Analysis of the Commercial Aspects of using a Capacitor Bank as a Source of Reactive Power Supply in 220 KV Substation MPPTCL Narsinghpur

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ABSTRACT
Reactive power supply is essential for reliable operation of the electric transmission system. Inadequate supply of reactive power can contribute to voltage collapse, as demonstrated in several recent major power outages. Along with the placement of different reactive power supply measures in electric power systems a proper economic analysis is the must as far as energy conservation and sustainable development is concerned. Capacitor banks were introduced in the electric grid during the first years of 20th century. At that time the electric network with alternating current soon become very large and losses caused by reactive power became a problem.

Keywords - Annual Savings, Capacitor Bank, Payback Period and Reactive Power Compensation.

I. INTRODUCTION
It is well known that shunt power capacitors are the most economical source for the reactive power (KVAR) required by the loads and lines when operating at less than unity power factor. Studies show that supply systems from the power companies’ lines require reactive power (KVAR) in addition to the consumers' electric load. Looking at a simple system, if the only reactive power source is the central station generation, this reactive power will have to be generated by the generators and then transmitted over the lines to the loads. If the power company has capacitor banks at the supply substation, this will aid in supplying reactive power. However, if the consumer’s plant has a poor power factor the substation and the lines to the plant will have to handle the additional currents required. Coupled with the additional currents developed by poor power factor, there is also corresponding power loss (I²R loss) associated with transmission and distribution of reactive power current to the plants load. These losses create an undesirable voltage reduction on the lines to the plant. Shunt capacitors affect the voltage rise when connected to the system. The addition of switched capacitors not only improves the voltage levels, but also provides an effective method of controlling the voltage levels. The installation of power capacitors enables a utility, as well as the industrial customer, to realize savings on their systems. The following benefits can be realized such as raised voltage levels, released generation capacity, reductions of system loses, regulations of voltage levels.

In the process of energy management, at some stage, investment would be required for reducing the energy consumption of a process or utility. Investment would be required for modifications/retrofitting and for incorporating new technology. It would be prudent to adopt a systematic approach for merit rating of the different investment options vis-à-vis the anticipated savings. It is essential to identify the benefits of the proposed measure with reference to not only energy savings but also other associated benefits such as increased productivity, improved product quality etc. The cost involved in the proposed measure should be captured in totality viz.
• Direct project cost
• Additional operations and maintenance cost
• Training of personnel on new technology etc

II. METHODOLOGY

Introduction of 220 KV Substation MPPTCL Narsinghpur:

220 KV substation MPPTCL Narsinghpur is one of transmission company’s substations and is located at Narsinghpur district. It is a major and vital transformation
and switching substation of the company. It is established in the year 1995 having total installed capacity of 320MVA (2x160MVA auto-transformer) at 220/132 KV level. Along with this there are 83MVA capacity (1x63MVA and 1x20MVA two winding transformer) at 132/33 KV level as shown in single line diagram.

Here we have observed that 132 KV bus has 6 export feeders (load) and only 2 import feeders (source). As from the load flow study by past software tool it has been observed that maximum reactive load of Narsinghpur district flows at 132 KV bus of 220 KV sub-station Narsinghpur. By addition of this compensator at 132 KV bus, the excess energy losses in 160 MVA BHEL and 160 MVA CGL transformer is being saved considerably

Table 1 Capacitors Minimum Ratings (As Per Is)

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>Minimum Rating of Capacitor Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3 KV, 6.6 KV</td>
<td>750 KVAR</td>
</tr>
<tr>
<td>11 KV</td>
<td>2000 KVAR</td>
</tr>
<tr>
<td>22 KV</td>
<td>6000 KVAR</td>
</tr>
<tr>
<td>33 KV</td>
<td>12000 KVAR</td>
</tr>
<tr>
<td>132 KV</td>
<td>33000 KVAR</td>
</tr>
</tbody>
</table>

Table 2 Selection of Capacitor According To Non Linear Load

<table>
<thead>
<tr>
<th>% Non Linear Load</th>
<th>Type of Capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;=10%</td>
<td>Standard duty</td>
</tr>
<tr>
<td>Up to 15%</td>
<td>Heavy duty</td>
</tr>
<tr>
<td>Up to 20%</td>
<td>Super heavy duty</td>
</tr>
<tr>
<td>Up to 25%</td>
<td>Capacitor + reactor (detuned)</td>
</tr>
</tbody>
</table>

Here at 220 KV sub-station Narsinghpur, installed capacity at 132 KV bus is 320MVA. Therefore non linear load for calculation of capacitor bank size is:
70 MVAR / 320MVA = 0.21
Or 21% Non Linear Load

Table 3 Components Attached in Capacitor Bank

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>No. of series group</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>i.</td>
<td>No. Of units in parallel in each series group</td>
<td>2</td>
</tr>
<tr>
<td>ii.</td>
<td>Total units per phase per star group</td>
<td>10x2x2 = 40</td>
</tr>
<tr>
<td>iii.</td>
<td>Total units in 3 phase in one star</td>
<td>20x3 = 60</td>
</tr>
<tr>
<td>iv.</td>
<td>Total units in 3 phase</td>
<td>40x3 = 120</td>
</tr>
</tbody>
</table>

Bank rating
Rating of each unit = 275 KVAR / 8.37 KV
Rating of bank = 275 KVAR x 120 = 33 MVAR
Output of (ø) of capacitor (KVAR) x (base system voltage)²
33 MVAR x (132 KV)²

![Figure 4 Gas Circuit Breaker](https://example.com/gas_circuit_breaker.png)

**III. RESULTS**

**Table 4 Bus Voltages and Power Factor before Addition of Capacitor Bank**

<table>
<thead>
<tr>
<th>Bus standard voltage</th>
<th>Bus voltage before pf correction</th>
<th>Bus power factor before pf correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>132 KV bus</td>
<td>132.02 KV</td>
<td>0.82</td>
</tr>
<tr>
<td>33 KV bus</td>
<td>32.9 KV</td>
<td>0.81</td>
</tr>
</tbody>
</table>

**Table 5 Bus Voltages and Power Factor after Addition of Capacitor Bank**

<table>
<thead>
<tr>
<th>Bus standard voltage</th>
<th>Bus voltage after power factor correction</th>
<th>Bus power factor after power factor correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>132 KV bus</td>
<td>137.5 KV</td>
<td>0.97</td>
</tr>
<tr>
<td>33 KV bus</td>
<td>34.5 KV</td>
<td>0.98</td>
</tr>
</tbody>
</table>

**Calculating the Size of Capacitor Bank / Annual Savings**

Calculation at 220 KV substations Narsinghpur
- For industrial connection at 132 KV voltage level
- Total maximum load m MW for connection = 200 MW
- Average load connected = (max load )/ √2
  = 200/ √2
  = 141.42 MW
- Total load MVA (old) for connection = MW/ old power factor
  = 141.42/0.82
  = 172.46 MVA
- Total load KVA (new) for connection (1) = KW/new power factor
  = 141.42/0.98
  = 144.306 MVA
- Total load MVAR = MW x ([√1-(old p.f)²] / old p.f) - ([√1-(new p.f)²] / new [p.f])
- Total load MVAR1 = 141.42x ([√1-(0.82)²] / 0.82) - ([√1-(0.98)²] / 0.98)
- Total load KVAR = 69.29 MVAR

**Capacitor bank details**
- Installed capacitor bank capacity = 33 MVAR × 2 = 66 MVAR
- Capital cost of installation = Rs 72,318.36

**Annual savings and payback period**

**Before power factor correction**
- Total electrical load KVA(old) = 172.46 MVA
- Total electrical load KW = 141.42 MW
- Load current = MVA/KV
  = 172.46 MVA/132 KV
  = 1306.5 amp
- Load current = 1306.5 amp
- KVA demand charge = KVA × charge
  = (172.46 × 1000) × rs 4.80
  = Rs 827808.00 (as per tariff schedule 2014-15)
- Annual unit consumption = KW × daily uses × 365
  = 1,23,88,39,200 KWh
- Per unit charges = Rs 5
- Annual charges = 1, 23, 88, 39,200 × 5
  = Rs 6,19,41,96,000
- Total annual cost = total demand charges + total annual charges
  = Rs (8,27,808 + 6,19,41,96,000)

**Total annual cost before power factor correction = Rs 6,19,50,23,808**
- After power factor correction
- Total electrical load KVA(old) = 144.306 MVA
- Total electrical load KW = 141.42 MW
- Load current = MVA/KV
  = 144.306 MVA/132 KV
  = 1093.228 amp
• Load current  
  = 1093.228 Amp  
• KVA demand charge  
  = KVA × charge  
  = (141.306 × 1000) × Rs 4.80  
  = Rs 6, 92,668.80  
(As per tariff schedule 2014-15)  
• Annual unit consumption  
  = KW × daily uses × 365  
  =141.42× 1000 × 24×365  
  = 1,23,88,39,200 KWh  
• Per unit charges  
  = Rs 5  
• Annual charges  
  =1, 23, 89, 32,00 × 5  
  = Rs 6,19,41,96,00  
• Total annual cost  
  = Total demand charges + Total annual charges  
  = Rs (6, 92,668.80 + 6, 19, 41, 96,00)  
• Capital cost of capacitor  
  = Rs 72, 32,318.36  
• Annual interest and depreciation cost of capacitor bank  
  = 72, 32,318.36× 12%  
  = Rs 8, 67,878.20  
• Total annual cost  
  = Rs (6, 92,668.80 +6, 19, 41, 96,00+  
  72, 32,318.36+8, 67,878.20)  

Total annual cost after power factor correction  
= Rs 6,202,988,865.00  

4.3 Annual Savings and Payback Period of Capacitor Banks  
• Total annual cost before power factor correction  
  = Rs 6,19,50,23,808.00  
• Total annual cost after power factor correction  
  = Rs 6,20,29,88,865.00  
• Annual savings  
  = cost after correction – cost before correction  
  =6,20,29,88,865.00 - 6,19,50,23,808.00  
  = Rs 7965057.00  
• Payback period  
  = capital cost of capacitor / annual savings  
  = 7232318.36 / 7965057.00  
  = 0.91 years  

Payback period of capacitor banks = 0.91 years or 11 months.  

IV. CONCLUSION  

From all the previous discussion and observations of 220 KV sub-station MPPTCL Narsinghpur, we can conclude that reactive power compensation is a must for improving the performance of the ac system. By reactive power compensation we can control the power factor, reduce the consumption of electricity, minimize the transmission losses resulting in increased overall system power transmission efficiency, reduced loading of power transformers, reduced current flow over long lines, and many other advantageous aspects of power system.  
To maintain the system reliability it is necessary to compensate the reactive power and thereby the selection of reactor (capacitor or inductor) bank is required. This work is solely devoted to develop a fast and simple algorithm for the computation of capacitor and inductor bank size for static var compensator. In traditional method several trials and errors are to be done each of which comprises several iterations which make this method complicated and time consuming, whereas the proposed method of computation needs a trivial computation which is less time consuming and simple. It is very tough to implement the time consuming and complicated traditional method for online capacitor or inductor bank computing purpose. On the other hand, being extremely fast, the proposed method of computation has high opportunities to be used for online capacitor or inductor bank computation purpose.

REFERENCE  
[1] Importance of series and shunt compensation and shunt reactors – by k.p. chaturvedi (additional chief engineer)  
[2] Capacitor banks – operation & maintenance a.ghosh executive engineer o/o ce(t&c)  
[3] Shunt reactive power compensation of long transmission lines q. Wang,ss choi nanyang technological university singapore  
[5] Economical optimization of capacitor placement for large-scale practical distorted distribution network tamer m. Khalil selim1), member, iee; alexander v. Gorpinich2), member, iee  
[7] Capacitor bank designing for power factor improvementashish chandra1, taru agarwal21deputy manager, birla industries, india2assistant professor, acts, india