Energy Efficiency based on Capacitor Sizing and Placement using Monte Carlo Technique

Siti Nur A'rfah Binti Shamsudin
Faculty of Electrical Engineering
UniversitiTeknologi MARA
40450 Shah Alam, Selangor, Malaysia
e-mail: r_fa91@yahoo.com.my

Abstract **- Capacitor have been used for power factor correction. The benefit to improve the power factor is reduced the losses such as transformer and line losses. Power factor correction also can improved voltage profile, reduced maximum demand, and improved power quality. Thus energy efficiency is increased and the power bills of end users are reduced. Therefore in this paper, the capacitor placement and sizing using Monte Carlo technique is proposed. Monte Carlo technique allows the sizing and placement of capacitor optimally selected. Results show some capacitor sizing and placement are effective and some others are not, depending on the size of capacitor and its location in the load at distribution system.**

Keyword – **Capacitor, Placement, Sizing, Monte Carlo technique**

I. INTRODUCTION

Capacitor sizing and placement has become the popular solution to reduce the system losses, regulating bus voltages and improving power factor. The low power factor will result in more losses in the power system. Power factor correction capacitors should be installed to compensate the losses. The capacitors installed need to be of appropriate sizes and should be placed at appropriate location where they produce maximum loss reduction. To get the best result, capacitors have to be located close to the load in the distribution system.

In distribution system, the reactive load is always changeable and it is not a good plan to determine fixed sizing and location of capacitor based on an average of the reactive load [1]. Variety methods have been used to solve the capacitor sizing and placement problem. Salama *et al* [11] have used fuzzy approach for the sizing and placement of capacitor for optimal operation. Fuzzy sets theory method is used to determine the optimal capacitor location and sizing by differentiating the saving function with the respect to the distance to place the capacitor and equating it to zero. This method is simple and does not require any sophisticated optimization procedures. Masoum *et al* [12] used Genetic Algorithm (GA), which is a search technique based on the principles of genetics and natural selection to attempt the optimal location and sizing of shunt capacitors. The advantages using GA are it is ease of implementation and does not require the differentiability of the objective function. The disadvantages of using GA are relatively complex when it comes to incorporating the algorithm into a software program and also relatively large computational time and effort. This paper presents a Monte Carlo technique to attempt the optimal location and sizing of capacitors. Regarding both location and capacitor size as continuous variables, a Monte Carlo technique is used to determine the variable optimally [4]. The capacitor placement and sizing is reformulated by taking into account the real power, the total losses at the branch load, the value of power factor, and total harmonic distortion (THD) voltage. This method is applied to distribution system that contains 8 buses, 7 loads and 1 transformer.

II. BASIC CONCEPT OF OPTIMAL CAPACITOR PLACEMENT AND SIZING

To correct the power factor, the shunt capacitors have been using for power factor correction long time ago. The leading current drawn by the shunt capacitors compensates the lagging current drawn by the load [3]. The choice of shunt capacitor is depend on many aspects, but the main key is the amount of lagging reactive power taken by the load [9]. Fixed capacitor bank will often lead to either under compensation or over compensation [9]. Since the load is assumed inductive, it needs reactive power for appropriate operation. If the reactive power is supplied near load, the power losses can be minimized or reduced. It is also can reduce line current and voltage regulation at the load terminals can be improved.

Figure 1 show the different between two power systems. Figure 1(a) shows the power system without compensation while Figure 1(b) shows the power system has shunt compensation with a current source. The current source device is used to compensate the reactive component of load current in Figure 1(b). As a result, the reactive current from source is reduced and voltage regulation is improved. The excess of reactive power flowing in the power system can cause undesirable voltage drops and excess heating in the system [5].

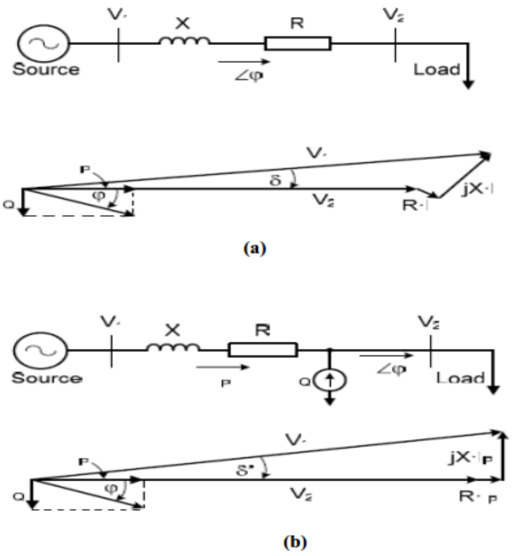

Fig 1: Principles of compensation (a) without capacitor compensation (b) capacitor compensation with current source

The voltage collapses also a main problem for networks. Unsatisfactory of power system to meet enough of the demand of reactive power is one of the main factors of voltage collapse. One of the solutions is by injecting the reactive power load using the capacitor which can reduce the losses in the system and the system can operate in reliable power [10]. The sizing and location of capacitor is randomly selected to obtain the best capacitor sizing and its location. The amount of capacitor need to be installed at the load also randomly selected. The right amount of capacitor need to be installed can be determined using this method. But in industrial plant that contain power factor correction capacitor, the harmonic voltage and current can be increase due to the interaction between capacitor and transformer. Therefore, inductor is installed together with the capacitor to avoid the parallel resonance

The equation of total harmonic distortion of the voltage and currents is shown in formula below:

$$V_{THD} = \frac{1}{V_1}\sqrt{\sum_{h=2}^{n} V_h^2} \qquad (1)$$

$$I_{THD} = \frac{1}{I_1}\sqrt{\sum_{h=2}^{n} I_h^2} \qquad (2)$$

Where V_h and I_h are the value of the n-th harmonic of the voltage and current.

III. METHODOLOGY

In this study, Monte Carlo is used as a technique to select the size of capacitor, number of capacitor to be installed and the location of capacitor to be installed at the load. All loads in simulation are installed with capacitor first, but not all capacitor will operate. The algorithm of programming is outlined by following steps:

1. Determine the parameter of maximum system loading, sampling time (Ts), sampling frequency (Fs), list of harmonic order (f), starting point to evaluate waveform (start), number of point multiply with number of cycles (N), maximum number of capacitor (max_no), minimum number of capacitor (min_no), num_cap, matrix_location, capsize, minimum size of capacitor (min_size), and matrix_sizing.
2. Random number of capacitor need to be install is generate. It has to be performing first in order to obtain how much number of capacitor need to operate instead of all seven capacitor at loads. The formula for random number of capacitor is as shown below:

$$loc = (max\_no - min\_no)*rand + min\_no \qquad (3)$$

loc = number of capacitor
max_no = maximum number of capacitor
min_no = minimum number of capacitor

3. Choose the random location of capacitor based on the number of capacitor need to be installed. The location of capacitor will randomly selected from seven loads. The location is determine by using the equation given below:

$$x1=round(rand*6.5 + 0.5) \qquad (4)$$

x1 = location of capacitor

4. The size of capacitor is randomly generated based on the chosen placement of capacitor into the system. The size of capacitor will be inserted into the three phase capacitor in the system. The equation used to select the size of capacitor randomly is shown below:

$$\text{matrix\_size} = (\text{max\_size} - \text{min\_size}) * \text{rand} + \text{min\_size} \quad (5)$$

matrix_size = size of capacitor
max_size = maximum size of capacitor
min_size = minimum size of capacitor

5. The system is evaluated and all the data that randomly selected will be installed into it.
6. All the data is recorded.
7. If the numbers of cycle not reach 20 times, the system will generate the random number of capacitor again.
8. The data that have been recorded is analyzed. The lowest value of real power and total line losses is tabulate into the table.

A. Flowchart

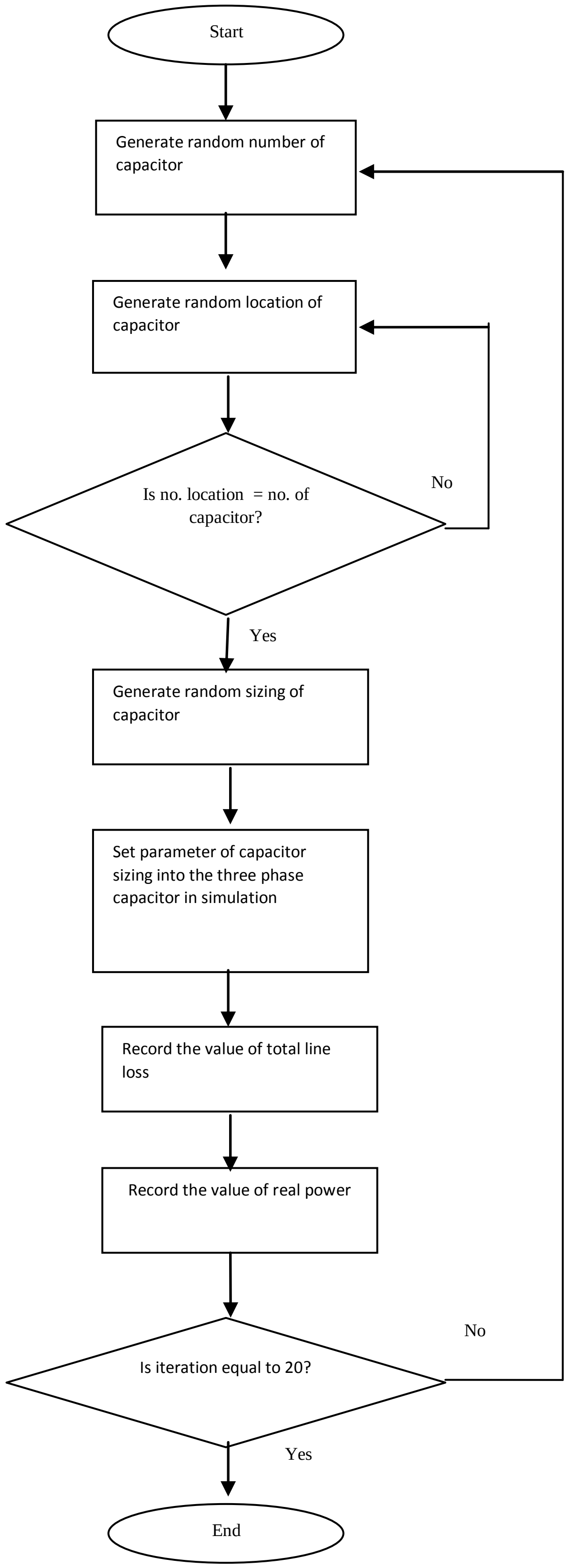

Fig 2: Flowchart of the programming

IV. RESULTS AND DISCUSSION

Figure 3 show a simulation of three phase distribution system of a building. The building contains seven loads that are connected with the bus feeder. After that, the system has been injected with the amount of harmonic. The value of incoming power or real power and total line loss should be increase after harmonic have been injected. The value of real power is increase about 20 percent after the system have been injecting by harmonic. The harmonic distortion (THD) is also occurred after the harmonic is injected [7]. To reduce the real power, total loss, and enhanced the power quality, the power factor need to be correct to 0.95. The power factor penalty charged by the utility also can be eliminated if the power factor is improved. The capacitor is the most economical and simplest way to improve the power factor. kVAR that needs to be injected into the system to improve the power factor will provided by capacitor [6]

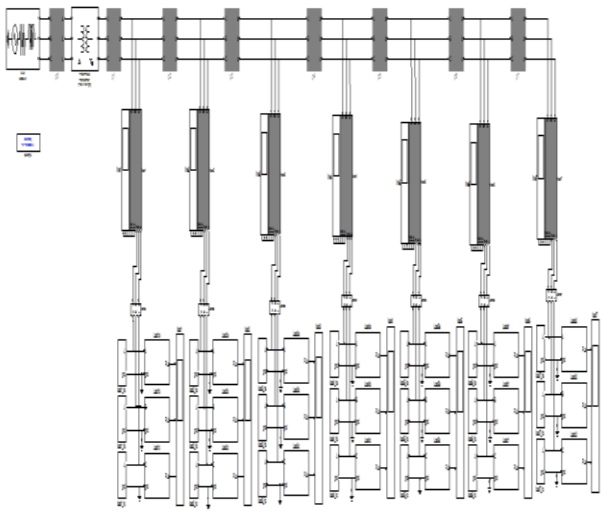

Fig 3: A three phase distribution system in a building

Hence, Figure 4 shows three phase capacitor that is installed into the system. The capacitor is installed at the load for the better result.

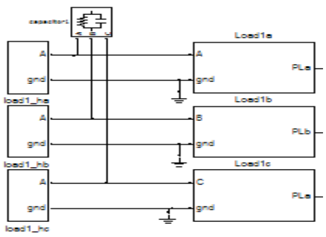

Fig 4: Three phase capacitor that were installed at the load

In this paper, the data will be compared between the data from the simulation that only have harmonic and the data from simulation that have been injected with capacitor. The data that have been collected are tabulated in table. The types of collected data were the real power, total line losses, power factor and total harmonic distortion of the voltage.

The cost of capacitor, location of capacitor and the sizing is tabulate in Table I. From 20 iteration, the best 10 result is recorded in the table. Each iteration give different location and different capacitor sizing. The capacitor sizing must not over the size of reactive power in the system.

TABLE I. THE CAPACITOR SIZING AND LOCATION IN THE DISTRIBUTION SYSTEM

No.	Location of capacitor at the load	Sizing of capacitor at the load (kVAr)	Cost of capacitor (RM)
1	5	15.3	918.00
2	7	24.8	1488.00
3	4	17.4	1044.00
4	3	26.8	1608.00
5	5 and 6	10.3 and 53.3	3816.00
6	2 and 4	13.3 and 15.6	1734.00
7	5, 6, and 7	19.4, 16.3, and 28.5	3852.00
8	4	43.8	2628.00
9	3, 5, 6, and 7	172.2, 52.4, 13.9, and 18.6	15426.00
10	6	83.2	4992.00

From Table II, it is been shown that after injecting capacitor into the system, the real power have decrease. To increase the efficiency of the system, the real power have to be low. By decreasing the value of real power, electric bill cost that consumer have to pay to utility also decreased. The value of real power before the capacitors have been injected is 964837W. After the capacitors have been injected, the value decreases to about 600000W. The lowest value of real power is 675662W.To get this value, the capacitor is placed at load 5 at the distribution system with the sizing of 15.3 kVAr. The cost of capacitor need to be install also cheaper than others that is about RM918.00. When the harmonic is injected into the system, the real power is increase. Real power is the actual amount of power being used or dissipated. When the value of real power (kW) increase, the value of apparent power (kVA) also increase. Therefore at larger kW, kVA rating has to made more, will result in larger size equipment, hence the higher cost is required.

TABLE II. THE COMPARISON OF REAL POWER BETWEEN THE SYSTEM BEFORE AND AFTER PLACING THE CAPACITOR

No.	Real power before placing capacitor (W)	Real power after placing capacitor (W)
1	964837	675662
2	964837	676261
3	964837	676406
4	964837	676408
5	964837	676862
6	964837	678265
7	964837	678753
8	964837	678755
9	964837	679221
10	964837	679235

Table III show the comparison of total line losses between the system before placing the capacitor and after placing the capacitor. From the table, the total line losses after capacitor being injected is much lower that before the capacitor is injected into the system. The value of total line losses before capacitor injected is 5559. But when the capacitor is injected, the value of total line losses is reduced and the lowest total line loss is 3769W. The location and the sizing of capacitor for the lowest total line loss is same as the location and sizing for the real power that is at load 5 with 15.3 kVAr. Large total line losses mean the line current also large. The low power factor will add more current into the system. If current increase, the total line losses (P) also increase thus will result in poor power factor.

TABLE III. THE COMPARISON OF TOTAL LINE LOSSES BETWEEN THE SYSTEM BEFORE AND AFTER PLACING THE CAPACITOR

No.	Total Line Losses before placing capacitor (W)	Total Line Losses after placing capacitor (W)
1	5559	3769
2	5559	3825
3	5559	3835
4	5559	3779
5	5559	3817
6	5559	3788
7	5559	3813
8	5559	3818
9	5559	3781
10	5559	3787

From the Table IV, the power factor of system has been increased a little. The value of power factor before placing capacitor is 0.8017. But after placing capacitor, the largest power factor is 0.8330. To get this value of power factor, the capacitors need to install at 3, 5, 6, and 7 with the sizing of 172.2 kVAr, 52.4 kVAr, 13.9 kVAr, and 18.6 kVAr. But it will cost about RM15426.00 to install these capacitor. Therefore, it is not worth to install these capacitor into the system because the power factor increment is only about 0.03. To improve the power factor, the correct amount of power factor correction (kVAr) needs to be injected into the system.

TABLE IV. THE COMPARISON OF POWER FACTOR BETWEEN THE SYSTEM BEFORE AND AFTER PLACING THE CAPACITOR

No.	Power factor before placing capacitor	Power factor after placing capacitor
1	0.8017	0.8257
2	0.8017	0.8282
3	0.8017	0.8326
4	0.8017	0.8244
5	0.8017	0.8257
6	0.8017	0.8282
7	0.8017	0.8320
8	0.8017	0.8272
9	0.8017	0.8330
10	0.8017	0.8310

Before inserted the capacitor, the total harmonic distortion of the voltage is 0.1504%. But after capacitor is installed, the THDv is decrease. The lowest total harmonic distortion of the voltage is 0.0014%. The location of the capacitor for the lowest THDv is at the load 3, 5, 6 and 7. It means that if capacitor is installed at these load , the THDv will decrease greatly. But like the situation of power factor above, these capacitors are not suitable to install into the system because the cost to install the capacitor is too high. For the system that containing power factor correction capacitors, the harmonic voltages will be magnified due to the interaction between capacitor and transformer. This is referred as harmonic resonance or parallel resonance. Therefore, inductor have been installed together with the capacitor to avoid the parallel resonance

TABLE V. THE COMPARISON OF TOTAL HARMONIC DISTORTION OF THE VOLTAGE BETWEEN THE SYSTEM BEFORE AND AFTER PLACING THE CAPACITOR

No.	THDv before placing capacitor (%)	THDv after placing capacitor (%)
1	0.1504	0.0054
2	0.1504	0.1236
3	0.1504	0.0306
4	0.1504	0.0105
5	0.1504	0.1039
6	0.1504	0.0261
7	0.1504	0.1130
8	0.1504	0.0122
9	0.1504	0.0014
10	0.1504	0.0193

.

V. CONCLUSION

The energy efficiency of the distribution system can be improve by install the capacitor into the system. By installing the capacitor, it can improve the voltage profile, reduce the real power and total line loss and also improve the power factor. This paper illustrates that the MATLAB/Simulink application could be used to simulate and investigate the suitable location and sizing of capacitor. By using the Monte Carlo technique, the best capacitor location and capacitor sizing can be determined. From the result and discussion, the most suitable location to installed capacitor in the distribution system is at the load 5 with the sizing of capacitor equal to 15.3 kVAr. This location and sizing is selected because it reduces the real power and total line losses. Beside that, only one capacitor need to be injected into the distribution system, so it will reduce the cost to install the capacitor. The price of capacitor for this sizing and location also the cheapest among others that is RM918.00

VI. RECOMMENDATION

For the future recommendation, it is aspired to add the filter with the capacitor to increase more of the energy efficiency. This is because filter is the most reliable and economical solution when power factors correction is needed in the presence of non-linear load or the amount of harmonic must be reduces to solve the power quality problem. So to eliminate or reduced the harmonic and to increase the energy efficiency, the capacitor should be installed with the filter together.

VII. REFERENCES

[1] C.F. Chang, "Reconfiguration and Capacitor Placement for Loss Reduction of Distribution Systems by Ant Colony Search Algorithm," IEEE Trans. Power System, Vol. 23, No. 4, pp. 1747–1755, July 2008.

[2] O. P. Mahela, D. Mittal, and L. Goyal," Optimal Capacitor Placement Techniques in Transmission and Distribution Networks to Reduce Line Losses and Voltage Stability Enhancement," IEEE Trans. Power System , Vol. 3, No. 4, pp. 1–8, November 2012

[3] A. Elmitwally, "Optimal Sizing And Location Of Capacitor Banks In Distorted Distribution Networks With Distributed Wind Generation," *21 st International Conference on Electric Distribution*, No. 0298, pp. 6–9, June 2011.

[4] S. O. Faried and S. Aboreshaid, "A Monte Carlo Technique for the Evaluation of Voltage Sags in Series Capacitor Compensated Radia1 Distribution Systerns," IEEE Conference, pp. 41–46, 2002.

[5] Soo-Hyoung Lee and Jung-Wook Park, "Selection of Optimal Location and Size of Multiple Distributed Generations by Using Kalman Filter Algorithm," IEEE Trans. Power Syst., Vol. 24, No. 3, pp. 1393–1400, 2009.

[6] S.Bindu, "Reactive Power Compensation in Three Phase Circuits by Different Power Definition: A comparative study", IEEE Region 10 Conference, November 2008.

[7] J. Kim, Y. Park, and D. Lee, "Harmonic Analysis of Reactor and Capacitor in Single-tuned Harmonic Filter Application," Journal of Electrical Engineering And Technology, Vol. 6, No. 2, pp. 239–244, 2011.

[8] A. Ghosh, and A. Joshi, "A New Approach to Load Balancing and Power Factor Correction in Power Distribution System," IEEE Trans. Power Delivery, Vol. 15, No. 1, pp. 417–422, January 2000.

[9] M. Brenna, R. Faranda, and E. Tironi, "A New Proposal for Power Quality and Custom Power Improvement: OPEN UPQC," IEEE Trans. Power Deliv., Vol. 24, No. 4, pp. 2107–2116, Oct. 2009.

[10] O. García, J. A. Cobos, R. Prieto, P. Alou, and J. Uceda, "Single Phase Power Factor Correction : A Survey," IEEE Trans. Power Electronics, Vol. 18, No. 3, pp. 749–755, May 2003.

[11] H. N. Ng, M. M. A. Salama and A. Y. Chikhani, "Capacitor Allocation by Approximate Reasoning: Fuzzy Capacitor Placement," IEEE Trans. Power Delivery, Vol. 15, No. 1, pp. 393-398, January 2000.

[12] M. A. S. Masoum, M. Ladjevardi, A. Jafarian and E. F. Fuchs, "Optimal Placement, Replacement and Sizing of Capacitor Banks in Distorted Distribution Networks by Genetic Algorithms," IEEE Trans. Power Delivery, Vol.18, No. 4, pp.1794-1801, October 2004.