Synchronous Condensers for Transmission Systems

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Outline

1. Synchronous Condenser Basics
2. GE Condenser Product Overview
3. ERCOT Concerns
4. Summary
1. Synchronous Condenser Basics
Electrical Power

- +P
- + or - Q

Mechanical Power

MOTOR

- MS
- Torque

GENERATOR

- GS
- Torque

SYNCHRONOUS CONDENSER

- +P for losses only
- P ~ 0
- + or - Q

- No Torque
- No Mechanical Power
SYNCHRONOUS CONDENSER CAN ONLY OPERATE ALONG THE VERTICAL "Q" AXIS AS P~0.
Synchronous Condenser V-Curves

Inductive VAR requirement will determine size of the machine

The Rotor is the machine FIELD. Adjustment of the FIELD Amps result in change in Reactive Power “Q” on the Armature or Stator.
2. GE Condenser Product Overview
## 2. GE Condenser Product Overview

<table>
<thead>
<tr>
<th></th>
<th>Peterborough Factory</th>
<th>Schenectady Factory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ratings</strong></td>
<td>≤ 100 MVArS</td>
<td>52 – 478+ MVArS</td>
</tr>
<tr>
<td><strong>Rotor</strong></td>
<td>Salient pole</td>
<td>Round rotor</td>
</tr>
<tr>
<td><strong>Poles</strong></td>
<td>4 or 6</td>
<td>2</td>
</tr>
<tr>
<td><strong>Excitation</strong></td>
<td>Brushless, static</td>
<td>Brushless, static</td>
</tr>
<tr>
<td><strong>Starting</strong></td>
<td>Full V, Reduced V, Reactor start, Capacitor assist, Motor</td>
<td>LCI</td>
</tr>
<tr>
<td><strong>Cooling</strong></td>
<td>Air</td>
<td>Air, H2</td>
</tr>
</tbody>
</table>
## 2. Sample GE Machine Ratings

<table>
<thead>
<tr>
<th>Frame</th>
<th>Cooling</th>
<th>Condenser Ratings</th>
<th>H</th>
<th>kV</th>
<th>Hz</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Motor</td>
<td>Air</td>
<td>+25/-12.5</td>
<td>~2</td>
<td>12.47-13.8</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Large Motor</td>
<td>Air</td>
<td>+50/-25</td>
<td>~2</td>
<td>12.47-13.8</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Large Motor</td>
<td>Air</td>
<td>+100/-45</td>
<td>~2</td>
<td>12.47-13.8</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>6A8</td>
<td>Air</td>
<td>+52/-26.5</td>
<td>2.13</td>
<td>13.8</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>7A6</td>
<td>Air</td>
<td>+91.8/-38.2</td>
<td>2.21</td>
<td>13.8</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>9A4+</td>
<td>Air</td>
<td>+125/-67</td>
<td>2.10</td>
<td>13.8</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>170A</td>
<td>Air</td>
<td>+175/-85</td>
<td>1.72</td>
<td>13.8</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>7FH2</td>
<td>H2</td>
<td>+198/-86</td>
<td>1.27</td>
<td>18</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>7FH2B</td>
<td>H2</td>
<td>+237/-94</td>
<td>1.2</td>
<td>18</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>324</td>
<td>H2</td>
<td>+332/-128</td>
<td>0.96</td>
<td>18</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>
2. Peterborough Factory: Reliability

Series 9000 Salient Pole Machines

- 5MVA – 100MVA
- Up to 13.8kV 50/60Hz
- Advantages
  - **Integral** rotor pole tips
  - **Minimize** rotating components
  - Highest **efficiency** - best in class
Cylindrical Forging

One-Piece Forging
Integral Pole Tips

Machined Poles and Pole Tips
Completed Rotor
Integral Pole Tips
Integral Pole Tips

GE’s Design

Competition
2. Peterborough Factory: Reliability

Series 9000 Installed Base
Over 400 units installed in 30 years

- Meets stringent American Petroleum Institute (API) standards:
  - Minimum 25 years of service life
  - Minimum 5 years of uninterrupted continuous operation

- Proven reliability in O&G industry as process critical equipment in large refineries
2. Peterborough Factory: Reliability
Recommended Maintenance

• Monthly:
  • Listen for any unusual noise
  • Clean surfaces as required
  • Check oil flow and filters

• Annual:
  ▪ Test bearing oil

• Extended Outage (or every 5 years):
  ▪ Inspect stator and rotor winding
  ▪ Inspect brushless exciter
  ▪ Measure insulation resistances (stator, rotor and exciter windings)
  ▪ Estimated outage length: 1-2 days
  ▪ Estimated cost: $15,000 per outage

• Condenser protective equipment (RTD’s, vibration sensors, cooler leak detector, differential protection CT’s) is monitored continuously.
3. ERCOT Concerns
3a. New vs. Re-Purpose Existing Machine

**Existing**

**What is the right size?**

- Existing machine is often a compromise in size
- Location – is it in the right place? Moving can be costly
- Condition / age. Reliability covers a wide range depending on machine used
- Starting/clutch can be costly

**New Machines**

- Size and number of machines desired
- Located where most effective
- All new components (bearings, windings, pumps, fans)

Re-purposing an existing machine is usually a compromise. But sometimes is attractive because the savings are worth the compromised performance.
3b. Performance

**Starting / Stopping**

Many starting methods exist

- Across the line
- Reduced voltage (Reactor, Auto-transformer)
- Pony motor
- LCI

**Coast stop**

Grid strength and tolerance of voltage dip will influence recommended starting method
3b. Performance
Dynamic Response

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.
### 3b. Performance

#### Power Consumption / Losses

<table>
<thead>
<tr>
<th>Performance Criteria</th>
<th>Synchronous Condenser</th>
<th>Static Var Compensator</th>
<th>STATCOM or DVAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses (Device Base)</td>
<td>~0.94% at idle</td>
<td>~0.16% at idle</td>
<td>~0.17% idle</td>
</tr>
<tr>
<td></td>
<td>~1.6% full on</td>
<td>~0.27% TSC only</td>
<td>~1.0% full on</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~0.80+% with TCR</td>
<td></td>
</tr>
<tr>
<td>Losses (SVC Base)</td>
<td>~0.47% at idle</td>
<td>~0.16% at idle</td>
<td>~0.14% idle</td>
</tr>
<tr>
<td></td>
<td>~0.80% full on</td>
<td>~0.27% TSC only</td>
<td>~1.0% full on</td>
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3c. SSR Concerns

**Sub-Synchronous Resonance**
Likelihood is Lower than with a generator
(But is still possible)

GE can do screening studies and check for issues

Possible mitigations include:

- Multiple smaller machines vs. one large machine or vice-versa
- Blocking filters on transformer neutral can mitigate
- A filter can be added to the series bank

GE has done all the above and is qualified to handle SSR concerns
GE Summary

• Recently, GE has supplied highly reliable and proven systems (VELCO and KEPCO)

• GE can study, design, engineer and install modern Synch Condenser systems for any grid application need, without concern for control interactions

• GE’s 4-pole technology utilizes superior design, allowing for a robust, efficient and reliable solution

• 100+ years of experience and continuous improvements – modern controls and excitation
  • With brushless excitation, operated continuously for years with no outages
  • Expect decades of operation without major maintenance
  • Superior insulation systems – extremely long life