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Research Article

Optimal PV Placement to Reduce Power Loss and Improve Voltage in Distribution Network System using K-Means Clustering Method

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A B S T R A C T

Placing the PV in the right location will maintain the utility voltage, but if the placement of PV in the wrong location will cause the stability of the system to be affected. In this study, optimization of PV placement uses the K-means Clustering method. This method will group each node in the system from the point of view of operating characteristics LSF (loss sensitivity factor) and dV (voltage deviation). The results of grouping each bus with the K-means Clustering method will be the basis for determining the location of PV placement in the IEEE 37 and 69 bus distribution systems. In this method, grouping results are used based on the size of the proximity and have the same characteristics with each other. In determining the optimal location for PV placement, the addition of PV will reduce power losses and improve voltage. Optimal PV location placement in the IEEE 37 bus distribution system is placed on 3 buses with a capacity of 60% power capacity, where the value of power losses drops to 176.2 kW and the voltage profile is the best but there are some buses that are still under voltage and overvoltage. Meanwhile, the most optimal PV location for the IEEE 69 bus distribution system is placed on a 6 bus with a capacity of 60% of the power capacity, where the value of power losses drops to 149.5 kW and the voltage profile of each bus is in normal condition (allowable voltage limit).

INTRODUCTION

Electrical energy is energy that is needed to support all human activities. Energy requirements have increased significantly every year, especially the demand for electrical energy [1], [2]. With this increase, it causes the addition of an electrical energy distribution system. And this also causes the load on the electricity network to also increase [3]. The development of a radial distribution system that is getting bigger and more complex today causes higher power losses and a poor voltage profile. Studies show that almost 10-13% of the total power generated is lost as line losses leading to increased energy costs and poor voltage profile along distribution lines. Currently, many solutions have been offered, one of which is the placement of a solar power plant (PV) [4].

Placing the PV in the right location will maintain the utility voltage, but if the placement of the PV in the wrong location will cause the stability of the system to be affected. And if the PV is connected to a strategic location, the system will be more stable [5].

The optimal placement of solar power plants (PV) has been developed by several previous studies [5]–[7]. In this study, PV optimization was carried out using IEEE 37 and 69 [7]. The 37 bus is considered to be a balanced load.

For the determination of optimization, a PV placement optimization study will be proposed using the K-means Clustering method to obtain optimal power losses and voltage profiles. This method will group each node in the system from the point of view of operating characteristics LSF (loss sensitivity factor) and dV (voltage deviation). The results of grouping each bus with the K-means Clustering method will be the basis for determining the location of PV placement on the IEEE 37 and 69 bus on power distribution line [8]. This method is used because the results of grouping are based on the size of proximity and have the same characteristics with each other [9], [10]. In addition, this method is easy to implement [9]. By using this method, determining the location of PV will be obtained as a solution to reduce power losses and improve the voltage distribution network system. The study is focused on determining the optimal location for PV placement. In helping to analyze the system, ETAP 12.6 software was used. By using the ETAP 12.6 program the results that will be obtained in this study are improvements that occur in reducing losses and voltage profiles [8].

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Photovoltaic (PV)

Photovoltaic (PV) is a power plant that can convert solar energy into electrical energy. Photovoltaic cells are basically composed of two layers of semiconductors [9]. Photovoltaic on grid (a photovoltaic system integrated with the electricity grid) is a Green Energy solution for urban residents.

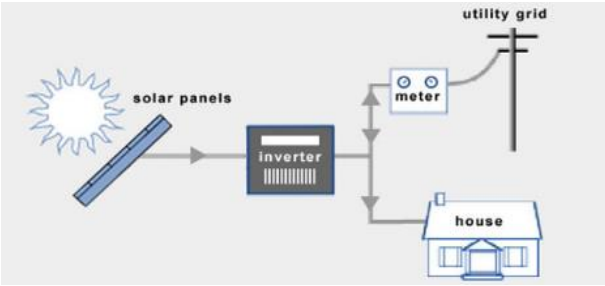

Figure 1. On grid Photovoltaic

Figure 1 describes the working principle of a photovoltaic system that is integrated with the power grid. Photovoltaic converts sunlight into direct current (DC) electrical energy. Then it is converted into alternating electric current (AC) using an inverter, then it is used to supply various equipment [10].

Effect of PV on Distribution Networks

Photovoltaic (PV) interconnection in the electric power network will change the active power flow, so that it will affect the voltage drop and power losses along the network. Power injection from photovoltaic (PV) into the power system will replace the load current so as to reduce the voltage drop and power loss in each component [11].

Losses and Voltage Drop in Distribution Networks

Losses (power loss) is the difference between the electrical energy supplied and the electrical energy used [12]. Losses in the distribution line are formulated as follows:

$$P = I^2 \cdot R \tag{1}$$

The equation to determine the amount of power losses on a 3-phase line is stated as follows:

$$\Delta P = 3I^2 \cdot R \tag{2}$$

Voltage drop can be defined as the amount of voltage lost in a conductor [12]:

$$\Delta V = V_s - V_R \tag{3}$$

$$\Delta V = \frac{V_s - V_R}{V_s} \times 100\% \tag{4}$$

Loss Sensitivity Factor

One type of sensitivity analysis is loss sensitivity factor whose function is to find a factor value. To be able to calculate the LSF value of each node in a power distribution system, it is necessary to first know the load and voltage values on each bus, the current and power flowing in each power line and the losses that arise in each power line obtained by analytical calculations. power flow [13]. The sensitivity factor for losses can be calculated by the following equation:

$$LSF = \left(\frac{2 \times P[j] \times R[k]}{V[j]^2} \right) \tag{5}$$

K-means Clustering

K-means clustering is an algorithm for classifying or grouping objects based on attributes into a number of K groups (positive integers number). The clustering is done by minimizing the sum of the squares of the distance between the data and the corresponding cluster centroid [14], [15]. This K-means clustering method partitions data into groups so that data with the same characteristics are included in the same group and data with different characteristics are grouped into other groups [16], [17].

One of the important steps in applying the K-means Cluster method is to determine the centroid, the number of clusters and the distance of the centroid. By forming several clusters using the Kmeans algorithm. It can also find out the distance between the central clusters (centroids) in the data to be analyzed. These results become the basis for classifying new data that later appears so that the group is known [9].

In more detail, the K-means Clustering algorithm is as follows [18]:

a. Define the number of K clusters
   The number of clusters is determined by the following equation (6):

$$K \approx \sqrt{\frac{n}{2}} \tag{6}$$

b. Initiation of the center value (centroid) of each cluster.
   The Centroid value can be determined by a random value or chosen from the first K data objects.
c. Calculate the distance of each data with the centroid of each cluster.
   The distance data used for the K-means Clustering method in this final project is Euclidean Distance. The Euclidean Distance equation is as follows [8]

$$d\left(x_j, C_j\right) = \sqrt{\sum_{j=1}^{n} \left(x_j - C_j\right)^2} \tag{7}$$

d. Group each data into one of the clusters with the closest distance.
e. Recalculate the centroid value of the cluster as the average value of all data in each cluster.
f. Check the centroid value
   If the centroid value shifts / changes from the previous centroid value, then return to step 3. However, if the value of the centroid of each cluster does not change (converge), then the K-means process has been completed.

METHODS

This research uses Loss Sensitivity Factor (LSF) and K-means Clustering methods to determine the optimal location for photovoltaic (PV) placement. The same formula is also used for the determination of PV injection power.

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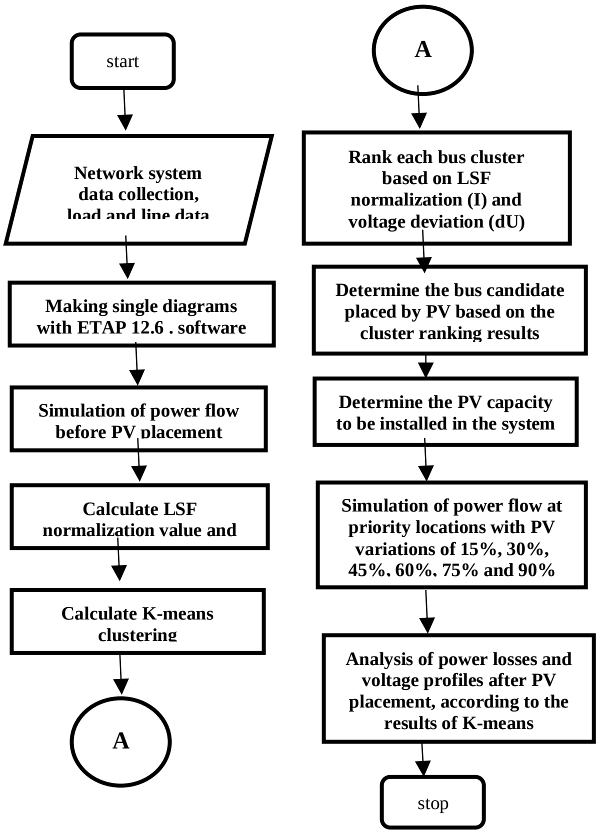

Figure 2. Research flowchart

RESULTS AND DISCUSSION

First, using the K-means Clustering method, each bus is grouped on the IEEE 37 bus and IEEE 69 bus radial distribution network systems. Then the simulation of power flow before and after PV placement is carried out based on the results of the grouping of the K-means Clustering method. This simulation will obtain the right number and location of PV placements to reduce line losses and improve voltage.

Analysis of Power Loss and Voltage Profile before PV Placement

In the IEEE 37 bus network system has a nominal voltage of 4.8 kV. The power loss in this system line is 353.9 KW. While the lowest voltage profile on the 740 bus is 0.6904 pu. The voltage profile before the photovoltaic placement can be seen in Figure 3 and the single-line diagram of IEEE 37-bus distribution test system is shown in Figure 4.

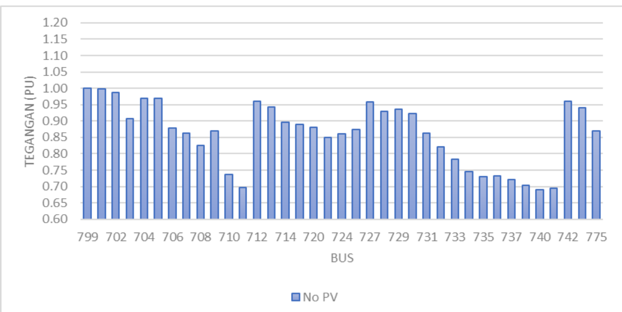

Figure 3. Voltage Profile before PV Addition On IEEE 37 bus network system

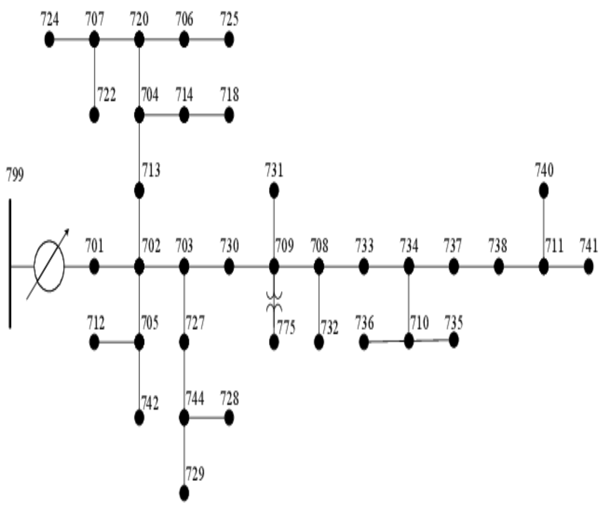

Figure 4. Single-line diagram of IEEE 37-bus (38-node) distribution test system

In the IEEE 69 bus system, the nominal voltage is 12.66 kV. The power loss in this system line is 225 KW. While the lowest voltage profile on bus 65 is 0.9257 pu. The voltage profile before the photovoltaic placement can be seen in Figure 5 and the single-line diagram of IEEE 69-bus distribution test system is shown in Figure 6.

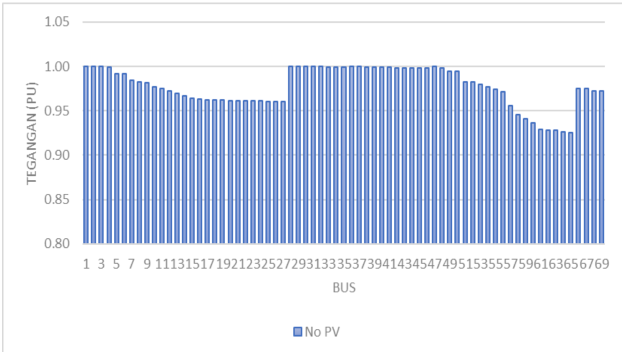

Figure 4. Voltage Profile before PV Addition On IEEE 69-bus network system

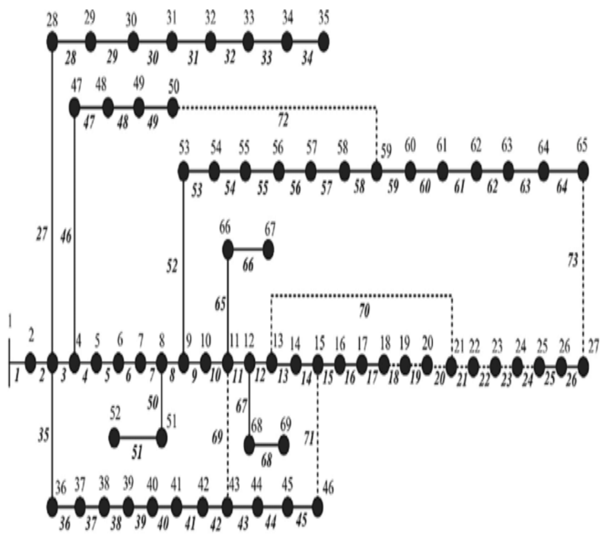

Figure 6. Single-line diagram of IEEE 69-bus distribution test system

Determination of PV Capacity

To find the optimal capacity, the penetration level of PV power injection in the distribution network is used. In the simulation used PV power injection of 15%, 30%, 45%, 60%, 75%, 90% of the power capacity which is obtained by the formula:

$$P_{PV} = PL \times P_T \quad (7)$$

Clustering Results in Determining PV Locations

The IEEE 37 bus distribution network system has 37 data objects. The number of K-clusters assigned to this system is 4. The power flow is calculated, then the buses are grouped using K-means Clustering. On the basis of bus selection as described previously the total calculation iteration for the clustering process is 8 times. Each cluster is sorted (Table 2). The ranking results for each bus in the cluster are bus candidates that will be paired with DG from each cluster as shown in Table 1. The candidate buses for PV installation are Bus 730, 713, 737 and 740.

Table 1. Results of Clustering Distribution Network System IEEE 37 bus

Bus	LSF normalization	dv normalization	Cluster index	K
702	0.5493	0.0015	0.2754	4
705	0.4394	0.0308	0.2351	3
713	0.6738	0.0567	0.3652	4
703	0.2923	0.0169	0.1546	3
727	0.6421	0.0410	0.3416	4
730	1.0000	0.0767	0.5383	2
714	0.2864	0.1038	0.1951	3
720	0.3764	0.0927	0.2346	3
742	0.2032	0.0398	0.1215	3
712	0.1789	0.0390	0.1089	1
725	0.0583	0.1256	0.0920	1
724	0.0584	0.1398	0.0991	1
722	0.3974	0.1500	0.2737	3
733	0.8211	0.2177	0.5194	2
732	0.0573	0.1785	0.1179	1
731	0.0609	0.1358	0.0984	1
708	0.8398	0.1750	0.5074	2
735	0.1810	0.2700	0.2255	1
736	0.0609	0.2669	0.1639	1
741	0.0001	0.3063	0.1532	1
740	0.1802	0.3096	0.2449	1
704	0.5689	0.0927	0.3308	4
718	0.1804	0.1113	0.1458	1
707	0.5088	0.1363	0.3225	4
706	0.0000	0.1219	0.0609	1
744	0.2354	0.0590	0.1472	3
709	0.9241	0.1292	0.5267	2
734	0.7261	0.2544	0.4903	2
737	0.4951	0.2796	0.3874	3
710	0.2941	0.2638	0.2789	3
738	0.2956	0.2956	0.2956	3
711	0.1190	0.3035	0.2113	1
728	0.2944	0.0708	0.1826	3
729	0.0591	0.0629	0.0610	1
701	0.3750	0.0015	0.1882	3

The IEEE 69 bus distribution network system has 69 data objects. The number of K-clusters assigned to this system is 6. The power flow is calculated, then the buses are grouped using K-means Clustering. The total calculation iteration for the clustering process is 4 times. Then each cluster is sorted and shown in Table 2. And the results of the ranking of each bus in the cluster that will be a candidate for a bus to be paired with PV from each cluster are shown in Table 2. The buses that are candidates for PV installation are Bus 57, 58, 61, 60, 15 and 65. Look at the table 2.

Table 2. Results of Clustering Distribution Network System IEEE 69 bus

Bus	LSF normalization	dv normalization	Cluster index	K
2	0.0006	0.0000	0.0003	6
3	0.0006	0.0001	0.0003	3
4	0.0018	0.0002	0.0010	3
5	0.0229	0.0009	0.0119	3
6	0.3394	0.0100	0.1747	1
7	0.3564	0.0192	0.1878	1
8	0.0845	0.0214	0.0529	6
9	0.0432	0.0226	0.0329	3
10	0.2120	0.0276	0.1198	2
11	0.0465	0.0287	0.0376	3
12	0.1346	0.0318	0.0832	6
13	0.1256	0.0348	0.0802	6
14	0.1249	0.0376	0.0812	6
15	0.1241	0.0405	0.0823	6
16	0.0229	0.0410	0.0320	3
17	0.0380	0.0419	0.0400	3
18	0.0004	0.0419	0.0212	3
19	0.0197	0.0424	0.0311	3
20	0.0127	0.0427	0.0277	3
21	0.0205	0.0431	0.0318	3
22	0.0003	0.0432	0.0217	3
23	0.0030	0.0432	0.0231	3
24	0.0066	0.0434	0.0250	3
25	0.0072	0.0436	0.0254	3
26	0.0030	0.0436	0.0233	3
27	0.0008	0.0437	0.0223	3
28	0.0001	0.0001	0.0001	3
29	0.0011	0.0002	0.0006	3
30	0.0037	0.0002	0.0020	3
31	0.0007	0.0002	0.0004	3
32	0.0033	0.0003	0.0018	3
33	0.0079	0.0006	0.0042	3
34	0.0086	0.0008	0.0047	3
35	0.0028	0.0009	0.0018	3
36	0.0002	0.0001	0.0002	3
37	0.0032	0.0002	0.0017	3
38	0.0044	0.0004	0.0024	3
39	0.0013	0.0005	0.0009	3
40	0.0001	0.0005	0.0003	3
41	0.0197	0.0012	0.0104	3
42	0.0082	0.0014	0.0048	3
43	0.0011	0.0015	0.0013	3
44	0.0002	0.0015	0.0009	3
45	0.0027	0.0016	0.0021	3
46	0.0000	0.0016	0.0008	3
47	0.0009	0.0002	0.0006	3
48	0.0228	0.0014	0.0121	3
49	0.0710	0.0053	0.0381	6
50	0.0100	0.0058	0.0079	3
51	0.0013	0.0215	0.0114	3
52	0.0004	0.0215	0.0110	3
53	0.1067	0.0254	0.0660	6
54	0.1246	0.0286	0.0766	6
55	0.1730	0.0331	0.1030	2
56	0.1696	0.0374	0.1035	2
57	1.0000	0.0599	0.5299	4
58	0.4907	0.0709	0.2808	1
59	0.1895	0.0753	0.1324	2
60	0.2275	0.0803	0.1539	2
61	0.3018	0.0877	0.1947	5
62	0.0117	0.0879	0.0498	3
63	0.0157	0.0883	0.0520	3
64	0.0773	0.0902	0.0838	6
65	0.0233	0.0908	0.0571	3
66	0.0024	0.0287	0.0155	3
67	0.0000	0.0287	0.0143	3
68	0.0139	0.0321	0.0230	3
69	0.0000	0.0321	0.0161	3

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PV Placement Optimization Analysis

The most optimal PV placement to reduce power losses and improve voltage is with scenarios using 3 PV with a PV injection power of 60%. In this scenario, PV is installed on buses 730, 713 and 737, a decrease in the value of power losses is obtained up to 176.2 kW or a decrease of 49.79%. As for the value of the voltage profile, it is also the best where there are only 2 buses in a state of under voltage, namely buses 722 and 724 and 2 buses in an overvoltage state, namely buses 703 and 730.

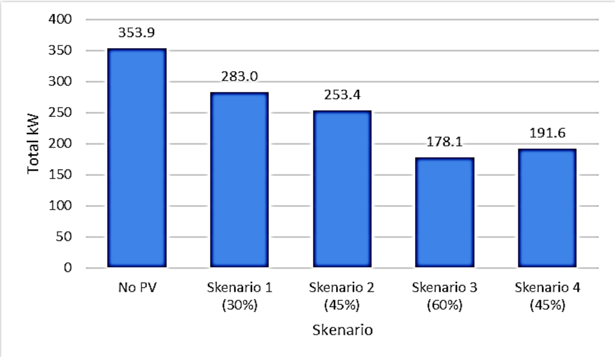

Figure 7. Comparison of the Best Reduction in Power Losses for Each Scenario on the 37 Bus Network

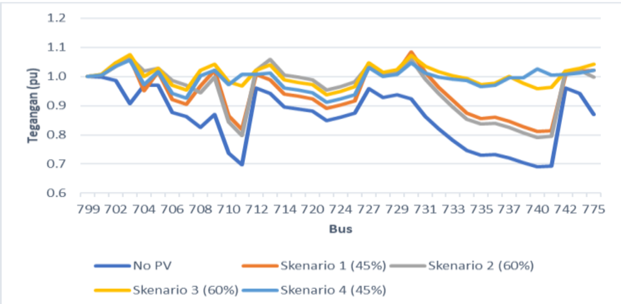

Figure 8. Comparison of the Best Voltage Profile Values from Each Scenario on the 37 Bus Network

The most optimal PV placement to reduce power losses and improve voltage is in scenario 6 using 6 PV with a PV injection power of 60%. In scenario 6, PV is installed on buses 57, 58, 61, 60, 15, 65, the minimum power losses are obtained when the injection power capacity is 60%, where there is a decrease in the value of power losses up to 149.5 kW or down by 66.4%. As for the value of the voltage profile at the time of injection power of 60% is not the best, but the value of the voltage profile of each bus is already in the range of 0.95-1.05 pu.

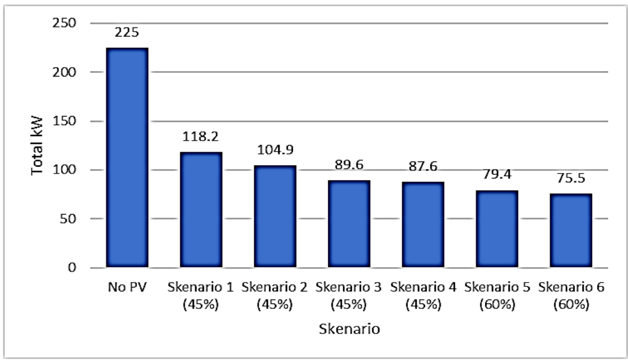

Figure 9. Comparison of the Best Reduction in Power Losses for Each Scenario on the 69 Bus Network

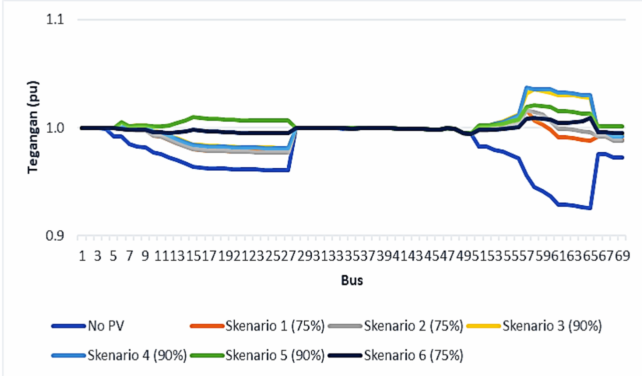

Figure 10. Comparison of the Best Voltage Profile Values from Each Scenario on the 69 Bus Network

CONCLUSIONS

After simulating and analyzing the 37 bus and 69 bus IEEE distribution system using the ETAP 12.6 software, it can be concluded here that the addition of a Solar Power Plant (PV) in the distribution network will reduce power losses when the PV capacity gets bigger. However, when it reaches the optimum capacity, the power losses increase again. This is caused when the current supplied by the PV exceeds the current capacity for the load. So the excess current will supply the line. Causes power losses on the line to increase again. And for the voltage profile, the greater the capacity of the PV, the better the voltage.

The most optimal PV placement for the IEEE 37 bus distribution network system is the installation of PV on 3 buses with a PV capacity of 60%. While the IEEE 69 bus distribution network system is the installation of PV S on 6 buses with a PV capacity of 60%.

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NOMENCLATURE

P = Losses on the conductor line (Watts)
I = Current flowing in conductor (A)
R = Conductor resistance (Ω)
ΔP = Power losses (KW)
I = Current flowing (Amperes)
ΔV = Voltage Drop (V)
V_S = Voltage on the sending side (V)
V_R = Voltage at the receiver side (V)
K = Number of clusters
n = Number of data
d = Distance
c = Centroid
x = Data
PL = Power injection rate (%)
P_{PV} = PV injection power (kVA)
P_T = Total load (kVA)