Shunt Capacitor Bank Protection in UHV Pilot Project

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INTRODUCTION

- State Grid Corp. of China, the largest electric power provider in the country, has first build a 1000 kV transmission network covering North and Central China, from Southeast Shanxi via Nanyang in Henan province to Jinmen in Hubei province. It is the first ultra high voltage (UHV) pilot project in the world currently which will operate in rated voltage over a long period of time.

- There is no standard or regulation yet for configuration and setting of the 110 kV shunt capacitor banks (SCB) protection in this project. This paper introduces the SCB connection and SCB protection configuration of the UHV pilot project. The application principle on the configuration and setting of this 110 kV capacitor protection is studied and discussed in detail.
BRIEF INTRODUCTION TO THE 110 kV CAPACITORS
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Primary connection of 110 kV equipments in Changzhi substation
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The model number of 1113C, 1121C SCB is TBB110-216500/501-AQW with a small reactor, connected in series, whose inductive reactance is 12% of the SCB reactance. This small reactor can be used to eliminate the 3rd power frequency harmonic component. The 1113C or 1121C has the following parameters: phase voltage is 136.4/√3kV, rated capacity is 216.5Mvar, rated capacity of capacitor unit is 501kvar, rated voltage of capacitor unit is 6.56kV, rated current of capacitor unit is 76.37A and rated capacitance of capacitor unit is 37.06μF. The model number of 1114C、1122C SCB is TBB110-200500/464-AQW with a small reactor, connected in series, whose inductive reactance is 5% of the SCB reactance. This small reactor can be used to eliminate the 5th power frequency harmonic component. The 1114C、1122C has the following parameters: phase voltage is 126.32/√3kV, rated capacity is 200.5Mvar, rated capacity of capacitor unit is 464kvar, rated voltage of capacitor unit is 6.08kV, rated current of capacitor unit is 76.32A, and rated capacitance of capacitor unit is 39.96μF.
BRIEF INTRODUCTION TO THE 110 kV CAPACITORS

Primary connection of 110 kV equipments in Changzhi substation
BRIEF INTRODUCTION TO THE 110 kV CAPACITORS

The connection for SCB in China UHV project is shown in Fig.2. The protection of shunt capacitor banks requires understanding the basics of capacitor bank design and capacitor unit connections. Shunt capacitors banks are arrangements of series/paralleled connected units. Capacitor units connected in paralleled make up a group and series connected groups form a single-phase capacitor bank. As a general rule, the minimum number of units connected in parallel, which is 12, is such that isolation of one capacitor unit in a group should not cause a voltage unbalance sufficient to place more than 110% of rated voltage on the remaining capacitors of the group. Equally, the minimum number of series connected groups, which is 12, is that in which the complete bypass of the group does not subject the others remaining in service to a permanent over-voltage of more than 110%.
The discharge transient from a large number of paralleled capacitors can be severe enough to rupture the failed capacitor unit or the expulsion fuse holder, which may result in damage to adjacent units or cause a major bus fault within the bank. To minimize the probability of failure of the expulsion fuse holder, or rupture of the capacitor case, or both, more capacitor groups connected in series with fewer units in parallel per group may be a suitable solution. However, this may reduce the sensitivity of the unbalance detection scheme. Splitting the bank into 2 sections as left tower and right tower, as shown in Fig.2, may be the preferred solution and may allow for better unbalance detection scheme. As long as all capacitors are normal, no current will flow through the current transformer. If a capacitor fuse operates, some current will flow through the current transformer TA1 or TA2. This bridge connection can be very sensitive. This arrangement is used on large banks with many capacitor units in parallel. Another possibility is the use of current limiting fuses.
CONFIGURATION AND SETTING OF SCB PROTECTION

- two levels of capacitor bank unbalance protection (alarm and trip);
- two levels of phase overcurrent protection (trip);
- overload protection (alarm);
- overvoltage protection (trip) and low voltage protection (trip).

The trip relay scheme has a lockout feature to prevent inadvertent closing of the SCB switching device if a trip has occurred.
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Instantaneous Overcurrent Protection

This element provides a definite time protection characteristic to protect against phase faults leading from the CTs to the capacitor bank. This protects against bus faults, inter-rack and arcing faults within the capacitor bank with the sensitivity no less than 2. So the threshold is set as 3.15p.u. rated SCB current and time delay is set as 0.2s, which can avoid the influence of the inrush current as shown in Fig.3 and Fig.4, where $I_{A1}$, $I_{B1}$, $I_{C1}$ are the three phase currents when 1113C is energized, $I_{A2}$, $I_{B2}$, $I_{C2}$ are the three phase currents when 1114C, with 5% current-limiting reactors, is energized. An appropriate filter method is used to get the power frequency component and avoid the mal-trip of SCB.
This element provides an definite time overcurrent characteristic for the SCB protection. Compared to the instantaneous overcurrent protection, this element has lower threshold and longer time delay. The threshold is set as 1.5p.u. rated SCB current and time delay is set as 0.9s, which can also avoid the influence of the inrush current. An appropriate filter method is also used to get the power frequency component.

the capacitor currents when 1114C is energized
Overvoltage protection

- Now the switches can interrupt the back to back capacitive current no more than 1600A~2000A and normal capacitive current no more than 3600A~4000A reliably, as the manufacture said.

- Some steady state overvoltage control devices (SSOVCD) are added in the 3 substations of first China UHV project in order to ensure the safe operation of the project and insulation margin of the main equipments, like transformer, GIS and shunt reactor. The total 1000kV switches will be opened by communication when 2 1000kV switches in any substation are opened or the steady state overvoltage of 1000kV lines in any substation exceeds 1150kV for 0.5 second. The 1000kV switches will be opened before the SCB does so when the trip signal issued by local or remote SSOVCD is received. So the thresholds value and time delay of overvoltage, 132kV and 9s respective, should and could corporate with that of the SSOVCD to prevent the mal-trip of SCB switches before the 1000kV line switches.
Overload Protection

- This element provides an inverse time overcurrent characteristic, shown in equation (1), for the protection of series connected shunt reactors. Unlike capacitors, which are relatively unaffected by current overloads, series reactors, often used for inrush limiting or filter tuning, are sensitive to RMS current overloads. This element accurately measures the RMS current \( I \) through the ninth harmonic, which determines the time delay by equation (1).

\[
\begin{align*}
t &= \frac{80}{(1/Ip)^2 - 1} \cdot tp \\
\end{align*}
\]  
\( (1) \)

- Where \( Ip \) is set as 1.5p.u. rated SCB current and \( tp \) is set as 0.02s. The capacitor over load characteristic curve is shown in Fig.5.
Lowvoltage protection should operate reliably when there is no voltage for a short period of time. When power is restored, the relay will return automatically. The threshold is 0.6p.u. rated SCB voltage and time delay is 9s, which can corporate with the time delay of line protection. The blocking current should be set in case the mal-trip of relay for TV breaking.
Capacitor Unbalance Protection

- Removal of a failed capacitor element or unit by its fuse results in an increase in voltage across the remaining elements/units causing an unbalance within the bank. A continuous overvoltage (above 1.1p.u.) on any unit shall be prevented by means of protective relays that trip the bank.

- Unbalance protection normally senses changes associated with the failure of a capacitor element or unit and removes the bank from service when the resulting overvoltage becomes excessive on the remaining healthy capacitor units. Unbalance protection normally provides the primary protection for arcing faults within a capacitor bank and other abnormalities that may damage capacitor elements/units. Arcing faults may cause substantial damage in a small fraction of a second. The unbalance protection should have minimum intentional delay in order to minimize the amount of damage to the bank in the event of external arcing.
Capacitor Unbalance Protection

- In most capacitor banks an external arc within the capacitor bank does not result in enough change in the phase current to operate the primary fault protection (an overcurrent relay). The sensitivity requirements for adequate capacitor bank protection for this condition may be very demanding, particularly for SBC in UHV project. The need for sensitive resulted in the development of double bridge unbalance protection where currents parameters of TA1 and TA2 are monitored and compared to the bank balance conditions, shown if Fig.2.

- The SCB per phase in Changzhi substation have 432 capacitor units, which are 23328 capacitor elements. The degree of unbalance introduced by an element failure is less than that which occurs with externally fused units (since the amount of capacitance removed by blown fuse is less) and hence a more sensitive unbalance protection scheme, the double bridge unbalance protection, is required when internally fused units are used.
## Capacitor Unbalance Protection

<table>
<thead>
<tr>
<th>N</th>
<th>M</th>
<th>$I_1$</th>
<th>relay</th>
<th>$I_2$</th>
<th>S</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.0956</td>
<td>0.258A</td>
<td>alarm</td>
<td>0.34A/10s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.1506</td>
<td>0.407A</td>
<td></td>
<td></td>
<td>1.22</td>
<td>2.91</td>
</tr>
<tr>
<td>4</td>
<td>1.2115</td>
<td>0.571A</td>
<td>trip</td>
<td>0.66A/0.2s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.2791</td>
<td>0.753A</td>
<td></td>
<td>0.115A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

the setting value of bridge differential unbalance protection
Capacitor Unbalance Protection

- If the inherent unbalance error approaches 50% of the alarm setting, compensation should be provided in order to correctly alarm for the failure of one unit or element as specified. It could be seen in Table I that the inherent unbalance error approaches 33% of the alarm setting and no compensation has been made. In China UHV project a different bank connection, a double bridge connection, is utilized to improve the sensitivity without adding compensation, thereby doubling the sensitivity of the protection and eliminating the system voltage unbalance effect. In other large banks like DC filter or AC filter in HVDC systems, the unbalance signal produced by the loss of one or two individual capacitor units is small compared to the inherent unbalance and the latter can no longer be considered negligible.

- Unbalance compensation used in HVDC systems can be carried out for SCB protection in China UHV project. Harmonic voltages and currents can not influence the operation of the unbalance relay because power frequency band-pass filtering is provided.
Capacitor Unbalance Protection

- The time delay of the unbalance relay trip should be minimized to reduce damage from an arcing fault within the bank structure and prevent exposure of the remaining capacitor units to overvoltage conditions beyond their permissible limits. The unbalance trip relay should have enough time delay to avoid false operations due to inrush, system ground faults, switching of nearby equipment, and non-simultaneous pole operation of the energizing switch. In China UHV project, 0.2s should be adequate. For unbalance relaying systems that would operate on a system voltage unbalance, a delay slightly longer than the upstream protection fault clearing time is required to avoid tripping due to a system fault. Longer delays increase the probability of catastrophic bank failures.

- To allow for the effects of inherent unbalance within the bank, the unbalance relay alarm should be set to operate at about one-half the level of the unbalance signal determined by the calculated alarm condition based on an idealized bank. The alarm has sufficient time delay, 10s, to override external disturbances.
CONCLUSION

- The protection of shunt capacitor banks uses simple, well known relaying principles such as overvoltage, overcurrents. However, it requires the protection engineer to have a good understanding of the capacitor unit, its arrangement and bank design issues before embarking in its protection. Unbalance is the most important protection in a shunt capacitor bank, as it provides fast and effective protection to assure a long and reliable life for the bank. This paper introduces the shunt capacitor banks connection and shunt capacitor banks protection configuration of the China first UHV pilot project. The application principle on the configuration and setting of this 110 kV shunt capacitor banks protection is studied and discussed in detail. The principle to ensure the safety of power equipment is chiefly taken into account in order to achieve a reasonable configuration and setting. It may be useful when implementing a protection scheme to a shunt capacitor bank.