Synchronous Condensers for Transmission Systems - The Second Generation

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Outline

- Traditional synchronous generation
- The challenge
- Synchronous condenser overview
- Modern Synchronous Condensers
  - Conversions
  - New units
Synchronous Generation, Watts and VARs

Power Factor (pf) = \( \frac{P}{MVA} \)

Typical rated pf = 0.8 to 0.9
Usual operating pf = 0.95 to 0.99

Criterion for power factor rating is emergency condition, not normal operation.
Synchronous Generation & Short Circuit MVA

System strength stated as Short Circuit MVA
Machine contribution ≈ Machine MVA / (X” + Xtran)

Higher MVA_{sc} = stronger system
Strong system needed to support loads, renewables, HVDC,…

Only synchronous machines can provide short circuit current
Challenge to Operators and Planers

Short long term challenge
Transmission & generation outages

Long term changes trends
Generation retirements
Renewable integration
HVDC projects

Possible impacts ...
Reduced system strength
Erosion of reactive power margin
Criteria violations

The Reactive Power Balance should be obtained on a local basis
What happens when the system has insufficient reactive resources?

Voltage instability

Problems usually arise after a disturbance
System needs additional reactive support
Fault induced delayed voltage recovery (FIDVR)
Can lead to loss of load for design criteria outages
Synchronous Condenser Basics:

Synchronous machine with no prime mover (P=0)
Brought up to speed and synchronized to the power system
– Variable frequency drive, reactor starting, pony motor
Field voltage is controlled to either generate or absorb reactive power as needed.

\[
\begin{align*}
I_f &> A_{FNL} & \text{Overexcited} \\
I_f &< A_{FNL} & \text{Underexcited}
\end{align*}
\]
Are all VARs created equal?

Dynamic VARS from Rotating Machines are Highly Advantageous

Capacitor Bank

VARs DECREASE Proportional to $V^2$

Do not increase system strength

Synchronous Condenser

VARs INCREASE to maintain $V_t$

Increase system strength

$X_T = \text{transformer reactance}$

$V_T$

System Event

$X_T$
Synchronous Condenser Advantages

Provide highest level of performance for:

Increased short circuit MVA – strengthen the system

Response to power system fluctuations
    New condensers have high response excitation system

Voltage & frequency Ride-through capability

Overload capability
    High short and mid-term overload capability

Reliability, service life and maintainability
GE History

1919: +10 MVARs, First GE air-cooled synchronous condenser. Customer: Ontario Hydro.

1919 to 2012 200 GE condensers manufactured (excludes conversions and clutches).
Number of Utility GE Condensers & Average Size by Decade

![Graph showing the number of GE condensers and average MVAr by decade.]

- **Decades:** 1900, 1920, 1940, 1960, 1980, 2000, 2020
- **Y-axis:** GE Condensers / Avg. MVAr
- **X-axis:** Decade
- **Legend:**
  - Red bars: Units
  - Blue line: Avg. MVAr

**Observations:****

- The number of GE condensers and average MVAr varies significantly by decade.
- The first generation (1900-1940) shows a gradual increase in units followed by a decrease.
- The second generation (1960-2000) exhibits a significant increase in units and MVAr, peaking around 1980.
- There is a drop in the number of units post-2000.

**Labels:**

- 1st Generation
- 2nd Generation
Today’s Synchronous Condensers

Conversions
Remove or disconnect turbine
Reuse generator & GSU
Typical – new excitation

New Units
Typically associated with HVDC or large renewable generation site
Synchronous condenser conversion

Convert existing generator to produce only reactive power (VARs) ...

Overexcited VARs
- Typically 30% or more over generator full load operation
- Further increases with new or rewound rotors

Under-excited VARs
- Same as 0.95 leading PF

Sync Condenser Operating Capability @ 0 MW
756 MVA Unit Conversion – Vref Step Test

Coal unit to be retired in a Var deficient area

Converted to condenser, maintain +560/-320 MVAr reactive capability

High response static exciter
VELCO Synchronous Condenser Project

Identified the need for reactive power at Granite Substation

VELCO selected a combination of synchronous condensers and mechanical switched shunt capacitor banks.

The system was placed in service in 2008

Power System Requirements:
Voltage support under steady-state, short time under voltage, and transient conditions
Ride through of extended transient
VELCO Granite Substation

Project Scope:
Qty (4) +25/-12.5 MVAr sync condensers
Qty (4) 25 MVAr shunt banks (MSC)
Qty (2) LTC transformers
Qty (2) Phase shifting transformers
Integrated control system

Diagram:
- 230 kV / 115 kV / 13.8 kV
- 240 / 320 / 400 MVA
- 115 kV / 115 kV
- 210/280/350 MVA
- ± 60º Phase Shift
- 115 kV / 115 kV
- 210/280/350 MVA
- ± 60º Phase Shift
- 230 kV / 115 kV / 13.8 kV
- 240 / 320 / 400 MVA
- Each Condenser: 13.8 kV, +25 / -12.5 MVAr
- 25 MVAr
- 25 MVAr
- To Barre 115 kV
- To Chelsea 115 kV
- To Comerford 230 kV
## Unit Reactive Capability

25 MVA nameplate, MAVRs at terminals

### Table I. Low-ambient temperature condenser ratings.

<table>
<thead>
<tr>
<th>Ambient Temperature</th>
<th>+MVAr (with all cooler in service)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40°C</td>
<td>+25</td>
</tr>
<tr>
<td>30°C</td>
<td>+27.5</td>
</tr>
<tr>
<td>20°C</td>
<td>+30</td>
</tr>
<tr>
<td>10°C</td>
<td>+32</td>
</tr>
<tr>
<td>0°C</td>
<td>+34</td>
</tr>
</tbody>
</table>

### Table II. Condenser Short-Time Overload Capability.

<table>
<thead>
<tr>
<th>Permissible Time</th>
<th>Overexcited (Capacitive) MVAr</th>
<th>Underexcited (Inductive) MVAr</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5 seconds</td>
<td>+75</td>
<td>-12.5</td>
</tr>
<tr>
<td>0 – 10 minutes</td>
<td>+42</td>
<td>-12.5</td>
</tr>
<tr>
<td>2 hours</td>
<td>+30</td>
<td>-12.5</td>
</tr>
<tr>
<td>Continuous (SF=1.15)</td>
<td>+28.75</td>
<td>-12.5</td>
</tr>
<tr>
<td>Continuous (SF=1.00)</td>
<td>+25.0</td>
<td>-12.5</td>
</tr>
</tbody>
</table>

Avg. July High Temp 26°C

Avg. Feb High Temp -4°C
Simulation – loss of major 345 kV line
Impact of synch condensers and shunt caps

New Synchronous Condensers

Synchronous condensers react quickly to low voltage in < 1sec

Shunt capacitors (static VARs) switch in at 20 and 48 seconds; offset VARs

Voltage, First 5 seconds

Voltage, 80 seconds

Condenser MVAr, 80 seconds
Overload and JVC Test

During commissioning tests, able to produce more than 200% nameplate reactive power for several seconds!

After 5 seconds, shunt capacitors provide assistance.
Step Response Test

Response to a 25 MVAr shunt bank tripped off line and then placed back into service.

Long tail-in is the master controller slowly raising the system voltage.

Voltage dips to 98.8% at 0.059 seconds.

Voltage returns to 99.5% at 0.271 seconds.

Response time to reactive power peak is 0.339 seconds.
Thanks!