Review of Capacitor Bank Control Practices

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• Introduction
• Overview of standards and regulations
• Methods to control voltage/VARs
• Transients control
• Interlocking
• Optimizing multiple banks control and coordination with other Volt/VAR controls
• Conclusions
Shunt capacitor bank controller offer many options to switch the capacitor bank on or off, ensuring security and safety:

- Automatic control based on VARs, current, voltage or power factor
- Automatic control based on time-of-the-day, month and season
- Manual control, local at the bank location or remote by the system operator
- Optimizing operation to minimize number of the switch operations
- Interlocking to allow capacitors discharge to a safe level
- Ability to control and coordinate multiple banks by one controller
The capacitor banks support the system voltage and reduce reactive power flow through the power system with following benefits:

- Voltage support
- VARs support
- Increased system capacity
- Reduced system power losses
- Reduced billing charges
Overview of Standards and Regulations

- IEEE Std. 1036-2010 - IEEE Guide for the Application of Shunt Power Capacitors defines Capacitor Controller as:

  *The device required to automatically operate the switching device(s) to energize and de-energize shunt power capacitor banks*

- The IEEE considers capacitor control to operate automatically and are coordinated with generator voltage and power factor controls.

- NERC reliability standard VAR-001-5 “Voltage and Reactive Control” requires transmission owners to:

  *Develop a transmission voltage schedule and to “schedule sufficient reactive resources to regulate voltage levels under normal and Contingency conditions*
Methods to Control Voltage/VARs

- It reduces reactive power required from the system by bank capacitance $C$
- It reduces reactive power plus apparent power flow through the line
- Inherently, current through the line will decrease from $I$ to $I_C$ and
- Voltage at the bus $V_L$ will increase because losses were decreased
- Power factor is improved with the capacitor bank switched on
Methods to Control Voltage/VARs

A. Time-based automatic control

• Beneficial when the VAR demand pattern is well known during each day and during certain seasons

• Minimizes the number of switching operations of the capacitor banks and reduce switching transients
B. Voltage measurement-based automatic control

- Primary objective of voltage support, installed at the major transmission and distribution buses serving large geographic area

- Switching the capacitor bank in results in a voltage rise at the capacitor bank location

\[
\Delta V \approx \frac{I_C}{I_{SC}} \approx \frac{Q_C}{Q_{SC}} \times 100\%
\]

- To minimize effect on power quality for the customers, voltage change is recommended to be within 2-3% range for distribution systems and <5% for transmission systems
B. Voltage measurement-based automatic control

- Capacitor bank located at a distribution station serving a critical customer located downstream on a radial line, may be enhanced with a voltage drop compensation

\[ V_L = V_{ST} - I_L \times Z \]
B. Voltage measurement-based automatic control

- When multiple banks are used to control voltage, it’s important that all controllers respond to the same voltage, \( V_1, V_{ll} \)
- Set the close voltage settings lower than the open voltage setting by more than the voltage change expected from capacitor switching, plus margin
- Coordinate between multiple banks in the area, which is achieved by proper voltage level setting value and time delay
- Coordinate with a load tap changer (LTC)
B. Voltage measurement-based automatic control

- LTC regulate voltage in steps of 0.625% to 2.5% with a time delay 1-3 minutes, switching on a capacitor bank can give similar effect but add VARs and improve PF
- Exclude possible counter action between these two control devices
C. Reactive power-based control

- Directly provides all benefits of the shunt capacitor banks
- Can be used on both transmission and distribution substations

![Diagram showing control of reactive power (VAR) levels.](image-url)
D. Power factor-based control

• Although it’s looking attractive, in general, power factor alone is not a good basis to control capacitor bank
• Because power factor measurement itself cannot distinguish between low load and high load, may result in the leading power
• At low load it can also cause a “pumping” condition
• At high loads possible to use power factor-based control, which requires adding VAR or current measurement to distinguish
E. Temperature and current-based control

• Although temperature and current magnitude increases are an indication of the VAR demand, they are not giving direct measurement of the VAR deficit, low PF or voltage decrease

• These methods are not preferred when measurements of the voltage and current are available

• Possible when direct correlation between temperature/current and voltage/VAR change is well known
Methods to Control voltage/VARs

F. Manual control

• Manual control, local or remote, still can be used by the operator for switching the capacitor bank On/Off depending on system conditions

• With the communications available today, remote control is very attractive

• Local control may still be needed as well in case of communications failures and emergency situation
Energization of the shunt capacitor bank creates severe transient over-voltages, affecting insulation of the adjacent equipment.

230kV 26MVAR bank energization where all 3 breaker poles were closed simultaneously with phase A at the voltage peak.
Capacitor bank energization transient frequencies are from 300Hz to 1kHz.

To reduce these over-voltages, it is desirable to energize each phase separately close to voltage zero-crossings.
- Capacitor bank de-energization can cause breaker restrike
- The worst case voltage is interruption at the phase voltage - 2 times peak system line to ground voltage (2pu) appears across the breaker contact
Interlocking

- Capacitor bank cannot be re-energized immediately, as capacitors need to be discharged
- 5 minutes delay is frequently used in the industry, re-energizing capacitor sooner or later may be required and can be calculated

![Diagrams showing interlocking system with internal discharge resistor](image-url)
Interlocking

- Capacitor control includes On/Off commands from various sources protective trips, local/remote/auto close and open commands.
- It is important, for safety and administrative reasons, that the control maintains remote/local and auto/manual privileges.
- It is important to open the capacitor bank switching device when the connection point to the system de-energizes with subsequent reclosure.
- This is easily accomplished by tripping the switching device with an under-voltage element set to operate on loss of connection point voltage with a time delay less than the line reclosing time.
Optimizing Multiple Banks Control and Coordination with Other Volt/VAR Controls

System A

230kV

System B

69kV

13.8kV
Optimizing Multiple Banks Control and Coordination with Other Volt/VAR Controls

• In reality there are many capacitor banks and other Volt/VAR regulating apparatus on the transmission, sub-transmission and distribution substations

• Volt/VAR regulating problem becomes multi-dimensional and very complicated

• Another requirement is to keep the number of switching operations for both capacitor banks and LTCs as low as possible to extend the life of switching devices

• Optimization programs available for the system planner are the right answer to set and coordinate controllers
Conclusions

• Modern capacitor bank controllers offer many options and functionality to control capacitor banks for voltage/VAR regulation
• They allow manual (local or remote) or automatic control based on the available measurements
• They also provide interlocking means to ensure safe operation of the capacitor banks
• When it comes to coordination with other devices controlling voltage and VAR, it becomes quite complicated
• Distribution Management Systems can provide a centralized Volt/VAR strategy by taking measurements from multiple points of the system and controlling capacitor banks and LTCs remotely
Thank You

Questions?