# Comparative Study between Capacitor Placement Optimization (PSS/Adept) and Bus Ranking Method for Optimal Capacitor Placement

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***Abstract*** **—This paper proposed efficient method for determining optimal capacitor placement in distribution network. The capacitor placement optimization was determined by the CAPO application available in the power system simulation programmed for planning, design and analysis of distribution system (PSS/Adept) and bus ranking method. Bus ranking determines suitable location by calculate loss reduction index. High loss reduction index is considered as critical area. CAPO is determined by application in PSS/Adept that already programmed inside that. Comparison between these methods has been made to determine more suitable method to optimal capacitor placement in term of low power losses and high power factor. This paper consists of finding the optimal location and size of capacitors in electrical distribution with an objective to improving the voltage profile, reduction power loss, and power factor correction. The proposed study was conducted on the 45 bus distribution system contain 33Kv bus and 11Kv bus. The result has shown that significant reduction in power losses, voltage profile and power factor improvement was obtained with the installation of capacitor bank at the suitable location with appropriate sizing. Proposed solution methodology has been implemented and the test results are including in this paper.**

***Keywords*** **- capacitor placement, loss reduction, bus ranking, PSS-ADEPT, capacitor size and power factor correction.**

## I. INTRODUCTION

Power distribution from electric power plan to consumer is accomplished via the transmission line and distribution line. Studies have indicated that total power generated from power plan distribute to costumer has some losses. The losses can cause low voltage, low power factor and low power at the load. The losses that have been generated at the distribution level are $I^2R$ losses [1]. The $I^2R$ losses can be separated to active and reactive component of branch current, where the losses produced by reactive current can be reduced by the installation of shunt capacitor. The main function of a power system is to feed the load with electrical energy as economically and reliably as feasible. The distribution system is responsible for transfer electrical energy from substation to load [2]. In distribution system low voltage at load end will caused big power losses and the power factor become small [3]. Growing load on the distribution system result is can increase of reactive power demand necessary to maintain the voltage within acceptable level [4].

The advantages with addition of shunt capacitor bank are to improve the power factor, voltage profile, power loss reduction, increase capacity feeder, to reduced energy losses, and release KVA also to maintain voltage profile also as system improvement. Therefore it is important to find optimal location and size capacitor in system to achieve the objective. Proper placement of capacitor on distribution network reduces power and energy losses. Increase the available capacity of feeder and improve the voltage [5]. So that to improve power system load capacitor need to install at the load or low voltage profile bus.

The increasing demand in the power system has posed a challenging task to power system engineers in maintaining a reliable and secure system economically. In the heavily loaded network, the load current drawn from the source would increase. This may lead to an increase in voltage drop and system losses. The performance of distribution system becomes inefficient due to the reduction in voltage magnitude and increase in distribution losses [6]. The system analysis of a power system in normal steady state operation is known as a power flow or load flow study [7]. A power flow analysis of a particular power system calculates the voltages and voltage angle at each node in a power system. From this information current, real and reactive power flow through the line in the difference bus can be analyze. Power flow program are use for planning, economic scheduling and control the system as well as planning it future. The system is assumed to be operating under balanced condition and single phase is used to represent the system [8].

This paper studies implementation of network reconfiguration in the power distribution systems for loss reduction, power factor correction and voltage profile improvement with the installation of capacitor bank at the load bus. The capacitor placement optimization was determined by the CAPO application available in the power system simulation programmed for planning, design and analysis of distribution system (PSS/Adept) and bus ranking method. This application determines optimal capacitor placement based on minimum losses, high power factor and high voltage at load bus. For bus ranking method, suitable location by determines by calculate the loss reduction index. High loss reduction index is considered as critical area. Various locations for 11Kv and 33Kv load bus were also tested in order to realize the effect of location and sizing of capacitor bank in terms of loss reduction, power factor correction and voltage improvement during network distribution. The results also were compared to obtained good method for optimal capacitor placement in distribution system. The study was implemented on the 45 bus containing 11Kv and 33Kv in distribution system.

## II. METHODOLOGY

Purpose of implementing the capacitor placement on the distribution system is for voltage support, power factor correction and loss reduction. To solve this problem with good result and efficiently this paper focuses on bus ranking method and PSS/Adept CAPO simulation method. All simulation conducted on the 45 bus distribution system contain 33Kv bus and 11Kv bus. Figure 1 below shows the diagram that has been used.

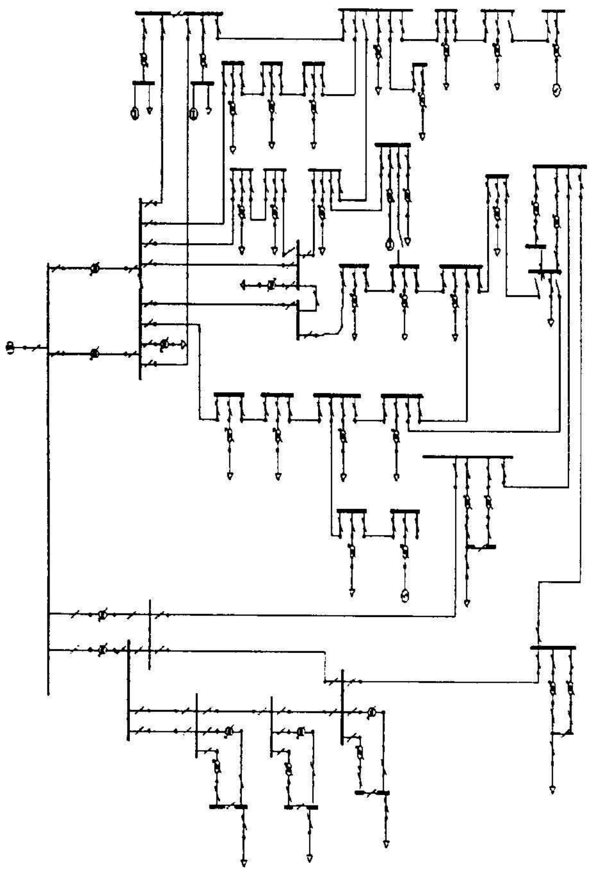

Figure 1: 45 bus system diagram modeling in the PSS/Adept.

The capacitor placement optimization was determined by the CAPO application available in the power system simulation programmed for planning, design and analysis of distribution system (PSS/Adept) and bus ranking method. This application determines optimal capacitor placement based on minimum losses, high power factor and high voltage at load bus. For bus ranking method suitable location by determines by calculate the loss reduction index. High loss reduction index is considered as critical area that needs to install capacitor bank. Finally, after this method was simulated, result for this two method was compared to get good result and more suitable method in term of low total system losses and low cost for installation capacitor.

### *A. Bus ranking method*

Identification of weak buses in operating distribution system is an important task to make sure the [illegible] is stable. Voltage stability problem usually result [illegible] heavy loading in the load bus. Bus ranking method [illegible] ranking critical bus in a power system network base [illegible] duction index and voltage profile at load buses. Base [illegible] reduction index, critical buses are ranked. The bus [illegible] rank is the critical buses. Figure 2 shows flowchart to perform load flow analysis for bus raking method by using PSS/Adept.

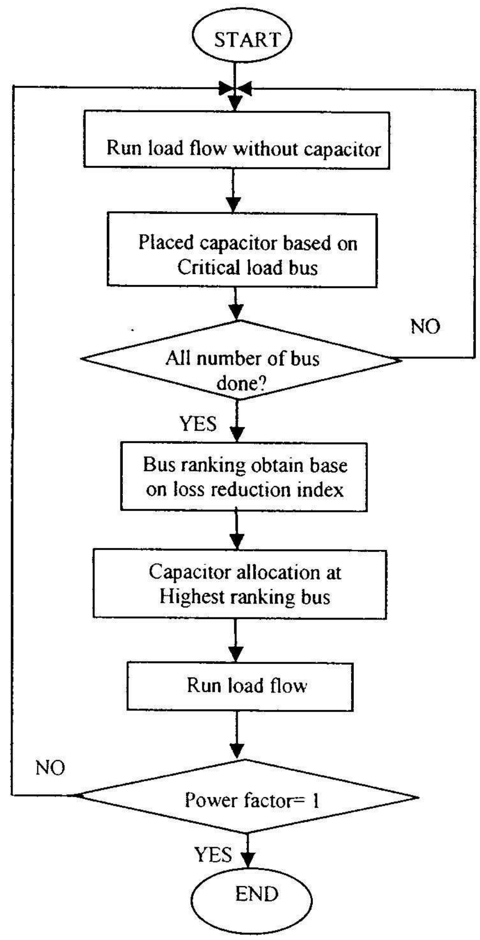


Figure 2: Flow chart for process flow of bus ranking method.

For bus ranking method, the first assumed that to meet the voltage constraint, the maximum of shunt [illegible] citor to be placed at any bus does not exceed the bus p[illegible] demand. The capacitor need to be install at all bu[illegible] itical point with the highest total loss. Total lo[illegible] ex is calculated every time on a critical bus [illegible] acitor placement. The step is repeated until there [illegible] bus to install the capacitor. Loss reduction ind[illegible] mply the measure of the amount kW saved for every [illegible] capacitor installed at the bus.

Loss reduction index for bus 'n' = 100 × (lo[illegible] capacitor Kvar) .......... (1)

Loss saved (Kw) = system without capa[illegible] em with capacitor...... (2)

From the simulation, the bus which produces the maximum loss reduction will be chosen for the next simulation. Therefore capacitor is installed and highest ranking bus to matches the highest reactive demand to the nearest number of discrete size. If the power factor obtained from the first capacitor allocation is less than 1, the remaining busses will be ranked again. This time only the remaining bus will be ranked again while the previously allocated capacitors are fixed. With the new ranking, capacitor will be allocated to the highest ranking bus among those remaining. This process continues until power factor value reached 1. Load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system [6]. All the result without installing capacitor or installing capacitor was recorded.

### *B. Pss-Adept software method*

Another method that has been used in this paper is simulation program by using PSS/Adept software. The capacitor placement optimization was determined by the CAPO application available in the power system simulation programmed for planning, design and analysis of distribution system (PSS/Adept). The procedure is same with bus ranking method but the step for simulation to get the capacitor place is difference. This application determines optimal capacitor placement based on minimum losses, high power factor and high voltage at load bus. The suitable location for install capacitor was determined using the load flow analysis in the PSS/Adept software to get critical area. Various locations for 11Kv and 33Kv load bus were also tested in order to realize the effect of location and sizing of capacitor bank in terms of loss reduction, power factor correction and voltage improvement during network distribution. CAPO in PSS/Adept determines suitable location for placement capacitors depend on iteration to determine other location.

For PSS/Adept simulation, the capacitor placement optimization was determined by the CAPO application available in the power system simulation programmed for planning, design and analysis of distribution system (PSS/Adept). Some setting must be doing before make simulation. The setting need to be considered is transformer tap, existing capacitor value and base voltage. There will be no further adjustments of these transformer or capacitor settings as CAPO simulation progress. Before the allocation proper is carried out, specifications such as load flow convergence limits, discrete capacitor size and load loss factor are to be provided. The initial power losses were determined by performing the load flow analysis of the system. All result for PSS/Adept simulation was recorded. Since the capacitor installation guideline requires a target power factor of above 0.95, the following approach has been adopted [9]:

i. Identify distribution network with power factor at the source having low factor.

ii. Locate and determine the suitable size capacitor in distribution network with power factors in range up to 1.0.

## III. SIMULATION RESULT AND DISCUSSION

The purpose method that has been using in this paper is bus ranking and PSS/Adept CAPO simulation method. The effectiveness of this method for optimal capacitor placement and loss reduction was measure on 45 buses in a distribution system. All simulation tests were conducted on 45 buses which contain 33Kv and 11Kv busses. The result of bus ranking method is compared with result by using PSS/Adept method. Result by using bus ranking is more quality and very accurate when compared to the result obtain by PSS/Adept simulation method. The results obtain in this method are explaining in the following section:

### *A. Bus Ranking method result (33Kv)*

The size of capacitor used in this method is 2000KVar for the minimum size and the maximum size is around 24000KVar. Based on bus ranking method simulation, the initial total loss without install capacitor is 2230.37Kw.

Table 1: Result for capacitor placement optimization based on bus ranking method at bus 33Kv.

| **Bus ranking no.** | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| **Voltage (Kv)** | 32.614 | 30.559 | 31.379 | 31.472 | 30.88 |
| **Voltage with capo** | 32.9821 | 32.501 | 32.625 | 32.717 | 32.995 |
| **Total power Kw** | 49653.86 | 49480.81 | 49273.71 | 49206.11 | 49159.46 |
| **Total power Kva** | 55416.52 | 53599.11 | 50732.54 | 49786.316 | 49246.63 |
| **Power factor** | 0.9 | 0.923 | 0.971 | 0.985 | 1 |
| **Capacitor size** | 0 | 4000 | 12000 | 20000 | 16000 |
| **Total CAPO install** | 0 | 1 | 2 | 3 | 4 |
| **33Kv bus install capo** | Trans. 33Kv | PPU D, F | PPU D, F, C | PPU D, F, C,B,E | PPU D, F, C,B,E |
| **Total system losses(Kw)** | 2230.37 | 2057.32 | 1850.22 | 1782.62 | 1735.98 |
| **Loss saved(Kw)** | 0 | 180.05 | 380.14 | 500.74 | 600.39 |
| **Loss saved (Kvar)** | 0 | 858.61 | 2210.13 | 2958.49 | 3397.68 |

From table 1, power factor of 1 is archived after done 4 bus ranking iteration. Power factor increased at every rank and total loss is reducing at all rank. Low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment [7]. During power factor 1, voltage was increased from 30.88Kv to 32.995Kv. From table 1 also showed loss saved is reduced proportionally based on ranking. Figure 4 below is illustrated the total losses of the system is decreased proportionally by power factor.

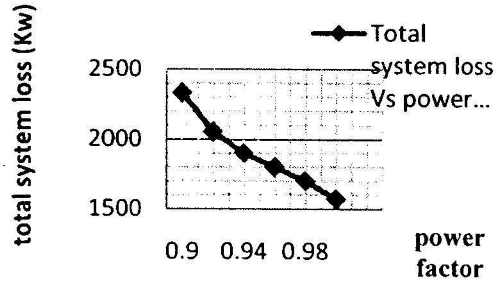


Figure 3: Graph of total loss versus power factor

From the graph shown in figure 3, it can be observed that load increased at all busses has caused an increased in the total losses of the system significantly. However with the installation capacitor bank at critical busses was increased the power factor and produced minimum losses in the system. So with installation capacitor bank, system produced more power to distribute with minimum losses. From graph 3, at power factor 1, total loss was reduced from 2230.37Kw to1735.98Kw. Figure 4 below shown voltage comparison between without install capacitor and after install the capacitor bank.

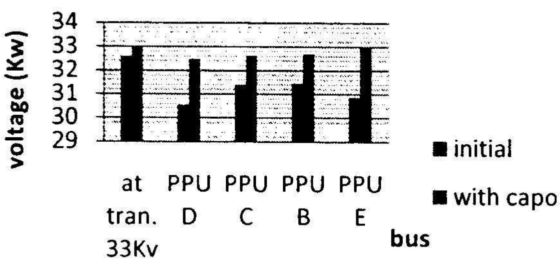


Figure 4: Voltage comparison between without install capacitor and after install the capacitor bank.

The graph in figure 4, conclusion can be made the improvement in voltage profile after install capacitor bank at critical bus area. By installing capacitor bank, voltage profile was increased so that distribution system becomes more stable. For example, at power factor 1 voltage was increased from 30.88Kv to 32.995Kv. This is because of total system loss in the system was reduce. It can show that by installing capacitor bank, value of power factor increased at all critical bus and minimum losses were produced and more power was saved. Beside that, it can be observed that the total real power and reactive power loss saves in the system was increased proportionally by the power factor. By increasing power factor, total system loss was reduced, voltage in the system was increased and loss saved increased. All of this is increased or decreased proportionally due to power factor.

Refer to the objective this project, capacitor placement optimization technique need to reduce the loss, improve power factor and stabilized the voltage after install capacitor. So this is archived the objective.

*B. Bus Ranking method result (11Kv)*

Table 2: Result for capacitor placement optimization based on Bus ranking method at bus 11Kv.

| **Bus ranking no.** | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| **Voltage (Kv)** | 10.98 | 10.798 | 10.88 | 10.5 | 10.76 |
| **Voltage with capo** | 11 | 10.998 | 11 | 10.892 | 10.9 |
| **Total power Kw** | 2248 | 2245 | 2243 | 2242 | 2241 |
| **Total power Kva** | 2445 | 2405 | 2369 | 2324 | 2261 |
| **Power factor** | 0.9 | 0.95 | 0.97 | 0.99 | 1 |
| **Capacitor size** | 0 | 200 | 150 | 300 | 200 |
| **33Kv bus install capo** | Trans. 11Kv | PE SHI | PE SHI,SEM | PE SHI,SEM,SUN | PE SHI,SEM, SUN,PUC |
| **Total system losses(Kw)** | 2978 | 2974 | 2972 | 2971 | 2970 |
| **Loss saved(Kw)** | 0 | 100.05 | 350.14 | 447.74 | 498.39 |
| **Loss saved (Kvar)** | 0 | 880.61 | 2210.13 | 2758.49 | 3197.68 |

After observation on table 2, that can be shown the result is also similar with 33Kv. But it is difference size of capacitor size. Power factor of 1 is archived after done 4 bus ranking iteration. Power factor increased at every rank and total loss is reducing at all rank. Low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment [7]. Power saved and voltage profile also increases. Figure 5 below is illustrated the total losses of the system is decreased proportionally by power factor.

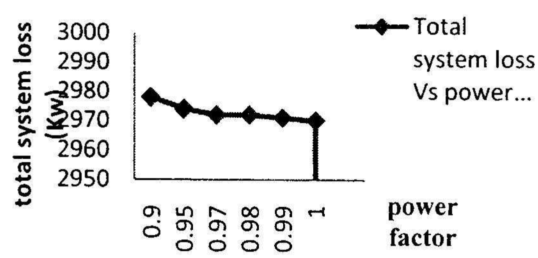


Figure 5: Graph of total loss versus power factor.

Graph shows in figure 5, is about total loss reduction proportionally to power factor. By increasing power factor, total system los in 11Kv system was reduced. It can show that by installing capacitor bank, value of power factor increased at all critical bus and minimum losses were produced and more power was saved. Base on the graph, since power factor is 1 total system loss is reduce from 2978Kw to 2970Kw.

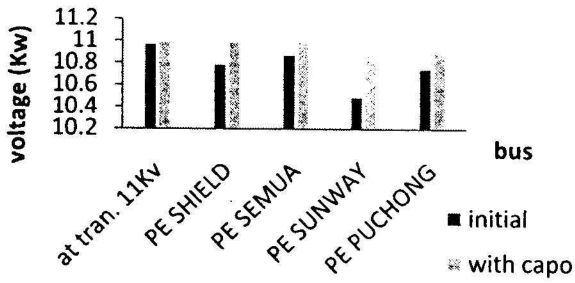


Figure 6: Voltage comparison between without install capacitor and after install the capacitor bank at 11Kv.

The graph in figure 6 showed the improvement in voltage profile after install capacitor bank at critical 11Kv bus area. In the heavily loaded network, the load current drawn from the source would increase. This may lead to an increase in voltage drop and system losses. The performance of distribution system becomes inefficient due to the reduction in voltage magnitude and increase in distribution losses [10]. Based on observation, total real power and reactive power loss saves in the system was increased proportionally by the power factor. By increasing power factor, total system loss in 11Kv system was reduced and more power saved was observed in the system.

### C. *Pss-Adept software method result(33Kv)*

Another method that has been used in this paper is PSS/Adept simulation. The size of capacitor used in this method is 2000KVar for the minimum size and the maximum size is around 24000KVar. Based on simulation, the initial total loss without install capacitor is 2230.3697Kw.Table 3 is the conclusion for the result simulation.

From the simulation, power factor is archive to 1 after 10 capacitor install in this system. Low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. After the simulation all busses, power loss saved is increased, voltage also increased and total power loss in the distribution system is decreased [5]. This is archive the objective before. Refer to the objective this project, capacitor placement optimization technique need to reduce the loss, improve power factor and stabilized the voltage after install capacitor. So this is archived the objective. The capacitor is placed at bus PPU A, PPU B, PPU C, PPU D, PPU E, PPU F because of during simulation on 33Kv this bus is in critical. Load increased at all busses has caused an increased in the total losses of the system significantly. However with the installation capacitor bank at critical busses was increased the power factor and produced minimum losses in the system. So with installation capacitor bank, system produced more power to distribute with minimum losses. Based on observation, total real power and reactive power loss saves in the system was increased proportionally by the power factor.

From the result, conclusion can be made is total system loss reduce from 2230.37Kw to 1735.98Kw. Voltage also increased from 30.88Kv to 32.99Kv after installing capacitors bank.

Table 3: result for capacitor placement optimization based on PSS/Adept method.

| | | | | | |
|---|---|---|---|---|---|
| **Voltage Kv** | 32.614 | 30.559 | 31.379 | 31.472 | 30.88 |
| **Voltage with capo** | 32.9821 | 32.501 | 32.625 | 32.717 | 32.995 |
| **Total power Kw** | 49653.86 | 49480.81 | 49273.71 | 49206.11 | 49159.46 |
| **Total power Kva** | 55416.52 | 53599.112 | 50732.54 | 49786.316 | 49246.63 |
| **PF** | 0.896 | 0.923 | 0.971 | 0.985 | 1 |
| **Capacitor size** | 0 | 4000 | 12000 | 16000 | 20000 |
| **CAPO install** | 0 | 2 | 6 | 8 | 10 |
| **33Kv bus install capo** | Trans. 33Kv | PPU D, F | PPU D, F, C | PPU D, F, C,B,E | PPU D, F, C,B,E |
| **Total system losses(Kw)** | 2230.37 | 2057.322 | 1850.22 | 1782.62 | 1735.98 |
| **Loss saved(Kw)** | 0 | 173.05 | 380.14 | 447.74 | 494.39 |
| **Loss saved (Kvar)** | 0 | 851.61 | 2208.13 | 2758.49 | 3197.68 |

### D. *Comparison between Pss-Adept CAPO software and Bus ranking method.*

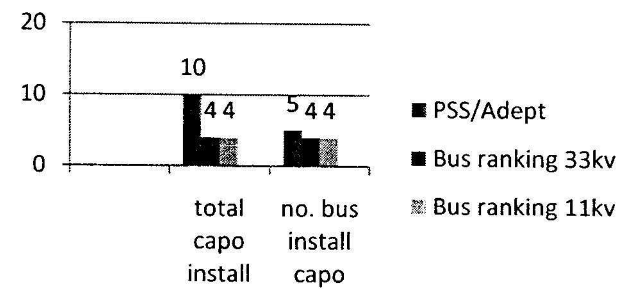


Figure 7: Graph of comparison between PSS/Adept with Bus ranking in term of total capacitor bank install.

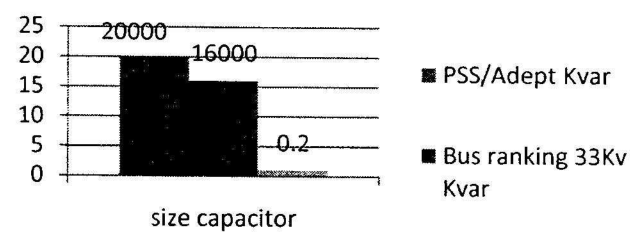


Figure 8: Graph of comparison between PSS/Adept with Bus ranking in term of size capacitor.

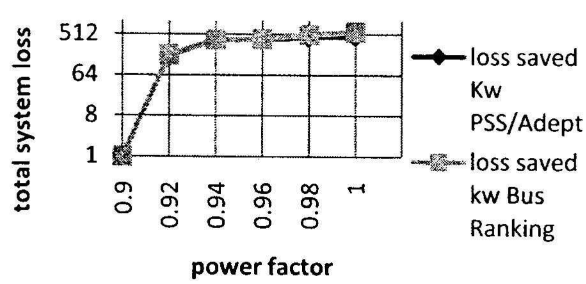


Figure 9: Graph of comparison loss saved for PSS/Adept CAPO and Bus Ranking.

From figure 7, 8 and 9 above, can be conclude that bus ranking method is more suitable to get the good result. This is because of bus ranking method can increased power factor, voltage increased and total power system loss is reduced by only install 16000Kvar capacitor bank. This is small then PSS/Adept CAPO simulation result. Beside that total of capacitor bank install for bus ranking is 4 otherwise PSS/Adept CAPO is 10 capacitor banks. Bus ranking method also has highest power loss compared to PSS/Adept CAPO. Bus raking method, power factor is archive to 1 after 4 capacitor install in this system but PSS/Adept CAPO archive power factor 1 after 10 capacitor bank install. Low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. After the simulation all busses, power loss saved is increased, voltage also increased and total power loss in the distribution system is decreased [5]. Conclusion can be made in comparison between this two method is suitable method for optimal capacitor placement in distribution system is bus ranking method.

## CONCLUSION

The best location of capacitor that needs to be installing on the network was choose for the analysis. Power factor correction may be applied by an electric power transmission utility to improve the stability and efficiency of the transmission network. Correction equipment may be installed by individual electrical customers to reduce the costs charged to them by their electricity supplier. A high power factor is generally desirable in a transmission system to reduce transmission losses and improve voltage regulation at the load. In an electric power distribution system, the power factor must be equal to 1 or unity power factor. This is because a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred.. The higher currents increase the energy lost in the distribution. The result show that installing compensating capacitor at the suitable location with appropriate sizing has able to decreased loss level from 2230.37Kw to 1708.27Kw and also increased the voltage profile from 30.88Kv to 32.99Kv. It is proved that bus ranking method is reliable in distribution system. Conclusion can be made that bus ranking method is more suitable and get quality result and minimize the cost. This is because bus ranking method only need to install 4 capacitor but the PSS/Adept simulation is need to install 10 capacitor. So the cost more low difference to PSS/adept simulation.

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