Optimizing HV Capacitor-Bank Design
Protection & Testing

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Introduction

Shunt Capacitor Bank Considerations
Protection Functions
Control Functions
Testing Considerations
Conclusion
Shunt Capacitor Bank – Considerations

- Used for local voltage and VAr support
- HV applications commonly use grounded and ungrounded banks of single- or double-wye configurations (some H-type too)
- Protection scheme linked to SCB configuration
- Choice of fused or unfused capacitor elements
- Choice of can voltage and VAr size (critical factor)
- Key challenge: detect unbalance at the element level
Shunt Capacitor Bank - Considerations

- What size bank is needed? (ex. 164kV, 161MVAr)
- Which configuration and protection scheme is preferred?
- What are the operational requirements?
- Desire one standard design, flexible deployment.
- Easy to test, commission, maintain.
- Maximize operational reliability.
- Most Important – know the standards (IEEE Std. 18 and IEEE C37.99)
SCB Wye or Wye-G Externally Fused Cans
SCB Wye or Wye-G Internally Fused Cans

- A, B, C
- Internal fuse
- Capacitor unit
- Discharge resistor
- Case
- Capacitor element
- Capacitor element group
- Capacitor unit series group
- N
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SCB Single Wye Bank Unbalance Protection

If System Unbalance = 0 & Cap Bank Unbalance = 0
Then Neutral Voltage = 0
SCB Double Wye Bank Unbalance Protection
SCB H-Bank (Grounded or Ungrounded) Protection
## Shunt Capacitor Bank System and Design Considerations

<table>
<thead>
<tr>
<th>System Bus Voltage</th>
<th>164kV L-L</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT Ratio</td>
<td>1400:1</td>
</tr>
<tr>
<td></td>
<td>(94.69kV / 67.63V L-G)</td>
</tr>
<tr>
<td>CT Ratio</td>
<td>120:1</td>
</tr>
<tr>
<td></td>
<td>(600:5)</td>
</tr>
<tr>
<td>Grounded Wye Bank (27MVAR) 1-Stack</td>
<td>3 parallel strings x 5 units w/ 9 groups per can</td>
</tr>
<tr>
<td></td>
<td>(19.92kV, 600kVAR /can)</td>
</tr>
<tr>
<td>Low Voltage Capacitor (VC1)</td>
<td>0.83kV, 167kVAR</td>
</tr>
</tbody>
</table>
Protection Considerations

Unbalance Protection (50N, 59N, 60V)
- Measure I neutral: subject to system/natural unbalance
- Measure 3V0: subject to system/natural unbalance
- Measure Vdiff: only compensate for natural unbalance

Double-wye banks and H-banks:
- Also secure from system unbalance
- Require natural unbalance compensation
Other Protection Elements – Total Bank Protection

Short Circuit (50)
Overload (51P)
Negative-Sequence (51Q)
Earth Fault (50/51N)
Undercurrent (37)
Under/over voltage (27/59)
Residual Overvoltage (59N)
Breaker Failure (50BF)
SCB Overload Capability Curve – determines 50/51 for SCB
Shunt Capacitor Bank Considerations

- **What size bank is needed?** (ex. 164kV, 161MVAr)
- **Which configuration is preferred?** (Wye-G, Min Cans)
- **Preferred protection scheme?** (60V + Bank Prot)
- **What are the operational requirements?**
  - Desire one standard design, flexible deployment.
  - Easy to test, commission, maintain.
  - Maximum operational reliability.
MultiStack for flexible VAr compensation

- Local/Remote and Manual / Automatic modes
- Voltage Control for Stack Switching (Wide Band/Narrow Band)
- Equalization of Stack Operation Time
- Hunting control during auto mode
- Minimize transient switching (zero crossing close)

Safety Protocols/Interlocks for Man/Auto & Rem/Loc

- HMI local controls
- Lockout / Tagout
- Remote Status and Control
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Advanced Capacitor Bank Control

Lessons from MV Capacitor Banks:
- Standardize configuration & element numbers
- Detect element level failures @ Alarm and Trip points
- Use transient free switching for applying SCB stacks to system
- Provide simple manual / auto operations for Local/SCADA/DA
- Modularize for ease of scalability, testing, commissioning, & training
Capacitor Bank Switching is Critical – Use Point on Wave Switching
Capacitor Bank Switching is Critical – technology comparison

- **A) No damping**: 13.6 kA
- **B) Detuning reactors**: 2.0 kA
- **C) Pre-insertion resistor**: 4.6 kA
- **D) Synchronized vacuum**: 3.2 kA
- **E) Diodes**: 0.95 kA
Capacitor Bank Switching is Critical – technology comparison

Overvoltage

A) No damping

B) Detuning reactors

C) Pre-insertion resistor

D) Synchronized vacuum

E) Diodes

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Advanced SCB Flexible VAr Protection & Control

Six-Stack Capacitor Bank Protection and Control Scheme
Advanced Modular SCB Flexible VAr Protection & Control

Six-Stack Capacitor Bank Protection and Control Scheme
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Understanding Advanced SCB Scheme Control

Operation equalization
- Stack operation (observe discharge times)
- Balances operations/service life (CS Counter)

Auto/Man VAr control (WB/NB operation)

Detect SCB hunting in Auto mode
- Operator safety features
- Consistent with utility operating philosophy
- Human-machine interface standard
- Lockout / tag out
- Maintenance reporting requirements
Adaptive Protection Makes Testing Interesting

Adaptive SCB protection, based on # stacks in use
- Voltage Diff (60V) requires accurate test sources, but easily verified
- Overall SCB protection is easily tested (50/51/51Q/59/64/50BF)

Local automatic control
- WB and NB voltage control (27/59)
- Also allows local operator to select WB or NB control for manual operations assistance

Remote automatic control
- Allows dispatcher to select WB or NB control for changing system conditions
Testing Control Functions Special Notes

IED voltage element measuring accuracy very important
Raise- and lower-voltage settings are only few kV apart
- 163 kV for raise
- 165 kV for lower
- Voltage transformer ratio is 1400:1

Relay measures secondary voltages of 67.22 V and 68.04 V
Difference is less than 1.0 volt!
Conclusions

SCB configuration drives the protection scheme
- Wye-G provides a simple cost effective & understandable base
- Internally fused capacitor cans are detectable / lower operation impact

Standardized stack design makes SCB’s scalable, lower cost
- Operation – advantages outweigh perceived complexity
- Testing – protection & control is simple, logic more complex but straightforward, capacitor failures easier to find

Point on Wave closing control is necessary
(future diode technology can improve this)
Conclusions

Voltage Differential (60V) is best for detecting capacitor element failures (but requires compensating for the natural unbalance)
  - Add SCB natural unbalance compensation to commissioning process
Testing the protection in a stack scheme is both easy and challenging
  - Elements are simple, but SCB adaptive protection adds tests (# of stacks)
  - Testing requires very accurate sources (ex. 60V differential)

Know the relevant standards (IEEE Std. 18 and IEEE C37.99)

Making the SCB modular simplifies the SCB application
Questions?

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