Optimization of DG Placement and Size Using PSO Based on GUI

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***Abstract*—The increasing demand for electricity at this time raises several problems to the power quality in the distribution network system. This is an opportunity to develop the power distribution network system. Distributed generation (DG) or small power plant spread over the distribution network level is one solution that could increase the power quality of the distribution system. Installation of distributed generation (DG) could increase the value of voltage, reduce power losses in the line, improve the reliability system, power quality, preventing drop voltages on the distribution network, maintain voltage level according to established standards and also as back up generation and voltage support especially at the summit load in the distribution network. So in accordance with the things described above it is designed a simulator determining the location and size of the optimally distributed generation (DG) by using Particle Swarm Optimization. In this simulator using the Graphical User Interface (GUI) system, so that in determining location, there's an easy view to understanding and it's expected to be used as non-technical considerations on the installation of distributed generation (DG).**

Keywords—Distributed Generation (DG) , PSO method, GUI

I. INTRODUCTION

An increase in electrical power demand raises several problems with the quality of power in the electricity distribution network system. This is an opportunity to develop and update the electrical power distribution network system to improve the quality of electricity services to customers. Distributed generation (DG) or electric power plants that are spread at the distribution network level is one solution that can improve the quality of electric power. Installation of distributed generation (DG) can reduce voltage drop, reduce power losses in the network, improve the level of reliability and technical safety parameters and reduce the flow congestion on the distribution network.

In previous research [1-2] has been discussed regarding the determination of the location and optimal DG using the Loss Sensitivity Factor method, then the PSO method [3-8]. These methods only display the voltage profile and do not display charts of active power losses, reactive power losses, or cos phi. Whereas in other research using Genetic Algorithms [9], Flower Pollination Algorithm (FPA) [10] and Artificial Bee Colony [11-12] the results obtained were not validated using other methods such as Newton Raphson [13], so the resulting data only refers to one method and also does not display Network SLD or Single Line Diagram.

This paper aims to optimize the placement and capacity of the DG to reduce power losses and improve the voltage profile on the system. This research was conducted with the distribution system model of the city of Surabaya, BasukiRahmat, using the Particle Swarm Optimization (PSO) method. In general, there is a type of DG. Type (1): active power supply, (2): reactive power supply, (3): active and reactive power supply, (4): active power supply and absorb reactive power. In this research, used DG with the type that can provide active and reactive power supply by referring to the leading of 0.8 - 0.9 power factor. This research uses two methods of power flow analysis, the first using Network Topology as the main data processor and the Modified Newton Raphson method as validation. For the interface using the Graphical User Interface (GUI) so that the data is presented to be more easily understood.

II. PROPOSED SYSTEM

Fig. 1 is a flowchart of the Optimization of DG Determination and size using PSO based on GUI

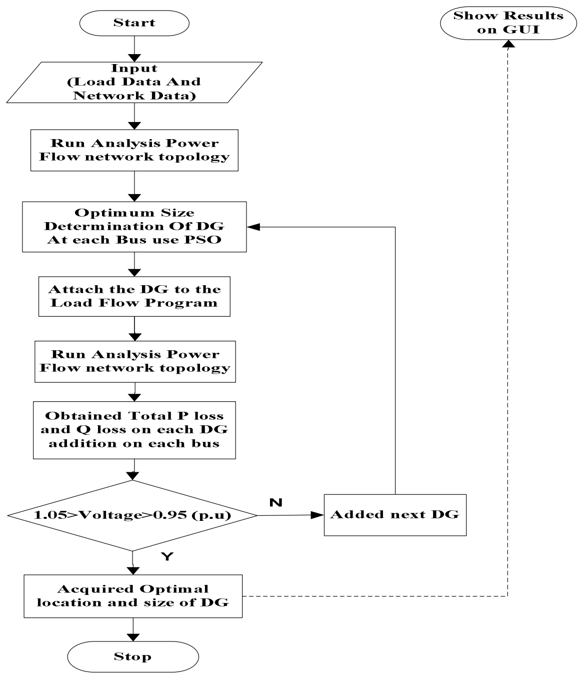

Fig. 1. Flowchart of Determination of Location and size DG

The flowchart in Fig 1. shows the application of PSO methods to determine the optimal location and size of DG for radial systems. In this research, a single line IEEE 33 bus diagram will be used as an object of comparison with other methods and is used as a validation of the results of the PSO method.

If the PSO method validation stage has been completed, then the PSO method will be applied to the electrical systems of the Surabaya city of Basuki Rahmat feeder. Graphical User Interface (GUI) is used in this study so that the data input process can be fast and practical and the results of determining the optimal DG location and size displayed are easy to understand. Power flow analysis is needed to determine the initial condition of the system, before it is carried out by adding DG to the system, which is seen from several parameters such as voltage, current, power factor, power flow from source to load and losses on the network.

A. Particle Swarm Optimization (PSO)

The Particle Swarm Optimization (PSO) algorithm was introduced by Kennedy and Eberhart in 1995, the algorithmic process inspired by social behavior in the flocks of birds that flew together [8]. Particle swarm optimization is a computational method that optimizes problems by iteratively trying to improve candidate solutions related to certain quality measures.

The following are the steps of the PSO process:

1. Determine the size of the swarm and determine the initial value of the position and speed of the particles randomly.
2. Evaluate the value of the objective function for each particle.
3. Determine Pbest and Gbest first.
4. Calculate the speed of the next iteration with (1)
   $Vj(i) = \theta Vj(i-1) + c_1r_1 [Pbest, j - Xj(i-1)] + c_2r_2 [Gbest - Xj(i-1)]$ (1)
   i = iteration; j = 1,2,3, ..., N; r_1 and r_2 are random numbers
5. Determine the position of the particles in the next iteration using (2)

   $$Xj(i) = Xj(i-1) + Vj(i) \quad (2)$$
6. Evaluate the value of the objective function in the next iteration
7. Updating *Pbest* and *Gbest*
8. Check whether the solution is optimal or not. If it is optimal, the algorithm process stops, but if it is not optimal, iterates again.

The main advantage of the PSO algorithm is that it has a simple concept, is easy to implement, is more flexible in maintaining a balance between global and local search for its search space and is efficient in calculations.

B. Network Topology For Load Flow Analysis

Electrical power flow analysis has various methods in analyzing an electric power system. Network topology is one method of power flow analysis which in its solution uses a network topology modeling to form a mathematical equation, which is then calculated and iterated to obtain the current value, voltage, power losses and the total generation power needed by the system. Network topology power flow analysis is very suitable to be applied in power systems with radial network topology. Following is an example of a radial system as shown in Fig. 1.

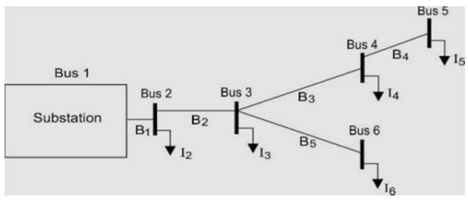

Fig. 2. Radial System

The initial step is to calculate the amount of current flowing on the network that is modeled in the form of a BIBC (Bus Injection to Branch Current) matrix. The value of network current can be written (3):

$$I_n = \left(\frac{P_n + jQ_n}{V_n}\right) \quad (3)$$

By applying the Kirchoff Current Laws equation to the network, the current injection on each bus can be modeled into a matrix function. Networks are modeled with variables B1 – B5. The current injection equation for each bus use equation (3) can be modeled into a matrix. The results of the modeling into the matrix is

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix} \quad (4)$$

Then a simpler equation can be written as

$$[B] = [BIBC][I] \quad (5)$$

The relationship between current and voltage can be obtained through (6)

$$V_2 = V_1 - B_1 Z_{12}$$

$$V_3 = V_2 - B_2 Z_{23} \quad (6)$$

$$V_4 = V_3 - B_3 Z_{34}$$

Where Z_{12}, Z_{23}, Z_{34} are the network impedances of sections 1-2, 2-3 and 3-4. By substituting equations (4) and (5) into equation (6), the voltage on bus 4 can be written as:

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \quad (7)$$

Furthermore, the bus voltage can be arranged in a matrix function of network current (BIBC), so that the BCBV (Branch Current to Branch Voltage) matrix is obtained in the same way as the above method is obtained (8) BCBV (Branch Current to Branch Voltage) matrix.

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (8)$$

Then a simpler equation can be written as :

$$[\Delta V] = [\boldsymbol{BCBV}][B] \quad (9)$$

Substituting (3) to (9) then at the end of the decline the value ΔV can be written with (9) and simplified to (10) as follows:

$$[\Delta V] = [\boldsymbol{BCBV}][\boldsymbol{BIBC}][I] \quad (10)$$

$$[\Delta V] = [\boldsymbol{DLF}][I]$$

Where, $[\boldsymbol{DLF}] = [\boldsymbol{BCBV}][\boldsymbol{BIBC}]$

$$[\Delta V^{k+1}] = [\boldsymbol{DLF}][I^k]$$

$$[V]^{k+1} = [V_1] - [\Delta V^{k+1}] \quad (11)$$

V_1 is the voltage of the Swing bus, so from (10) is obtained a voltage deviation value for each bus, then it will be updated to a value of (11) in each iteration, so that's obtained a valid voltage after the iteration becomes convergent.

C. Determination of Distributed Generation (DG) Size

Determination of the optimal size of distributed generation (DG) in a radial distribution system is explained as follows.

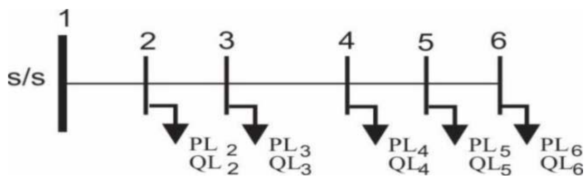

Fig. 3.Simple Example of a Radial System

From Fig.2, the distribution system model above can be modeled into the form of a simple mathematical equation, as shown in equations (12) and (13).

$$\mathrm{P_2} = \sum_{\mathrm{i=2}}^{\mathrm{NB=6}} \mathrm{PL_i} + \sum_{\mathrm{i=2}}^{\mathrm{NB-1}} \mathrm{Ploss'_i} \quad (12)$$

$$\mathrm{Q_2} = \sum_{\mathrm{i=2}}^{\mathrm{NB=6}} \mathrm{QL_i} + \sum_{\mathrm{i=2}}^{\mathrm{NB-1}} \mathrm{Qloss'_i} \quad (13)$$

From (12) and (13), it is shown that total active and reactive power is the total load and power losses in the network. Then bus 4 is installed a distributed generation (DG) is shown in Fig. 3.

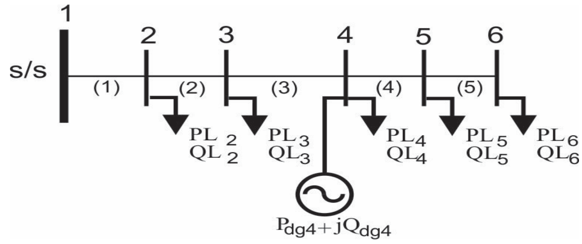

Fig. 4 Radial system installed (DG)

D. Determination of Distributed Generation Locations (DG)

After all, the buses get the optimal distributed generation (DG) installation size, furthermore, determine the optimal distributed generation (DG) location. In the stage of determining the location of distributed generation (DG) the calculation of TPloss values is carried out using (13) so that the optimal DG location and size are obtained and the DG installation is then performed at that location. To evaluate other parameters such as the voltage profile, power flow analysis is performed. If the result of the voltage value does not meet the predetermined constraint, then the next distributed generation (DG) size ranking will be obtained until the voltage is obtained that meets the constraint.

III. RESULT AND DISCUSSION

This system has been tested using a single line diagram for the IEEE 33 bus distribution system and a single line diagram in the Basuki Rahmat Surabaya feeder. Fig. 5 is a single line diagram on the Basuki Rahmat Surabaya feeder, while Table I and Table II are the load data and network data on the Basuki Rahmat Surabaya feeder.

Table III. is a result of the voltage profile program on the Basuki Rahmat feeder system before and after DG installation.

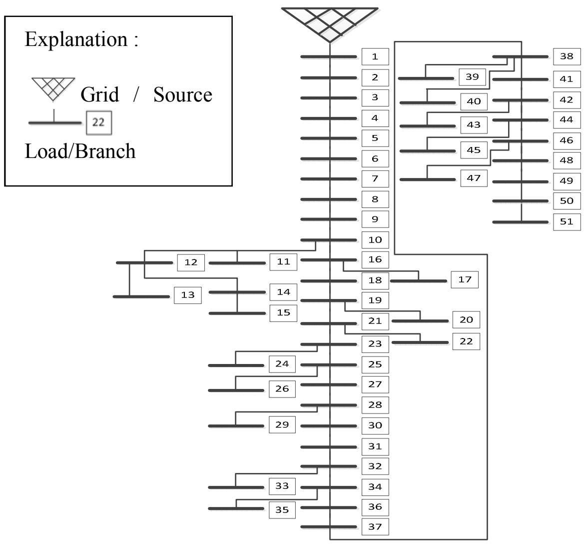

Fig. 5. Single Line Diagram Basuki Rahmat Surabaya Feeder

TABLE 1. LOAD DATA OF BASUKI RAHMAT SURABAYA FEEDER

Bus	Load		Bus	Load	
	P (MW)	Q(MVAR)		P (MW)	Q MVAR)
1	0.0000	0.0000	27	0.128	0.079
2	0.17	0.105	28	0	0
3	0.136	0.084	29	0.944	0.585
4	0.213	0.132	30	0.068	0.042
5	0.136	0.084	31	0.064	0.04
6	0.085	0.053	32	0	0
7	0.17	0.105	33	0.213	0.132
8	0.042	0.026	34	0	0
9	0.213	0.132	35	0.085	0.053
10	0	0	36	0	0
11	0.085	0.053	37	0.587	0.363
12	0	0	38	0	0
13	0.064	0.04	39	0.349	0.216
14	0.136	0.084	40	0.128	0.079
15	0.944	0.585	41	0.136	0.084
16	0	0	42	0	0
17	0.085	0.053	43	0.17	0.105
18	0.085	0.053	44	0	0
19	0	0	45	0.293	0.182
20	0.425	0.263	46	0	0
21	0	0	47	0.136	0.084
22	0.17	0.105	48	0.136	0.084
23	0	0	49	0.136	0.084
24	0.587	0.363	50	0.128	0.079
25	0	0	51	0.085	0.053
26	1.853	1.148			
Total	P = 9.385 MW and Q = 5.812 MVAR				

Table I. explains that system of the Basuki Rahmat feeder (Surabaya) with a base voltage of 20 kV, has a normal voltage profile, because the standard voltage is 1.05> voltage> 0.95 p.u. It is happening because the distance between buses is relatively short, so it has a small impedance value. So the voltage drop in the network is low and the lowest voltage profile in the system is bus 51 with a voltage of 0.99684512 *p.u* in Table III. Bus 51 is the bus with the farthest distance from the source (main substation).

In Table IV, the case of three DG installations the reverse power flow phenomenon occurs especially in the active power supply. This happens because active power supply by DG is greater than the power requirements of the system and the load voltage profile value is greater than the grid voltage, so that power flows from the load to the grid. The phenomenon of reverse power flow causes losses to the system, one of which is the increase in network losses in the system so that we optimize the installation of DG only 2 DG.

Fig. 6 is a comparison graph of bus voltage profile on the Basuki Rahmat feeder system before and after DG installation.

TABLE II NETWORK DATA

Network		Impedance (Ω)		Network		Impedance (Ω)	
Start Bus	Receive Bus	r	x	Start Bus	Receive Bus	r	x
1	2	0.021476	0.010738	25	27	0.00265	0.001325
2	3	0.002039	0.00102	27	28	0.002803	0.001401
3	4	0.001351	0.000675	28	29	0.001302	0.000651
4	5	0.002843	0.001422	28	30	0.004422	0.002211
5	6	0.008388	0.004194	30	31	0.009406	0.004703
6	7	0.010741	0.005371	31	32	0.001884	0.000942
7	8	0.014902	0.007451	32	33	0.002472	0.001236
8	9	0.002555	0.001278	32	34	0.003305	0.001653
9	10	0.00681	0.003405	34	35	0.002489	0.001244
10	11	0.002673	0.001336	34	36	0.004525	0.002263
10	12	0.007266	0.003633	36	37	0.003537	0.001769
12	13	0.000842	0.000421	36	38	0.005295	0.002647
13	14	0.002591	0.001295	38	39	0.002961	0.001481
14	15	0.007151	0.003575	38	40	0.00678	0.00339
10	16	0.004894	0.002447	38	41	0.004649	0.002324
16	17	0.004473	0.002237	41	42	0.00787	0.003935
16	18	0.005034	0.002517	42	43	0.001297	0.000648
18	19	0.009855	0.004928	42	44	0.003561	0.00178
19	20	0.003678	0.001839	44	45	0.002609	0.001305
19	21	0.004327	0.002164	44	46	0.000728	0.000364
21	22	0.001741	0.00087	46	47	0.000426	0.000213
21	23	0.003261	0.001631	46	48	0.005398	0.002699
23	24	0.005131	0.002566	48	49	0.0074	0.0037
23	25	0.006283	0.003141	49	50	0.004528	0.002264
25	26	0.005351	0.002675	50	51	0.003781	0.001891

TABLE III. VOLTAGE PROFILE ON THE BASUKI RAHMAT FEEDER SYSTEM BEFORE AND AFTER DG INSTALLATION

Bus	Voltage profile on bus (p.u)			Bus	Voltage profile on bus (p.u)		
	Initial	1 DG	2 DG		Initial	1 DG	2 DG
1	1.0000	1.0000	1.0000	27	0.9972	1.0000	1.0004
2	0.9993	0.9999	1.0000	28	0.9972	0.9999	1.0004
3	0.9993	0.9999	1.0000	29	0.9971	0.9999	1.0004
4	0.9992	0.9999	1.0000	30	0.9971	0.9999	1.0004
5	0.9992	0.9999	1.0000	31	0.9970	0.9998	1.0004
6	0.9989	0.9999	1.0000	32	0.9970	0.9998	1.0004
7	0.9986	0.9999	1.0001	33	0.9970	0.9998	1.0004
8	0.9982	0.9998	1.0001	34	0.9970	0.9998	1.0004
9	0.9981	0.9998	1.0001	35	0.9970	0.9998	1.0004
10	0.9979	0.9998	1.0001	36	0.9970	0.9997	1.0003
11	0.9979	0.9998	1.0001	37	0.9969	0.9997	1.0003
12	0.9979	0.9998	1.0001	38	0.9969	0.9997	1.0003
13	0.9979	0.9998	1.0001	39	0.9969	0.9997	1.0003
14	0.9979	0.9998	1.0001	40	0.9969	0.9997	1.0003
15	0.9979	0.9998	1.0001	41	0.9969	0.9997	1.0003
16	0.9978	0.9998	1.0002	42	0.9969	0.9997	1.0003
17	0.9978	0.9998	1.0002	43	0.9969	0.9997	1.0003
18	0.9977	0.9999	1.0002	44	0.9969	0.9997	1.0003
19	0.9975	0.9999	1.0003	45	0.9969	0.9997	1.0003
20	0.9975	0.9999	1.0003	46	0.9969	0.9997	1.0003
21	0.9974	0.9999	1.0004	47	0.9969	0.9997	1.0003
22	0.9974	0.9999	1.0004	48	0.9969	0.9996	1.0003
23	0.9973	1.0000	1.0004	49	0.9968	0.9996	1.0003
24	0.9973	0.9999	1.0004	50	0.9968	0.9996	1.0003
25	0.9972	1.0000	1.0005	51	0.9968	0.9996	1.0003
26	0.9972	1.0000	1.0004				

TABLE IV. LOCATION AND OPTIMAL DG SIZE IN THE PSO-BASED BASUKI RAHMAT FEEDER SYSTEM

DG	Optimal Size DG		PF DG	Optimal Location DG
	MW	MVAR		Bus
1	8.094	5.016	0.85	25
2	1.363	0.845	0.85	44
3	0.8412	0.400	0.85	14

At the beginning of the power flow analysis in the condition before the DG installation, the voltage profile is under voltage. After being installed 1DG or 2 DG, the voltage profile is obtained, which is 0.95 <voltage <1.05.

Fig. 7 is a comparison graph of Active Power Loss on the Basuki Rahmat feeder system before and after DG installation. While Fig. 8 is a Comparison graph of Reactive Power Loss on the Basuki Rahmat feeder system before and after DG installation.

Fig 7 and Fig. 8 are representing that before DG installation, there is an active and reactive power loss, but after DG installation 1 DG also 2 DG decreases active and reactive power losses. Fig 9. a graphical User Interface (GUI) Display

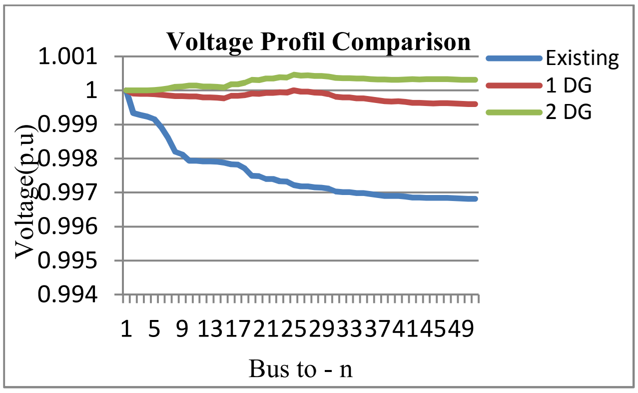

Fig. 6. Voltage Profile comparison

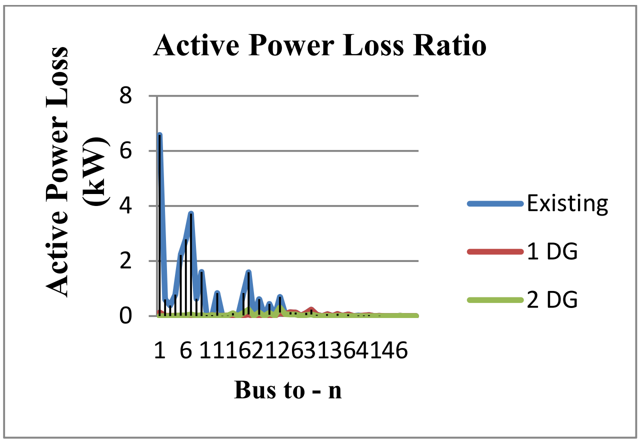

Fig. 7. Active Power Loss Ratio

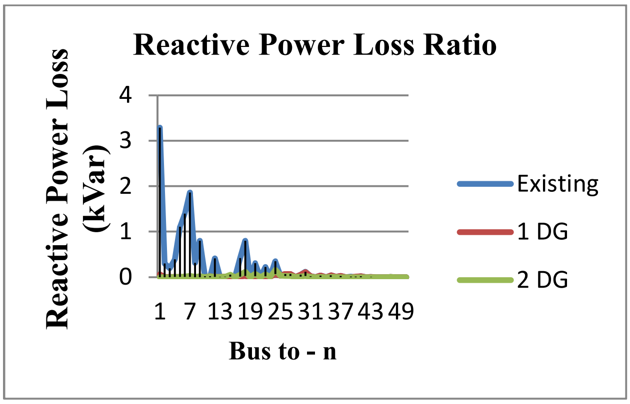

Fig. 8. Reactive Power Loss Ratio

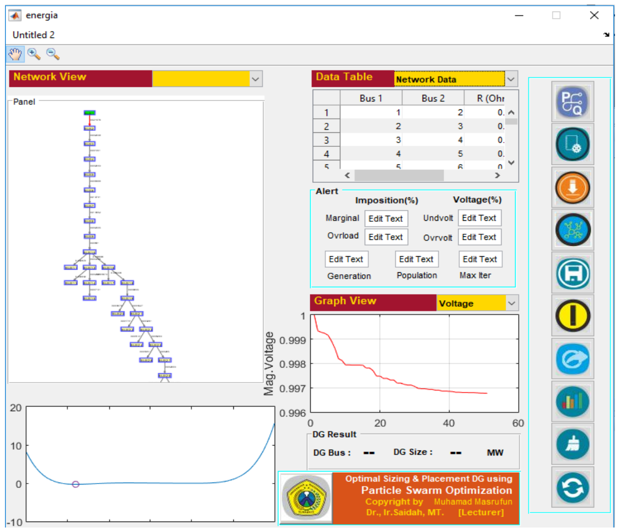

Fig. 9. Graphical User Interface

IV. CONCLUSION

In the Basuki Rahmat feeder system (Surabaya), the optimal DG number is 1 DG, that is, on bus 25 with a DG capacity of 9.5 MVA. The installation was able to reduce the total network power loss from 25.38 kW to 1.56 kW and raise the voltage profile for higher voltage values.

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