Bechtel - Copper Center of Excellence (CCoE)
Static VAr Compensator (SVC) for Large Mining Complexes

Santiago – Chile
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Introduction: Power Quality in Mining Plants
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SVC: Operational Limits
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Introduction: Power Quality in Mining Plants

Basic power quality issues in mining complexes are mainly addressed by the design and installation of harmonic filters, two aspects are covered:

- **Power factor correction:**
  
  Local grid power quality and/or energy supply contractual requirements to be fulfilled: overall plant power factor, in the Chilean case $\geq 0.98$ (lag) for 220 kV systems.

- **Harmonic mitigation:**
  
  Local grid power quality and/or international standards (such as IEEE 519, IEC 61000, or other), for individual and total harmonic distortion at the (usually) connection point with the utility (Point of Common Coupling or PCC, as per IEEE).

For mining plants in remote locations (long OH lines) and with relatively weak electrical grids, Synchronous Condensers (SC) have also been incorporated for improving the short circuit capacity (at the plant main distribution bus), allowing fast voltage stabilization and therefore keeping key systems/loads running (typically large non-lineal loads, such as Mill and Conveyor Drives, among others) [1]/[2].
**Introduction: Power Quality in Mining Plants**

Harmonic filters with reactive power contribution are extensively used, some Bechtel references:

- Peru (2000): 2x35 MVAR
- Peru (2012): 2x38 MVAR
- Peru (2015): 2x35 MVAR
- Chile (2002): 5x20 MVAR
- Chile (2003): 3x35 MVAR
- Chile (2011): 2x29 MVAR
- Chile (2015): 3x36 MVAR

For increased short-circuit and improved voltage stability, Synchronous Condensers have also been considered, Bechtel references:

- Peru (2000): 2x15 MVA
- Peru (2012): 2x20 MVA
- Peru (2015): 2x20 MVA
Context: A Large Chilean Mining Complex

Following are the particular characteristics of one of the largest Chilean Mining Complexes which have a significant influence on the operation and stability for the upstream HV network (grid):

- Mining Complex: One of the Chilean largest mining operations
  - 3 concentrator plants: 2 SAG and 8 Ball mill motors, just two plants totalize about 200 MW of cycloconverter-fed mill motors (Gearless Mill Drives)
  - Leach & oxide plants: about 175 MW (including power rectifiers)
  - Port facilities and desalinized water pumping (2017): about 170 MW

- Power demand and Chilean northern grid (SING): The largest single customer
  - Estimated power demand (2015): ≈ 620 MW (about 24% of the SING)
  - Other customers (2015): ≈ 2000 MW
  - Total Chilean northern grid (2015): ≈ 2620 MW

- Mining complex overall power factor about 0.96 (lag) which is below the minimum 0.98 (lag) stated in the Chilean standard for Power Quality, harmonic distortion (individual & total) within the limits of both Chilean and IEEE standards.
**Chilean Standard: Power Quality Requirements**

The Chilean Standard for power quality (NTSyCS, "Technical Standard for Safety and Power Quality") states several specific requirements for the HV systems:

- Overall power factor for large customers (connected at 220 kV levels):
  
  \[0.98 \text{ (lag)} \leq \text{PF} \leq 1.0; \text{ for 15 min integration periods (98\% of the time)}\]

- Steady state voltage limits and system conditions (for 220 kV voltage systems):

<table>
<thead>
<tr>
<th>Condition</th>
<th>Voltage Limits (pu)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0.95 – 1.05</td>
<td>Steady state voltage before contingency</td>
</tr>
<tr>
<td>Alarm</td>
<td>0.93 – 1.07</td>
<td>Permissible voltage after contingencies (simple faults)</td>
</tr>
<tr>
<td>Emergency</td>
<td>0.90 – 1.10</td>
<td>Permissible voltages after contingency (severe faults)</td>
</tr>
</tbody>
</table>

- Transient voltage excursions, under single contingencies (N-1):

  **Buses Voltage > 0.7 pu, elapsed 50 ms after fault clearance**
  
  **Buses Voltage > 0.8 pu, but for no more than 1.0 s after fault clearance**
  
  **Buses Voltage within ±10\% its final value, elapsed 20 s after fault clearance**

- Harmonic voltages & currents as per Chilean standard NTSySC (similar to IEEE 519).
### Potential Solutions: Dynamic Compensation Systems

Reactive dynamic compensation systems, features comparison [3]:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Synchronous Condensers</th>
<th>Static VAR Compensator</th>
<th>Statcom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compensation Accuracy</td>
<td>Good</td>
<td>Very Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Control Flexibility</td>
<td>Good</td>
<td>Very Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Reactive Power Capability</td>
<td>Leading/Lagging</td>
<td>Leading/Lagging</td>
<td>Leading/Lagging</td>
</tr>
<tr>
<td>Response Time</td>
<td>Slow (&gt; 0.5 sec)</td>
<td>Fast (0.01 – 0.05 sec)</td>
<td>Very fast (≤0.02 sec)</td>
</tr>
<tr>
<td>Voltage Support (V/I)</td>
<td>Good (overload)</td>
<td>Good (overvoltage)</td>
<td>Good (undervoltage)</td>
</tr>
<tr>
<td>Harmonic Distortion</td>
<td>None</td>
<td>High</td>
<td>Minimum</td>
</tr>
<tr>
<td>Power Losses (@ 0 MVAR)</td>
<td>Moderate (~1%)</td>
<td>Reduced (~0.3%)</td>
<td>Reduced (~0.2%)</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>Highest</td>
<td>Moderate</td>
<td>Lowest</td>
</tr>
<tr>
<td>Single Rated Unit Power</td>
<td>Up to 60 MVA</td>
<td>Above 100 MVA</td>
<td>Up to 32 MVA</td>
</tr>
<tr>
<td>Availability</td>
<td>≤ 98%</td>
<td>≥ 99%</td>
<td>≥ 99%</td>
</tr>
</tbody>
</table>
Adopted Solution: Static Var Compensator (SVC)

Main features and advantages of choosing an SVC:

- Improved grid stability: by making the network more robust to system contingencies (line switching/faults, generation/load changes, etc.); the SVC can deliver inductive/capacitive reactive power for counteracting to under/over voltages.

- Improved power quality: by controlling reactive power flow, the Mining Complex overall power factor and voltage are controlled in a very smooth way.

- System recovery after blackout: by compensating the high voltage that occurs due to the energization of long transmission lines, during system recovery after a general system blackout.

- No switching of passive components needed: with an SVC there is not switching of passive components and the voltage is controlled dynamically.
Adopted Solution: Static Var Compensator (SVC)

In addition the system/solution adopted for this Large Mining Complex had also to cope with the following considerations/requirements:

- Continuous topological changes of the electrical network, which shifts the system parallel resonances.
- Presence of relevant amount of harmonic (about 40% of power demand are harmonic producing loads) and inter-harmonic (200 MW of cycloconverter-fed sync. motors).
- Equipment sensible to voltage fluctuations (converter-fed loads) which may concatenate shutdown of big portions of the internal system, and hence the whole grid.
- Fast response and support to voltage fluctuations by delivering/drainaging the required amount of reactive power, allowing keeping systems/loads running; and with the capability of supporting the upstream network (220 kV) during contingencies.
- Extremely tight Project schedule: only 15 months from award to energization.

An SVC better than other possible solutions suits the above and other considerations, due to its particular operational characteristics, high dynamic performance, proven solution at the Project altitude, together with schedule and cost.
**SVC: Topology and Key Components**

- **SVC Transformer**
  - 120/150 MVA
  - 220-19.5 kV

- **SCV Operational Range:**
  - 80 MVar Inductive
  - 120 MVar Capacitive

- **TCR**
  - 200 MVar

- **Filter 3rd**
  - 40 MVar

- **Filter 5th**
  - 80 MVar
**SVC: Operational Limits**

Nominal Primary Voltage 220 kV (1.0 pu)

- **At 1.0 pu primary voltage & 50 Hz:**
  - Inductive Continuous: 80 MVAr (point D)
  - Capacitive Continuous: 120 MVAr (point A)

- **At 1.1 pu primary voltage & 50 Hz:**
  - Capacitive Continuous: 145 MVAr (point B)

- **At 1.135 pu primary voltage & 50 Hz:**
  - Inductive Continuous: 80 MVAr (point C)

- **At 1.3 pu primary voltage & 50 Hz:**
  - Maximum primary voltage
  - at which the TCR is controllable: (point E)
  - (TCR overload capability)

Slope setting range (200 MVA base): 0 - 10 %
SVC reference voltage: adjustable 0.9 – 1.1 pu
**SVC: Harmonic Performance**

Exhaustively modeled and evaluated is the harmonic performance, the SVC operation shall satisfy the Project definitions for maximum allowed individual and total voltage and current harmonic distortion. This is of especial relevance, care and complexity for a mining complex with a big portion of harmonic generating loads, being extensive the use of large cycloconverter-fed solutions.

- **Harmonic Impedance Study (HIS):** For design of the SVC filters; SVC primary system impedance is evaluated for the many different network conditions, traditional HIS for harmonic 1\textsuperscript{st} to 50\textsuperscript{th} and inter-harmonics up to 15\textsuperscript{th} harmonic were considered.

- **Harmonic Source Study:** The maximum voltage distortion at the SVC connection point caused by harmonics and inter-harmonic generated by all the plant cycloconverters; for background harmonic definition and SVC components rating design.

- **Harmonic Performance Study:** The maximum voltage and current distortion at the 220 kV bus due to TCR operation; harmonic performance is evaluated based on IEEE 519 and Chilean standards recommended limits.
**SVC: Harmonic Performance**

TCR Harmonics and Harmonic Performance (at SVC 220 kV bus):

![Graphs showing harmonic performance](image-url)
**SVC: Step Response**

Step Response for the selected SVC:
(dynamic study)
Response time: 34 ms
Max. overshoot: 25%
Settling time: 120 ms

Parameters Evaluation (0 MVAr before step)

<table>
<thead>
<tr>
<th>Thevenin Network</th>
<th>Step Type</th>
<th>Vstep [pu]</th>
<th></th>
<th>Bref.max</th>
<th>Rise Time [ms]</th>
<th>Overshoot [%]</th>
<th>Settling Time [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>Capacitive</td>
<td>1.073</td>
<td>1.295</td>
<td>22.8</td>
<td>22.8</td>
<td>41.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inductive</td>
<td>0.948</td>
<td>1.005</td>
<td>25.2</td>
<td>12.5</td>
<td>52.8</td>
<td></td>
</tr>
<tr>
<td>Strong</td>
<td>Capacitive</td>
<td>1.065</td>
<td>1.290</td>
<td>27.0</td>
<td>4.2</td>
<td>28.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inductive</td>
<td>0.953</td>
<td>1.013</td>
<td>30.3</td>
<td>2.1</td>
<td>33.0</td>
<td></td>
</tr>
</tbody>
</table>
**SVC: Step Response**

Step Response for the selected SVC

(design and commissioning)

Oscillations caused by a too high voltage regulator gain (network fault level lower than the used during design); therefore adjustment of the gain of the voltage regulator
**SVC: Dynamic Performance**

Dynamic performance is evaluated for several others SVC internal and system disturbances, to verify the SVC control system and the dynamic performance:

- **SVC Energization:** to verify that oscillations and harmonics due to SVC transformer saturation shall not cause any harmful transients in the system network; evaluated for SVC breaker different closing angles (0°, 30° and 60°) and system conditions.

- **SVC De-energization:** to verify that there shall not be switching transients that may stress the SVC circuit breakers; evaluated for SVC inductive/capacitive operation.

- **Remote transformer energization:** to verify that minimum disturbance is introduced to the SVC during transformer energization within the Plant network; again for breaker different closing angles (0°, 30° and 60°) and system conditions.

- **Local/Remote faults:** to verify that SVC withstands the voltage and frequency disturbances and contributes to network stabilization; evaluated single-phase, phase-to-phase and three-phase faults within the Plant’s HV network and for SVC inductive/capacitive operation.
**SVC: Dynamic Performance**

**SVC Step Response**
Capacitive step (35 MVAr before step)

**SVC Energization**
Connection at 0 degrees
SVC: Layout

Selected SVC – Overview 3D Model:
Summary: SVC for Large Mining Complexes

SVC for large and complex mining facilities allows:

- Regulate and control the voltage at the SVC connection point.
- Compensate and smooth control the overall power factor.
- Provide dynamic, fast response reactive power control during network contingencies.
- Keeping harmonic distortion within the very exigent limit of international (IEEE 519) and local (Chilean NTSyCS) standards.

For large mining complexes the installation of dynamic reactive compensation systems based on modern power electronic devices (FACTS), for dealing with nowadays more exigent grid power quality requirements and power systems vulnerability, are considered as a right solution and in some cases could even be the only feasible alternative.

Because the increased power demand, size and complexity of some mining industrial centers, it is envisaged that reactive dynamic compensation systems (such as SVC or Statcom) will probably be more common in mining; EPC and mining companies have to understand and identify, properly specify and apply, and adequately operate and maintain.
References:


