Design and Calculation of 5 MVAR Shunt Capacitor Bank at 33 kV Bus in Distribution Substation

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Abstract: Shunt capacitor bank improves the power factor, increases voltage level on the load and reduces current flow through the transmission lines. The main reason of installing a capacitor bank is to reduce electricity costs. This inappropriate installation without enough study gives rise to a great variety of technical problems. Therefore, the fact that capacitor banks are designed for long-term use should be considered. Capacitor have no moving parts, initial cost is low, upkeep costs are minimal, and they are compact, reliable, and highly efficient and can be installed basically three possibilities to correct loads individually, in groups or centrally. In this paper, model of 5 MVAR rating of shunt capacitor bank is designed installation for 33 kV busbar is Aung Chan Thar 132/33/11 kV substation in Myanmar.

Keywords: Power Factor Improvement, Reduce Electricity Cost, Reactive Power Stability, Shunt Capacitor Bank, Voltage Control.

I. INTRODUCTION
An electrical power system consists mainly of the components are generators, transformers and transmission lines. The transmission system consists of all the equipment from the generating-end, switchyard lines, switching stations, equipment at the receiving-end till the entrance to sub-transmission networks, and distribution networks. A large number of distribution systems have run into problems such as poor voltage regulation, poor power factor, high losses and poor efficiency, overloading and less reliability for continuity of supply. It is necessary to improve the working of the power distribution systems to reduce the unfavorable conditions and reduce losses, improve voltage regulation, etc. On a power line, besides the active power, the reactive power must also be available for inductive loads. An alternator can produce the reactive power for the line, but the reactive power can be supplied from any source that can be either an alternator or capacitor groups connected near the load. The reactive power source must be very close to the load for efficient operation of the system. If the reactive power of any load is supplied from a synchronous motor or a group of capacitors rather than the power line, this system is called reactive power compensation.

So, the power factor of the system can be kept at a required value. The voltage control is achieved by regulating the reactive output of the generating plants, tap changing on the transformers and switching on or out reactors or capacitors to achieve target system voltages. The system improvement has to be planned properly with the four objectives: (1) to reduce losses in the distribution and sub-transmission system, (2) to improve the voltage regulation so as to bring it within the prescribed limit, (3) to improve the continuity of supply, (4) to improve the power factor in the sub-transmission and distribution system so as to get optimum utilization of generation, sub-transmission and distribution capacities. Therefore, the capacitor banks were used in transmission and distribution system to improve the power factor and voltage regulation.

II. SPECIFICATIONS OF POWER CAPACITOR USED IN 33 KV LINE
When applied on a power system for the reduction if inductive current (power, factor correction), capacitors can be grouped into either transmission or distribution classes. In either case, they should be installed electrically as near to the load as possible for maximum effectiveness. When applied properly, capacitors balance out most of the inductive component of current to the load. The result is a reduction in size of the conductor required to serve a given load and reduction in $I^2R$ losses. Static capacitors may be used at any voltage, but practical considerations impose an upper limit of a few kilovolts per unit, therefore, high-voltage banks must be composed of many units connects in series and parallel.

High capacity transmission capacitor banks should be protected by a high-side circuit breaker and its associated protective relays. Small distribution capacitor may be vault or pole-top-mounded and protected by fuses. In this substation, at 33 kV bus, capacitors are grouped into the distribution classes. As industrial loads occasionally require very large amounts of power factor correction, varying with time and
industrial process cycle. There are 6 capacitor units in series and 3 group of units. If one capacitor element fails, the element is shorted and the voltage on the remaining elements is 17 or about 2.8% increase in the voltage. The capacitor bank continues in service; however, successive failures of elements will lead to the removal of the bank.

TABLE I: Data for Proposed Power Capacitor AT 33 kV Bus

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line voltage</td>
<td>33 kV</td>
</tr>
<tr>
<td>Rated voltage</td>
<td>9.5 kV</td>
</tr>
<tr>
<td>Rated current</td>
<td>87.8 A</td>
</tr>
<tr>
<td>Weight</td>
<td>6030 Ib</td>
</tr>
<tr>
<td>No. of phase</td>
<td>Single phase</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Rated capacity</td>
<td>834 kVAR</td>
</tr>
<tr>
<td>Insulation Level</td>
<td>No. 30</td>
</tr>
<tr>
<td>Test voltage T-T AC</td>
<td>19000 V</td>
</tr>
<tr>
<td>Test voltage T-E AC</td>
<td>70000 V</td>
</tr>
<tr>
<td>Manufactured Co. Ltd.</td>
<td>Nissin Electric Co. Ltd, Kyoto Japan</td>
</tr>
</tbody>
</table>

III. SHUNT CAPACITOR FOR VOLTAGE REGULATION

The capacitors used in the transmission systems for the purpose of voltage regulation, act to improve power factor. In these installations, reactive output rating of a unit capacitor is chosen at 834 kVAR and two groups are connected in series, and three of these groups in star connection with floating neutral make a three phase bank. The single phase discharge coil is connected so as to bridge each phase leg of a capacitor bank. The secondary windings of the discharge coil are used for protecting relay system. The series reactor is connected in series with capacitors at neutral side of the bank.

![Diagram of capacitor bank configuration](image)

SC = Capacitor Unit    SR = Series Reactor
CB = Circuit Breaker    DC = Discharge Coil

Fig.1. Capacitor bank configuration of 33 kV line for 45 MVA power transformer No.(2).

Once the list of additional reactive power requirements is finalized, determinations are made about the placement of each bank. The value of the kVAR connected to kVA per feeder, the position on the feeder of existing capacitor banks, and any concentration of present or future load are all considered in determining the position of the new capacitor banks. Aung Chan Thar substation is connected 132 kV to the 33 kV distribution network which applied 45 MVA transformer from 132 kV step down to 33 kV. This line is radial line system as shown in fig.1.

IV. ANALYSIS OF LOAD DATA WITH RESPECT TO POWER FACTOR CHANGES

Table II is to illustrate some variables obtained from power factor changes. Capacitor rating added to improve power factor can be determined. Capacitor rating is the difference between MVAR ratings of original power factor and desired power factor (fig.2).

![Diagram of 5 MVAR capacitor bank](image)

Fig.2. Proposed 5 MVAR capacitor bank installed at 33 kV main 45 MVA (2).
From Table II, 5 MVAR capacitor bank would be needed for 45 MVA power transformer to improve power factor.

**TABLE II: 33 kV MAIN 45 MVA NO.(2) Log Sheet Data**

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>kV</th>
<th>A</th>
<th>MVA</th>
<th>MW</th>
<th>pF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00</td>
<td>32.3</td>
<td>197</td>
<td>11.072</td>
<td>9.8</td>
<td>0.8851</td>
</tr>
<tr>
<td>2:00</td>
<td>32.4</td>
<td>122</td>
<td>6.878</td>
<td>6.1</td>
<td>0.8869</td>
</tr>
<tr>
<td>3:00</td>
<td>32.5</td>
<td>162</td>
<td>9.161</td>
<td>8.1</td>
<td>0.8841</td>
</tr>
<tr>
<td>4:00</td>
<td>32.8</td>
<td>203</td>
<td>11.585</td>
<td>10.2</td>
<td>0.8804</td>
</tr>
<tr>
<td>5:00</td>
<td>32.2</td>
<td>250</td>
<td>14.007</td>
<td>12.5</td>
<td>0.8924</td>
</tr>
<tr>
<td>6:00</td>
<td>32.1</td>
<td>317</td>
<td>17.706</td>
<td>13.8</td>
<td>0.8923</td>
</tr>
<tr>
<td>7:00</td>
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<td>364</td>
<td>19.698</td>
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</tr>
<tr>
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<td>31.2</td>
<td>325</td>
<td>17.644</td>
<td>16.2</td>
<td>0.9181</td>
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<tr>
<td>9:00</td>
<td>31.4</td>
<td>218</td>
<td>11.911</td>
<td>10.9</td>
<td>0.9151</td>
</tr>
<tr>
<td>10:00</td>
<td>32.2</td>
<td>227</td>
<td>12.718</td>
<td>11.2</td>
<td>0.8806</td>
</tr>
<tr>
<td>11:00</td>
<td>32.6</td>
<td>150</td>
<td>8.5086</td>
<td>7.4</td>
<td>0.8697</td>
</tr>
<tr>
<td>12:00</td>
<td>32.2</td>
<td>207</td>
<td>11.598</td>
<td>10.6</td>
<td>0.914</td>
</tr>
<tr>
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<td>32.9</td>
<td>146</td>
<td>8.358</td>
<td>7.3</td>
<td>0.8734</td>
</tr>
<tr>
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<td>32.1</td>
<td>251</td>
<td>14.019</td>
<td>12.5</td>
<td>0.8916</td>
</tr>
<tr>
<td>15:00</td>
<td>32.1</td>
<td>228</td>
<td>12.735</td>
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<td>0.8952</td>
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<tr>
<td>16:00</td>
<td>32.6</td>
<td>196</td>
<td>11.118</td>
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<td>0.8814</td>
</tr>
<tr>
<td>17:00</td>
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<td>300</td>
<td>16.861</td>
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<td>0.8777</td>
</tr>
<tr>
<td>18:00</td>
<td>31.7</td>
<td>342</td>
<td>18.864</td>
<td>16.8</td>
<td>0.8906</td>
</tr>
<tr>
<td>19:00</td>
<td>31.1</td>
<td>412</td>
<td>22.245</td>
<td>19.5</td>
<td>0.8766</td>
</tr>
<tr>
<td>20:00</td>
<td>32.1</td>
<td>360</td>
<td>20.11</td>
<td>17.1</td>
<td>0.8503</td>
</tr>
<tr>
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<td>314</td>
<td>17.648</td>
<td>15.7</td>
<td>0.8814</td>
</tr>
<tr>
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<td>270</td>
<td>13.081</td>
<td>13.5</td>
<td>0.8952</td>
</tr>
<tr>
<td>23:00</td>
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<td>205</td>
<td>11.664</td>
<td>10.2</td>
<td>0.8744</td>
</tr>
<tr>
<td>24:00</td>
<td>32.8</td>
<td>202</td>
<td>11.529</td>
<td>10.1</td>
<td>0.876</td>
</tr>
</tbody>
</table>

**V. DESIGN CALCULATION OF CAPACITOR BANK SIZE**

The following data are obtained from Aung Chan Thar Substation to design capacitor bank for power factor correction.

- Transformer rating = 45 MVA
- Transformer reactance = 15 %
- Voltage = 33 kV
- Present maximum load = 19.5 MW
- Present maximum MVA = 22.245 MVA
- Power factor (maximum load) = 87.66 %
- Desired power factor = 95 %

If the power factor is raised to 95 %,

\[ \text{Desired MVA Demand} = \frac{\text{Present Load}}{\text{Desired Power Factor}} \]

\[ = \frac{19.5}{0.95} = 20.526 \text{ MVA} \] (1)

The size of the capacitor required to accomplish this is determined from the MVAR at the two values of power factor as follows:

\[ \text{MVAR} = \sqrt{\text{MVA}^2 - \text{MW}^2} \]

\[ \text{MVAR}_1 \text{ at 87.66 % power factor} = \sqrt{22.245^2 - 19.5^2} \]

\[ = 10.704 \text{ MVAR} \] (2)

\[ \text{MVAR}_2 \text{ at 95 % power factor} = \sqrt{20.526^2 - 19.5^2} \]

\[ = 6.408 \text{ MVAR} \]

Capacitor rating = \text{MVAR}_1 \text{(Uncorrect)} - \text{MVAR}_2 \text{(Corrected)}

\[ = 10.704 - 6.408 = 4.296 \text{ MVAR} \]

Fig. 3 presents this power triangle shows apparent power demands on a system before and after adding capacitors. By installing power capacitors and increasing power factor to 95 %, apparent power is reduced from 22.245 MVA to 20.526 MVA (reduction of 7.73 %). Theoretically, capacitors could provide 100 % of needed reactive power. In practical usage, however, power factor correction to approximately 95 % provides maximum benefit.

Multiplying factor = 0.238

Capacitor Rating = Multiplying Factor × MW Demand

\[ = 0.238 \times 19.5 \]

\[ = 4.641 \approx 5 \text{ MVAR} \]

95 % is a good economic power factor for industrial purposes. In this thesis, this power factor is corrected from 87.66 %. Therefore the installation of 5 MVAR capacitor bank is determined for achieving power factor of 95 % while providing the same productive power of 19.5 MW.

**VI. CHECK CALCULATION FOR AFTER INSTALLATION OF 5 MVAR CAPACITOR BANK**

For maximum load condition,
\[ \text{MVAR}_2 \text{(Corrected)} = \text{MVAR}_1 \text{(Uncorrect)} - \text{Capacitor rating} \]

\[ = 10.704 - 5 \]

\[ = 5.704 \text{ MVAR} \]

\[ \text{MVAR}_3 = \sqrt{\text{MVAR}_1^2 - \text{MVAR}_2^2} \]

\[ = \sqrt{10.704^2 - 5.704^2} = 9.566 \text{ MVAR} \]

\[ \text{Power Factor} = \frac{\text{Present Load}}{\text{MVA Demand}} = \frac{19.5}{20.317} = 0.9598 \]
TABLE III: Power Factor Data After Installing Capacitor Bank

<table>
<thead>
<tr>
<th>Time</th>
<th>Power Factor</th>
<th>Time</th>
<th>Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00</td>
<td>0.9998</td>
<td>13:00</td>
<td>0.9919</td>
</tr>
<tr>
<td>2:00</td>
<td>0.9582</td>
<td>14:00</td>
<td>0.9942</td>
</tr>
<tr>
<td>3:00</td>
<td>0.9961</td>
<td>15:00</td>
<td>0.9982</td>
</tr>
<tr>
<td>4:00</td>
<td>0.9988</td>
<td>16:00</td>
<td>0.9996</td>
</tr>
<tr>
<td>5:00</td>
<td>0.9944</td>
<td>17:00</td>
<td>0.9791</td>
</tr>
<tr>
<td>6:00</td>
<td>0.9825</td>
<td>18:00</td>
<td>0.978</td>
</tr>
<tr>
<td>7:00</td>
<td>0.9716</td>
<td>19:00</td>
<td>0.9597</td>
</tr>
<tr>
<td>8:00</td>
<td>0.9925</td>
<td>20:00</td>
<td>0.9506</td>
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<tr>
<td>9:00</td>
<td>0.9998</td>
<td>21:00</td>
<td>0.9815</td>
</tr>
<tr>
<td>10:00</td>
<td>0.9938</td>
<td>22:00</td>
<td>0.9915</td>
</tr>
<tr>
<td>11:00</td>
<td>0.9942</td>
<td>23:00</td>
<td>0.9979</td>
</tr>
<tr>
<td>12:00</td>
<td>0.9996</td>
<td>24:00</td>
<td>0.9984</td>
</tr>
</tbody>
</table>

VII. VOLTAGE RISE

The approximate voltage change due to capacitors at a transformer secondary bus is determined by using the following equation:

\[
\text{% Voltage rise} = \frac{\text{Capacitor MVAR} \times \text{Transformer Reactance}}{\text{Transformer MVA}} \tag{4}
\]

Capacitor Rating = 5 MVAR
Transformer Reactance = 15 %
Transformer MVA = 45 MVA
% Voltage Rise = \(\frac{5 \times 15\%}{45}\% = 1.67\%\)

The voltage regulation of a system from no-load to full-load is practically unaffected by the amount of capacitors, unless the capacitors are switch. However, the addition of capacitors can raise the voltage level. The voltage rise due to capacitors in most industrial plants with modern power distribution system and a single transformation is rarely more than a few percent.

TABLE IV: Voltage Data after Installing Capacitor Bank

<table>
<thead>
<tr>
<th>Time</th>
<th>Voltage (kV)</th>
<th>Time</th>
<th>Voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00</td>
<td>32.839</td>
<td>13:00</td>
<td>33.449</td>
</tr>
<tr>
<td>2:00</td>
<td>32.941</td>
<td>14:00</td>
<td>32.636</td>
</tr>
<tr>
<td>3:00</td>
<td>33.043</td>
<td>15:00</td>
<td>32.636</td>
</tr>
<tr>
<td>4:00</td>
<td>33.348</td>
<td>16:00</td>
<td>33.144</td>
</tr>
<tr>
<td>5:00</td>
<td>32.738</td>
<td>17:00</td>
<td>32.839</td>
</tr>
<tr>
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<td>8:00</td>
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<td>32.636</td>
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<td>9:00</td>
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<td>11:00</td>
<td>33.144</td>
<td>23:00</td>
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</tr>
<tr>
<td>12:00</td>
<td>32.738</td>
<td>24:00</td>
<td>33.348</td>
</tr>
</tbody>
</table>

Therefore, improved voltage = \(31.1 + \frac{31.1 \times 1.67}{100}\) = 31.1 + 0.519 = 31.619 kV

VIII. LINE CURRENT REDUCTION

The percent line current reduction may be approximated from this equation.

\[
\text{% Line current reduction} = 100 \left[ 1 - \frac{\text{Present Power Factor}}{\text{Improved Power Factor}} \right] \tag{5}
\]

For maximum load condition,
Present current = 412 A
Present power factor = 0.8766
Improved power factor = 0.9597
% Line current reduction = \(100 \left[ 1 - \frac{0.8766}{0.9597} \right] = 7.726\%\)

Reduced current = \(412 \times \frac{8.658}{100} = 376.3\) A

TABLE V: Line Current Data after Installing Capacitor Bank

<table>
<thead>
<tr>
<th>Time</th>
<th>Line Current (A)</th>
<th>Time</th>
<th>Line Current (A)</th>
</tr>
</thead>
<tbody>
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<td>1:00</td>
<td>174.4</td>
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</tr>
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<td>2:00</td>
<td>112.9</td>
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<td>225.1</td>
</tr>
<tr>
<td>3:00</td>
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<td>7:00</td>
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<tr>
<td>12:00</td>
<td>189.2</td>
<td>24:00</td>
<td>177.2</td>
</tr>
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</table>

A. Lower Losses

An estimate of reduction of power losses can be made using following equations.

\[
\text{% Power losses} = 100 \left[ \frac{\text{Improved Power Factor}}{\text{Present Power Factor}} \right]^2 \tag{6}
\]

\[
\text{% Loss reduction} = 100 \left[ 1 - \left( \frac{\text{Present Power Factor}}{\text{Improved Power Factor}} \right)^2 \right] \tag{7}
\]

\[= 100 \left[ 1 - \left( \frac{0.8766}{0.9597} \right)^2 \right] = 14.855\%\]

There is 14.855 % reduction in power losses.
IX. CONCLUSIONS

Having low power factor does not cause a piece of machinery to shut down, but high power factor is important for the overall health of the power system. Operating in a high power factor environment ensures that the power system is functioning efficiently. It also makes economic sense. As the demand for electrical energy continues to grow and the resources for producing the energy become less and less available, the idea of not using more than what we need takes on more relevance. In this paper 5 MVAR shunt capacitor bank is installed at 33 kV bus for reactive power compensation in Aung Chan Thar 132/33/11 kV substation. In this substation have 5-outgoing lines of 33 kV bus for available loads. Distribution line voltage 33 kV has decrease to 31.1 kV at present maximum load 19.5 MW and decrease to 32.4 kV at present minimum load 6.1 MW. This voltage 31.1 kV is out of -5% range. So, a shunt capacitor bank (5 MVAR) has proposed installed for better voltage regulation, reduce transformer loading and improve the power factors of various loads.

X. ACKNOWLEDGEMENT

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XI. REFERENCES


Author’s Profile:
Moe Yu Mon received her B.E (Electrical power) degree from Technological University, in 2006 and now pursuing M.E (Electrical Power) at Mandalay Technological University.