Optimal Capacitor Placement by Using CAPO Application and Bus Ranking Methodology

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***Abstract*-Transfer of electrical energy from the source of generation to the distribution via the transmission networks is accompanied by losses. It is widely recognized that placement of shunt capacitors on the distribution system can lead to a reduction in power losses, improve voltage profile and release system capacity. Reduction of I^2R loss in distribution systems is very essential to improve the overall efficiency of power delivery. The I^2R loss can be separate into two parts based on the active and reactive power components of branch currents. This thesis work presents a method of CAPO and bus ranking to place the optimal capacitor. The performance of the proposed method was investigated on distribution systems consisting 9buses and it was found that a significant loss saving can be achieved by placing optimal capacitors in the system. This method has been implemented using Digsilent software. Digsilent is used to model, simulate, and analyze network in distribution system.**

Keywords*: *Capacitor placement, loss minimization, cost saving energy and size of capacitor.

I. INTRODUCTION

The increase in power demand makes the operation systems more complicated. To meet the load demand, the systems is required to expand by increasing the substation capacity and the number of feeders, but this may not be easily achieved for many utilities due to various constrains. The losses in the distribution system correspond to 70% of the total losses [1]. By minimizing the power losses, the systems may acquire longer life span and have greater reliability.

Capacitor placement is an effective method used in distribution systems to reduce the losses, power flow control and improvement in stability. The capacitor placement problem consists of determining the location, type and the size of capacitors to be installed in the nodes of radial distribution system such that the economic benefits due to peak power and energy loss reduction [2]

In this paper, Digsilent software is used as a simulation tool. Digsilent software has developed in 1976 in Digsilent Gmbh Company of Germany. Other than that, the capabilities of this software are power flow calculation, sensitivity analysis, contingency analysis, short circuit analysis and reliability modeling.

The main objective of this paper is to study optimal location and size of the capacitor to be placed in radial distribution feeders to improve the voltage profile, reduce energy loss based on the loss reduction and cost of energy saving. The comparison will be making to show effect of CAPO application and Bus Ranking method in the network that gives the result in terms of total losses and minimum voltage [3].

II. METHODOLOGY

For this study there are several steps that have been applied to get a result. By using Digsilent, simulation have been made step by step. This paper is focused an optimal location and size of capacitor. To determine suitable locations for capacitor placement, the CAPO application and bus ranking is approached.

A) CAPO application

The objective of the CAPO application is to reduce the power losses and the power losses cost. By using this application, CAPO application will determine the optimal location of capacitor to be installed based on the lowest total power losses CAPO application also give the suitable size of capacitor in order to reduce total energy losses. Below is the procedure of CAPO application.

a) The 9-bus test system is designed. The modeling test system has been designed accordingly in Digsilent.
b) Insert all data of line, bus and source in the network.
c) Run load flow to obtain the result base on the network.
d) Insert the value of capacitor at CAPO application with starting of 10MVAR.
e) Run CAPO application to obtain the result of load flow after installing capacitor.
f) CAPO will determine the optimal location of capacitor based on lower total power losses.
g) Insert another size of capacitor with the increment of 10MVAR and run CAPO application to obtain the result. Repeat the step until the CAPO could not reduce total power losses.
h) Analyze the result and select the optimal placement of capacitor based on lowest total power losses.
i) Stop the operation.

Figure 1 shows the flow chart for the proposed method based on the CAPO application by using Digsilent software.

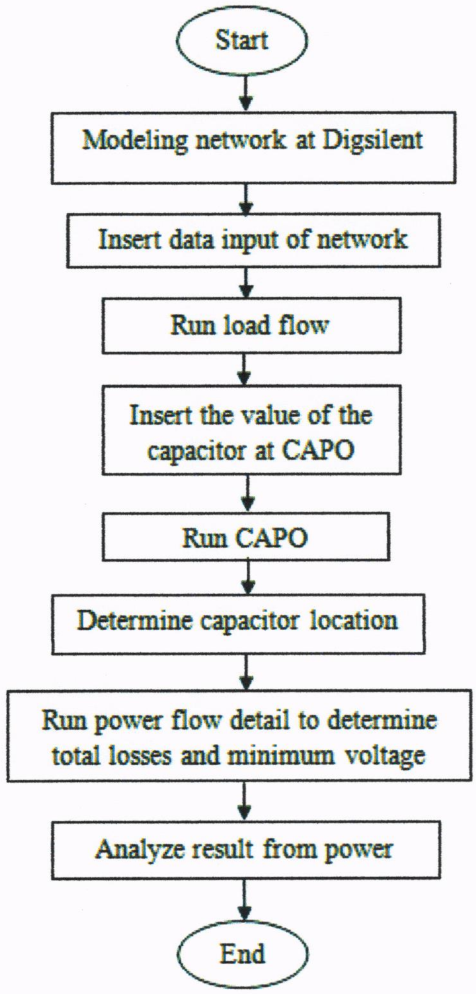

Figure 1. Flow chart of CAPO to obtain the capacitor placement on the network.

B) Bus Ranking method

Bus ranking method is used to determine the optimal location of the capacitor and the size of the capacitor. But the capacitor location and the size of the capacitor is depends on the load. Basically bus ranking consist of two parts which is simulation and calculation. To find the value of total power losses, the Digsilent was used to stimulate the network. The calculation part was used to determine the energy saving cost. Below is the procedure of bus ranking:

a) Run load flow to obtain the simulation result base on the network.

b) Place capacitor manually based on the value of reactive power at each load bus.
c) All load bus must be placed with capacitor to select the lowest total power losses at the placement of capacitor.
d) Run load flow detail to obtain the results of total power losses after installing capacitor. Capacitor is installed respectively and the result of each bus is obtained.
e) Analyzed the result from power flow analysis to determine the optimal location of capacitor based on the lowest total power losses.
f) Stop operation.

Figure 2 shows the flow chart for the proposed method based on the bus ranking method by using Digsilent software.

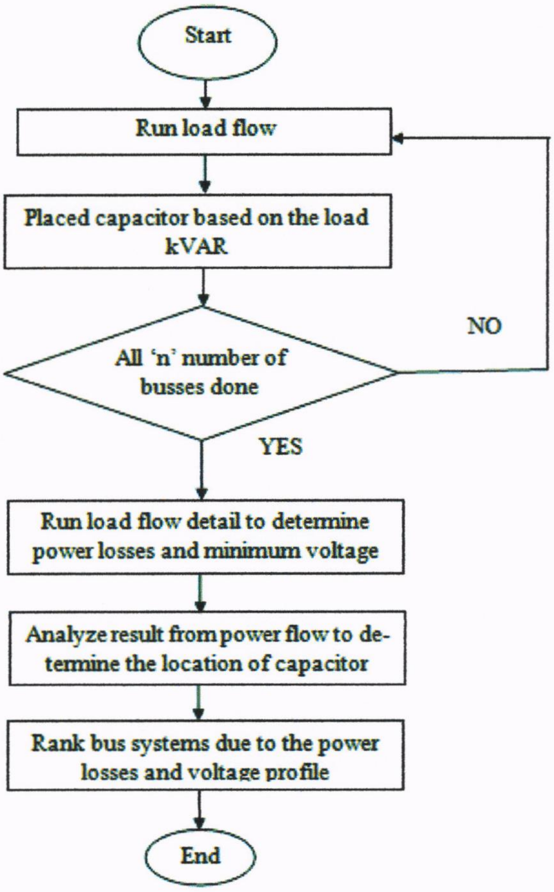

Figure 2. Flow chart of bus ranking method to obtain capacitor placement on the network

In bus ranking method, capacitor is installed manually instead of CAPO application using Digsilent simulation. The capacitor needed to be installed at every load buses with the total losses and minimum voltage are calculated at every time a capacitor is placed on a bus one after another using the load flow.

The bus which produces the maximum loss reduction and increasing in voltage magnitude are chosen to allocate the capacitor. The voltage magnitude must be in range 0.95-1.05 per unit (p.u). The analysis of bus ranking is same with CAPO application method that considering the total power reduction and minimum voltage magnitude.

C) Cost Energy Saving

Energy cost is the most concern in the distribution system. In order to reduce the cost of energy, capacitor placement has been installed at the appropriate place. For this purpose of project, saving cost energy has been calculated for both method and comparison has been made. The equation of saving energy is following:

$$KE = \Delta KE * r \tag{1}$$

Whereas:

ΔKE = Saving Energy (Annual energy before installing – Annual energy after installing capacitor)

r = cost of energy (RM 0.218 kWh)

III. RESULT AND DISCUSSION

The losses will represent the total power losses of the network. The total power reductions and the minimum voltage of the network without capacitor and with capacitor have been taken. This result also will be compared in the analysis. Figure 3 shows the IEEE-9bus test system that used in simulation to determine the total power losses and voltage magnitude. The system includes three generator and three large equivalent loads connected in a meshed transmission network through transmission line. Bus 1, 2 and 3 are generation. Bus 1 is selected as slack bus with a voltage 1.04p.u. Bus 2 and 3 are selected as bus PV type, with a voltage of 1.025p.u. Bus 5, 6 and 8 are load bus.

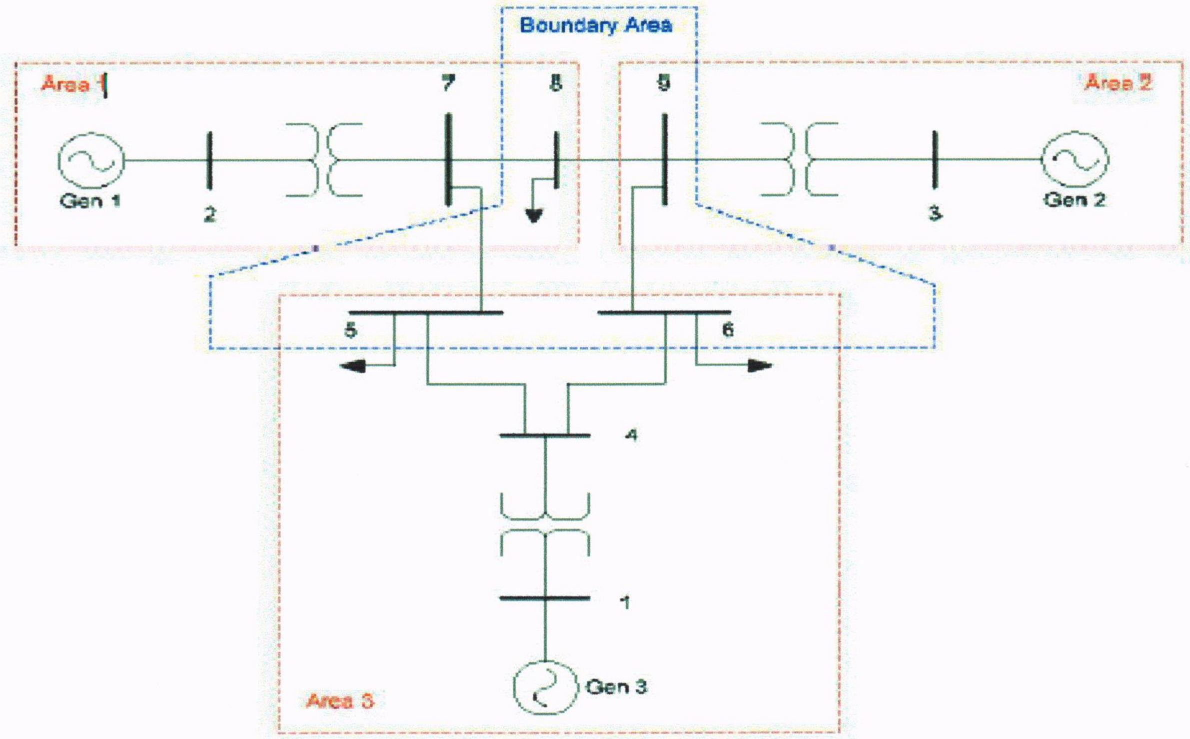

Figure 3. IEEE-9bus test systems.

A) Simulation result for bus network by using CAPO application

After done the simulation result by using CAPO, the capacitor will be added in network. The best location of the capacitor is chosen. The location of the capacitor is chosen depends on the maximum total power losses and the voltage magnitude is in range 0.95-1.05 per unit (p.u). The total power loss is in watt and minimum voltage is in per unit value.

Table 1 shows the result of the IEEE-9bus network using CAPO application to compare the result of the loss reduction before compensation and after compensation. After install the capacitor 40MVAR, the total power losses are reduced from 4637.417kW to 4493.067kW, i.e. 3.113% losses reduction. The result obtain in these systems are briefly describe as below.

TABLE I. TOTAL POWER LOSSES BEFORE COMPENSATION AND AFTER COMPENSATION

	BEFORE COMPENSATION	AFTER COMPENSATION
TYPE	**Loss Reduction (kW)**	**Loss Reduction (kW)**
Line 4-5	256.8226	153.3523
Line 5-7	229.8314	244.0123
Line 5-7	2069.252	2040.135
Line 7-8	474.6963	466.6207
Line 8-9	88.23463	79.94814
Line 6-9	1351.737	1332.23
Line 4-6	166.8389	176.7687
TOTAL	**4637.417**	**4493.067**

As it can be seen in table 2 capacitor size inserted with the increment of 10MVAR to 50MVAR and the total power losses and voltage magnitude is tabulated. 50 MVAR is the limit of capacitor size to be placed at each bus and if exceed the value, the total power losses will be increase.

TABLE 2. *CAPACITOR LOCATION OF THE SYSTEM*

Size Qcap (MVAR)	Bus location	Total power losses (kW)	Min. Voltage (p.u)
No capacitor	-	4637.417	1.014384
10	Bus 5	4569.314	1.01766
20	Bus 5	4521.807	1.020992
30	Bus 5	4496.003	1.024382
40	**Bus 5**	**4493.067**	**1.02783**
50	Bus 7	4494.315	1.02823

From the data tabulate by using CAPO, the optimal capacitor placement is at bus 5 with 40 MVAR optimal value of capacitor. The total power losses after installing capacitor are 4493.067kW and the minimum value of voltage is 1.02783p.u.

$$KE = \Delta KE * r$$

P_{losses} = 4637.417 kW (before compensated)

P_{losses} = 4493.067 kW (After compensated)

Reduction losses = 4637.417- 4493.067
= 144.35 kW

KE = (4637.417- 4493.067)(0.218)(24)(365)

= RM 275662308 per year

Based on the result obtained, saving energy cost is RM 275662308 per year. Bus 5 has been selected because by placing capacitor at this bus, the power factor have improve a lot rather than others bus. So the power losses in line will also reduce and improve the voltage stability.

B) Simulation result for bus network by using Bus ranking method

In bus ranking method, the size of the capacitor have been used is depends on load at each bus. The size have been used is shown in table 5. The capacitor is placed at bus 5, 6 and 8 that consist of loads. Table 3 shows the result of total power reduction. The result is compared with the bus that installed capacitor in each bus location.

TABLE 3. POWER LOSS REDUCTION BEFORE AND AFTER COMPENSATION

TYPE	BEFORE COMPEN-SATION Total Reduction (kW)	AFTER COMPENSATION Total Reduction(kW)			
		Capacitor Location			
		5	6	8	5,6,8 (simultaneously)
Line 4-5	256.8266	151.0708	269.3779	233.5757	149.4671
line 5-7	229.8314	250.8821	229.2794	223.6599	244.8348
line 5-7	2069.252	2060.443	2036.255	2039.44	1997.778
line 7-8	474.6963	464.7086	471.3283	477.2869	459.2741
line 8-9	88.23463	78.20499	92.92489	65.39029	67.54618
line 6-9	1351.737	1328.907	1395.046	1334.121	1381.186
line 4-6	166.8389	180.0137	168.7794	158.3878	160.5682
Total	**4637.4168**	**4514.230**	**4662.991**	**4531.862**	**4460.654**

Table 4 shows the result of minimum voltage magnitude between the capacitor locations at each bus.

TABLE 4. MINIMUM VOLTAGE BEFORE COMPENSATION AND AFTER COMPENSATION

TYPE	BEFORE COMPEN-SATION Min. Voltage(p.u)	AFTER COMPENSATION Min. Voltage(p.u)			
		Capacitor Location			
		5	6	8	5,6,8
Bus 1	1.032359	1.037672	1.038941	1.041461	1.05366
Bus 2	1.017359	1.022672	1.023941	1.026461	1.03866
Bus 3	1.017359	1.022672	1.023941	1.026461	1.03866
Bus 4	1.018177	1.041114	1.035043	1.030864	1.07143
Bus 5	0.988064	1.040286	1.003002	1.003957	1.07227
Bus 6	1.005039	1.024296	1.040385	1.019973	1.07564
Bus 7	1.018134	1.035124	1.028018	1.038682	1.06621
Bus 8	1.008248	1.022867	1.019632	1.043817	1.07067
Bus 9	1.024718	1.035344	1.037882	1.042921	1.06732
Total	**1.014384**	**1.031339**	**1.027865**	**1.030511**	**1.06161**

From the result obtain in table 3, the value of the power loss reduction is lowest at the bus 5, 6 and 8 that installed in simultaneously that is 4460.654kW, but the value of the minimum voltage is not in range, 1.06161 per unit. The range of the voltage has been mentioned before. So, the optimal placement of the capacitor is not in bus 5, 6 and 8(simultaneously installed). So, the optimal placement of the capacitor is shown in table 5.

TABLE 5. OPTIMUM SIZE OF CAPACITOR

Size Qcap (MVAR)	Bus location	Total power losses (kW)	Min. Voltage, p.u
50	**Bus 5**	**4514.23**	**1.031339**
30	Bus 6	4662.991	1.027865
35	Bus 8	4531.862	1.030511
115	Bus 5,6,8	4460.654	1.06161

Result shows the optimum size of the capacitor to be placed in network is 50MVAR at bus 5 because the total loss reduction is lowest and the minimum voltage is in range.

Table 6 below shows the differential of CAPO and Bus Ranking method. The CAPO application method is more saving than the bus ranking method. The cost of energy saving for CAPO application per year by using the equation in (1) is RM 275662308 and Bus Ranking method is RM 235247750.20 and the total loss power reduction by using CAPO application is less than Bus Ranking method. So, the best method to use by considering the total power loss reduction and voltage magnitude is CAPO application.

$$KE = \Delta KE * r$$

P_{losses} = 4637.41683kW (before compensated)

P_{losses} = 4514.23kW (After compensated)

Reduction losses = 4637.417-4514.23
= 123.187 kW

KE = (4637.4168-4514.230)(0.218)(24)(365)

= RM 235247750.2per year

TABLE 6. SUMMARY CAPO AND BUS RANKING METHOD

	CAPO	Bus Ranking
Power losses (kW)	4493.067	4514.23
Cost saving(RM)	275662308	235247750
Capacitor Placement	Bus 5	Bus 5
Improvement Voltage Regulation(p.u)	1.02783	1.031339

IV. CONCLUSIONS

This paper has discussed 2 method to finding the optimal locations and size capacitors in radial distribution for capacitor installation by using CAPO and Bus Ranking method. By installing shunt capacitor at all the potential locations, the total of real power loss of the system has been reduced and bus voltage is improved. From the result obtain, the objective of this project are fulfill. The optimal capacitor placement that needs to be installing on the network was choose for the analysis using CAPO application method. Using this method, the systems shows the best performance improving of power losses and increasing the minimum voltage that can be concluded as the proposed technique is reliable for the network systems compare Bus Ranking method.

V. FUTURE STUDY

The CAPO application can be implementing to the large distribution system network and the selection of the capacitor value must be available in the market.

ACKNOWLEDGMENT

Author would like to thank Dr. Muhammad Murtadha Bin Othman for supporting this research by providing some info regarding capacitor placement in distribution systems.

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