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A study on Power Factor Correction with Capacitor Bank Using ERACS' Software

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ABSTRACT
This paper intends to briefly compare the Power Factor Correction with Capacitor Bank & without Capacitor Bank Using **ERACS'** Software.
In this Study, capacitors are used in different locations of the network to get the best choice for correction and capacitor bank technique are applied for different voltage levels in the network such as 33, 11, 6.6 and 0.415 K volt.

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I. INTRODUCTION

This Study represents any distributed area having both residential and industrial loads, so we invented a network similar to real one.

We will explain the results for using capacitor bank to each case and the way for calculating the required size of capacitor bank to each case.

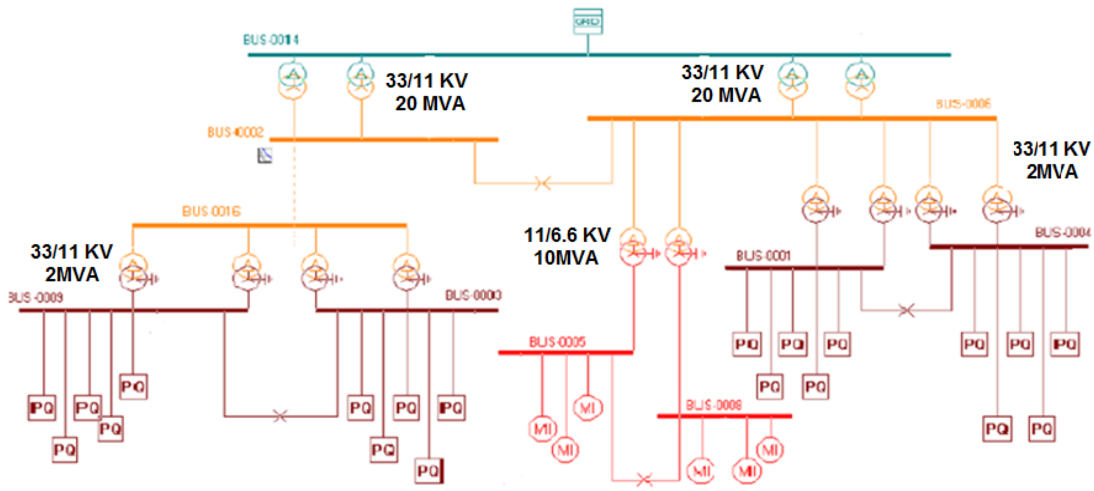

Figure 1: *The Project Network*

1.1 Case 1: installing Capacitor bank on bus bar 2

The plan is to improve the power factor from 0.75 to 0.95 by adding shunt capacitor to bus bar 2, but before that we need to know the value of the capacitor bank needs.

1.1.1 Part 1: getting the suitable capacitor rating

The first thing needed is getting the consumed load for the network from eracs simulation, which is done after building the network and simulated.

The consumed power in MVA is 13.518 + j 11.818 and the power factor for the network can be calculated by

$$old\ power\ factor\ = \frac{P_{Load}}{\sqrt{P_{Load}^2 + Q_{Load}^2}} = \frac{13.518}{\sqrt{13.518^2 + 11.817^2}} = 0.75$$

This power factor value indicates that the efficiency for the network is 75% and the losses equal 25%, which is huge amount and the network, is considered a low quality. Then we need the required reactive power to change the power factor from 0.75 to 0.95. This is done by applying the same formula again, which is the new power factor value:

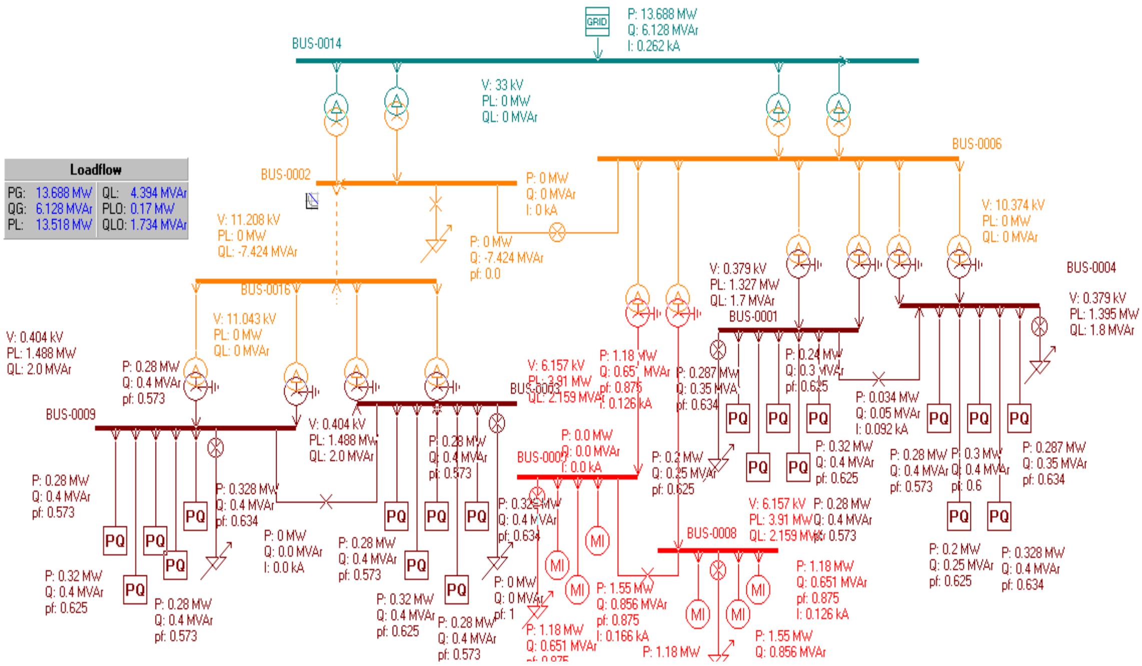

Figure 2: *this figure show installing capacitor bank on bus bar 2*

$$new\ power\ factor\ = \frac{P_{Load}}{\sqrt{P_{Load}^2 + Q_{Load\ new}^2}} = \frac{13.518}{\sqrt{13.518^2 + Q_{Load\ new}^2}} = 0.95$$

$$[13.518^2 + Q_{Load\ new}^2][0.95^2] = 13.518^2$$

$$164.91 + 0.9025 Q_{Load\ new}^2 = 182.736$$

$$Q_{new} = \sqrt[2]{\frac{182.736 - 164.91}{0.9025}} = 4.444\ MVAR$$

The amount of reactive power needed by capacitor bank is

$$Q_{old} - Q_{new} = 11.868 - 4.444 = 7.424\ MVAR$$

We used a simplified constant PQ shunt load to act as shunt capacitor and set the reactive power to -7.424 MVAR. Then after connecting the capacitor bank we got

$$new\ power\ factor\ = \frac{P_{Load}}{\sqrt{P_{Load}^2 + Q_{Load\ new}^2}} = \frac{13.518}{\sqrt{13.518^2 + 4.444^2}} = 0.95$$

The below table summarizes the data for this case:

Table 1: *Technical data for case 1 before and after correction*

Case 1	before correction	After correction
Generated Power MVA	13.701 + j 13.637	13.688 + j 6.128
Consumed power MVA	13.518 + j 11.818	13.518 + j4.394
Loss power MVA	0.183 + j 1.819	0.17 + j1.734
Power factor	0.75	0.95

1.1.2 Part 2: Calculation of the cost

The cost of adding capacitor bank that includes the fixed price of capacitor bank and the time needed to cover the cost of capacitor bank should be considered. In addition, the variable cost that is related to the cost of KVA and compared with the original network before the power factor correction should also be taken into consideration.

- **without the capacitor bank**

The calculation can be verified by the following steps:

1- The electric provider or company will produce a certain amount of power and a portion will be lost in the system because of the losses from the electrical equipment. These losses result from transformers, cables and over headlines which can be reduced if capacitor bank is installed to the generation side for network and this will reduce the total cost of generation to the electric provider before getting to consumers. From the ERCS simulation the generated power is equal to 13.701 + j 13.637Mvar, whereas the net power supplied the load is 13.518 + j 11.818Mvar which indicates that 1.819 Mw is the total loss to this network.

2- It is possible to get the cost of consumed power by taking assumption for the cost of each KVA. Assume that each 1KVA cost £100, the total cost for the consumed power can be computed as below:

The total cost for power in KVA = 17.95 x 10^3 x 100 £ /KVA = £1795554.087

The electric company can charge mainly the consumers for the real power used during certain time of the day or month. In case of using capacitor bank, the reactive power will be reduced and that provides extra space in cables, over headlines and transformers which can be used in the future to provide extra loads using same equipment taking assumption that in this case the number of hours for electricity are supposed to be 18 a day.

Total MwH = 13.518Mw x 365 days x 18 hour = 88813.26 MwH

According to the majority of electric companies in the UK, the cost for each KwH is equal to £0.2. Then, we can get the total cost for a year as follows:

The total cost for KwH = 88813.26 x 10^3 x 0.2 £/KwH = £17762652

The total cost for electric companies includes two parts, which are a fixed cost represented in consumed KVA and the real power consumed:

The total cost per year = the total cost for power in KVA + The total cost for KwH

= 1795554.087 + 17762652 = £19558206.09

- **with the capacitor bank**

It is seen that the consumed power was 13.518+j 11.818 before using capacitor bank, while it became 13.518+j 4.394 after the compensation which indicate reduction of the amount of reactive power by 7.424 MVAR which reduce the cost of consumed power to electric provider. This also can help to reduce the load for the electrical equipment, which can help for adding more loads in the future with the same equipment and extend the duration for the equipment because the usage is under the maximum rate. I will follow the same assumption above and we will get:

The total cost for power in KVA = 14.214 x 10^3 x 100 £ /KVA = £1421420.27

This cost is less compared to the network before using the capacitor bank. It can be approved by referring to the cost in both cases:

The total cost for KVA was £1795554.087, which means that £374133.811 is saved.

Assuming that the load of the network is working the whole year for 18 hours daily and the cost for KwH/year is equal to £0.2 then we can get the total cost for a year as follows:

Total MwH = 13.518Mw x 365 days x 18 hour = 88813.26 MwH

This calculation indicates that the total used energy is the same before and after using the capacitor bank because the compensation is done to the reactive power only:
The total cost for KwH = 88813.26 x 10^3 x 0.2 £/KwH = £17762652
The total cost per year = the total cost for power in KVA + The total cost for KwH
= £1421420.27 + 17762652 = £19184072.27
By comparing this to the original network, we found Total saving = 19558206.09 – 19184072.27 = £374133.82

This can help to save money to electric companies and it can be used to extend the network in the future on the long run.
To get the cost for the capacitor bank we need to assume that the cost for each 1MVAR.

Assumption: 1MVR costs £16000
Then, capacitor cost = £16000 / MVAR x 8MVAR = £128000

It is possible to get the spent money for installing capacitors by getting the ratio between capacitor bank cost and the saved amount form the correction.

Recovery cost for capacitor = $\frac{128000}{374133.82} = 0.34 = 4.13\ months$

That is a good indicator because the electric company can return the spent money for capacitor bank in a short period of time.
We can summarize the cost for adding capacitor bank in the following table:

Table 2: *Economical data for case 1 before and after correction*

Case 1	Network before PFC	Network after PFC
Total KVA	17950	14214
Total cost for KVA @100£/KVA	1795554.087	1421420.27
Total Mw H @ 18 hours /day in year	88813.26	88813.26
Total cost Kw H/year @0.2£/Kw H	17762652	17762652
Total cost / year	19558206.09	19184072.27
Total saving/year	-	374133.82
Capacitor bank cost @1MVAR =16000£	-	128000
Capacitor bank Cost recovery	-	4.13 months

1.2 Case 2 installing Capacitor bank on bus bar 9

The plan is to improve the power factor from 0.75 to 0.95 for the network by adding shunt capacitor to bus bar 9 which has nominal voltage that is equal to 415 volt.

1.2.1 Part 1 getting the suitable capacitor

The same process is done to calculate the reactive power needed form the capacitor bank from
Eracs simulation. The consumed power in the bus 9 is equal to 1.488 + j 2 and the power factor for the same bus bar can be calculated by:

$$old\ power\ factor = \frac{P_{Load}}{\sqrt{P_{Load}^2 + Q_{Load}^2}} = \frac{1.488}{\sqrt{1.488^2 + 2^2}} = 0.5969 \approx 0.6$$

Then, we need the required reactive power to change the power factor particularly in the bus bar 9 from 0.6 to 0.95 and this is done by applying the same formula:

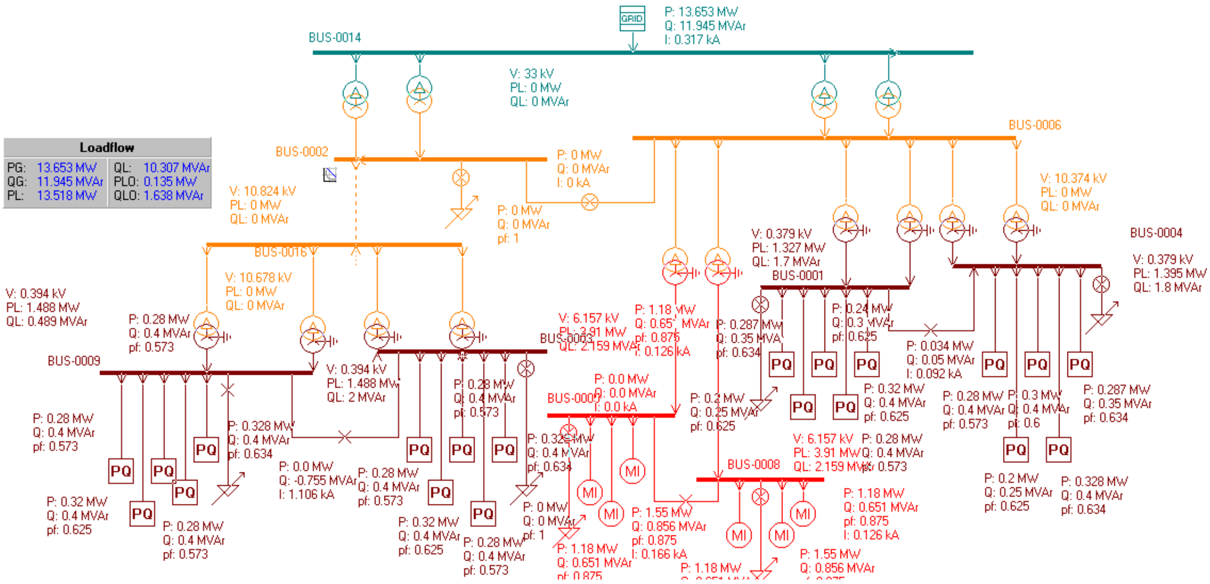

***Figure 3** :this figure show installing capacitor bank on bus bar*

$$new\ power\ factor\ = \frac{P_{Load}}{\sqrt{P_{Load}^2 + Q_{Load\ new}^2}} = \frac{1.488}{\sqrt{1.488^2 + Q_{Load\ new}^2}} = 0.95$$

$$[1.488^2 + Q_{Load\ new}^2][0.95^2] = 1.488^2$$

$$164.91 + 0.9025Q_{Load\ new}^2 = 182.736$$

$$Q_{new} = \sqrt[2]{\frac{1.488^2 - 1.488^2 \times 0.95^2}{0.95^2}} = 0.489\ MVAR$$

The amount of the reactive power needed by capacitor bank is $Q_{old} - Q_{new} = 2 - 0.489 = 1.5109\ MVAR$ which is a smaller amount compared to case 2 because the compensation is done to individual bus bar only.
I used the same element to represent the capacitor bank which is simplified constant PQ shunt because there is no ready shunt capacitor in the tools. Then, I entered the value of the reactive power as equal to -1.5109 MVAR.

Then, after connecting the capacitor bank, we checked the new power factor for bus bar 9 by applying the same formula:

$$new\ power\ factor\ = \frac{P_{Load}}{\sqrt{P_{Load}^2 + Q_{Load\ new}^2}} = \frac{1.488}{\sqrt{1.488^2 + 0.489^2}} = 0.95$$

This represents high quality for this bus bar and limited loss.
Then calculating the new power factor to the whole network to check the improvement, it can be seen as below:

$$new\ power\ factor\ = \frac{P_{Load}}{\sqrt{P_{Load}^2 + Q_{Load\ new}^2}} = \frac{13.518}{\sqrt{13.518^2 + 10.359^2}} = 0.793 \approx 0.8$$

This is still not what is recommended for correction and this means that 20% of the power is wasted. The below table summarizes the data for this case:

Table 3: *Technical data for case 2 before and after correction*

Case 2	before correction	After correction
Generated Power MVA	13.701 + j 13.637	13.653+ j 11.945
Consumed power MVA	13.518 + j 11.818	13.518 + j10.307
Loss power MVA	0.183 + j 1.819	0.135 + j1.638
Power factor	0.75	0.79

1.2.2 Part 2 Calculation of the cost

- **Without the capacitor bank**

The calculation is done in the previous case (case1)

- **After installing the capacitor bank**

From the simulation, the consumed power is equal to 13.653Mw + j10.307 Mvar and with comparing it to the power in case 1, it is found that the compensation at main bus bar can effectively reduce the reactive power more than the individual compensation. Global compensation is more economical because it can improve the power factor better than individual compensation.

The less quantity of reactive power means that loads to cables and transformers became lower than before installing the capacitor bank to the system.

The consumed reactive power in case 1 was 4.394Mvar, which is less by 5.913Mvar.
Then, the total MVA = 17.106 MVA
Using the same assumption 1KVA = 100 £ /KVA:
The total cost for power in KVA = 17.106 x 10^3 x 100 £ /KVA = £1710668.46
It is noticed that the cost in this case is higher than case 1 by £289248.19 and that represents higher cost for the compensation which is not recommended to apply.
Assuming that the load of the network is working the whole year for 18 hours daily and the cost for KwH/year is equal to £0.2, then we can get the total cost for a year as follows:
Total MwH = 13.518Mw x 365 days x 18 hour = 88813.26 MwH
The total cost for KwH = 88813.26 x 10^3 x 0.2 £/KwH = £17762652
There is no effect for the total consumed energy and its cost because the compensation does not affect this part of the network.
The total cost per year = the total cost for power in KVA + The total cost for KwH
= £1710668.46+ £17762652 = £19473320.46
Compared to case 1, the total cost is higher by £289248.19 and that indicates using correction in particular bus bar does not reduce the cost compared to the global compensation done in case1.

Total saving = 19558206.09 – 19473320.46 = £84885.63

This amount can be used in several ways such as regular and major maintenance to the network or help partly in the cost for replacing equipment.

Assume that the cost for 1MVAR is equal to £16000
Capacitor cost = 16000 £ / MVAR x 2MVAR = 32000
The recovery cost for capacitor = $\frac{32000}{84885.63} = 0.37 = 4.58\ months$

The time needed to get the cost of capacitor bank is similar to case 1, which is equal to 4 months. Then, the cost for adding capacitor bank in short shown in the following table:

Table 4: Technical data for case 2 before and after correction

Case 2	Network before PFC	Network after PFC
Total KVA	17950	17106
Total cost for KVA @100£/KVA	1795554.087	1710668.46
Total Mw H @ 18 hours /day in year	88813.26	88813.26
Total cost Kw H/year @0.2£/Kw H	17762652	17762652
Total cost / year	19558206.09	19473320.46
Total saving/year	-	84885.63
Capacitor bank cost @1MAVR =16000£	-	32000
Capacitor bank Cost recovery	-	4.58 months

II. CONCLUSION

For the simulation results in Eracs and the economic calculation, we have the following:

- In case 1, global compensation is done at the 33KV bus bar 2 and the power factor value improved from 0.75 to 0.95 which represents an ideal case. In addition, the consumed reactive power in Mvar was reduced by 7.509. The saving achieved in this case was £374133.82. Case 1 proved that global compensation had many advantages, which are reduction of the reactive power, minimizing the load to the electrical components and getting lower cost.
- The compensation done in case 2 had different technique, which was named individual compensation. The capacitors was installed to bus bar 9. The power factor at the mentioned bus bar became equal to 0.95, whereas the power factor to the whole network did not improve much and changed to 0.8 and this was not what designers look for. In addition, the resultant amount for reactive power was 11.945 Mvar, which indicated that only slight change happed. At this case, the total cost was £84885.63 and this showed low amount compared to case1.
- In conclusion, it has become clear how important is the power factor correction for electric network either in generation, transmission or distribution level. It proved that there are many merits that can be obtained from the power factor correction, which can be technical or economical. In this project, several aspects for the technical side are achieved such as reducing the reactive power, which can save this amount to additional inductive, loads in the future.

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