0.0766	0.0542	4
32	0.0071	0.0766	0.0418	4
33	0.0023	0.0766	0.0395	4
34	0.0000	0.0766	0.0383	4

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Table-3 shows the results of the clustering of each bus in the IEEE 34 bus system. Candidates buses are selected by the largest clustering index. Clustering index values areobtained from the average value of normalized LSF (l) and the voltage deviation (dV) of each bus. The selected candidate is the fourth bus of cluster 2, bus24 of cluster 3, bus 25 from cluster 1 and the bus 30 from cluster 4.

Table-4. Ranking cluster of IEEE 34 Bus System.

No	Cluster	Index
1	3	0.5036
2	1	0.1378
3	4	0.0371
4	2	0.0148

Table-4 shows the results of ranking clusters of IEEE 34 bus system. The index value is used to rank the clusters obtained by counting and sorting the average value of *l* and *dU* each of its members. From the consideration of the ranking can be concluded that the bus 24 be the first candidate, bus 25 bethe second candidate 2, bus 30 the third candidateand bus 4 is the fourth candidate.

Case study

There are five cases that will be discussed for the IEEE 34 bus network system shown in Table-5. The total load of the network system IEEE 34 bus is 0.606 MW and 0.44 MVAR, so DG total capacity is 0,303 MW and 0.22 MVAR.

Table-5. Case study of IEEE 34 Bus System.

Case	DG Location	DG Capacity	
B1 case - base case	Passive (without DG)	-	-
B2	Bus 24	0,303 MW	0,22 MVAR
B3	Bus 24 25	0,1515 MW	0,11 MVAR
B4	Bus 24 25 30	0,101 MW	0,074 MVAR
B5	Bus 24 25 30 4	0,0758 MW	0,055 MVAR

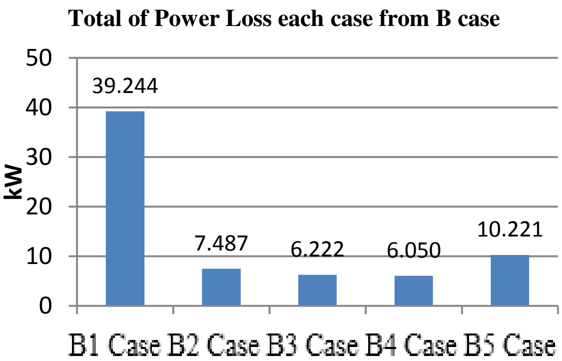

Figure-5. Result of case B simulation.

The result of the simulation case B shown in Figure-5. Installation of DG gives a significantreduction on power loss, at the time of installation one DG on bus 24, which is to be 7.487 kW. Rated power losses decrease at the time of installation two DG on buses 24 and 25 into 6.222 kW. The best results to improve the value of the power loss is obtained by placing 3 DG (case B4) on bus 24, 25 and 30 with the value of the power loss can be reduced up to 6,050 kW. At the time of installation of DG fourth, the value of the power loss increases up to 10.221 kW. This indicates the installation of DG fourth is not effective.

Power flow analysis validation result

Table-6. Study case validation result of IEEE 34 Bus System.

Case	P Loss MATLAB (kW)	P Loss ETAP (kW)	Error (%)
B1	39.2436	39.2312	0.0315%
B2	7.4874	7.4903	0.0389%
B3	6.2219	6.1790	0.6943%
B4	6.0499	6.0493	0.0093%
B5	10.2212	10.1775	0.4291%

CONCLUSIONS

Based on the result that obtained from simulation and analysis on this paper, the conclusion that can be made is:DG placement using K-means Clustering method has fast convergence. IEEE 34 bus Network system only need 5 times iteration. The result from active power calculation in IEEE 34 bus case (B case) has best improvement value on line losses at the4B case. There are at 3 DG installation with losses value become 6.0499 kW or 84.58% decrease from initial losses value. Validation result for voltage and losses value have biggest error value. There are 0,021% for the voltage at 7A case, and 0.6943% for losses at 3A case With equal total DG capacity and evenly divided at every DG, effective amount of DG installation is 3-4 DGs. Adding more amounts of DG make it inefficiently as the solution to improve value of power losses because from the case can be seen that the more DG installed did not make the value of power losses decrease, otherwise the value of power losses will be increased. K-means clustering method can be used as placement consideration to installing the DGs.

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