Real-Time Testing of STATCOM and SVC Controllers

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Power Electronic Devices in Power Systems

Solar farm

Wind farm

High Voltage Direct Current (HVDC)

SVC & STATCOM (for voltage regulation)
# Types of Shunt Devices for Voltage Regulation

<table>
<thead>
<tr>
<th>Switch mechanism</th>
<th>Fixed Cap/ Fixed Reactor</th>
<th>SVC</th>
<th>STATCOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive power (Q)</td>
<td>Mechanical</td>
<td>Power Electronics</td>
<td>Power Electronics</td>
</tr>
<tr>
<td>control method</td>
<td>Manual / Automatic</td>
<td>Automatic</td>
<td>Automatic</td>
</tr>
<tr>
<td>Q change step size</td>
<td>Large</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Both capacitive &amp;</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>inductive?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Need harmonic filter?</td>
<td>No</td>
<td>Large filter</td>
<td>Small filter</td>
</tr>
</tbody>
</table>
Hardware-in-the-Loop (HIL) Experiments on RTDS

RTDS

Circuit model

STATCOM or SVC controller

Converter States

STATCOM or SVC controller

V & I Signals

Breaker Signals

GTAI

GTAI

GTFO

GTFO

GTFO

GTFO

GTFO

GTFO
Introduction to the STATCOM

Static Synchronous Compensator

A regulating device that can act as either a source or sink of reactive power using IGBTs.

DC/AC Multilevel converter

2-level converter

3-level converter
Introduction to the STATCOM

Static Synchronous Compensator

A regulating device that can act as either a source or sink of reactive power

Reactive power control
(1) Fixed Q mode / Manual mode
(2) Voltage Control Mode

Current control

Switch control

Reactive power control

Current reference

Duty ratio

V

V_{\text{max}}

V_{\text{min}}

Q_{\text{ref}}

Inductive

Capacitive
**STATCOM RTDS Tests**

**Functional Performance Tests (FPT)**

- Operational behavior

✔️ Start up and shut down
✔️ V/Q characteristic
✔️ Gain controller test
✔️ Stability controller
✔️ Redundancy switchover

**System diagram**

- Voltage source
- DC/AC converter
STATCOM RTDS Tests
Mode transfer from fixed Q (FQM) to voltage control (VCM)

(1) In fixed Q (FQM) Q reference = 0
(2) Mode transfer
(3) Gain of VCM controller is adjusted
(4) Operation point in voltage control (VCM)
**STATCOM RTDS Tests**

**Dynamic Performance Tests (DPT)**
- Transient behavior

✅ Faults
✅ Load switching
✅ External transformer energization

![System diagram](image)
STATCOM RTDS Tests

Dynamic performance of STATCOM in phase to phase fault

- **t1**: Line to line fault
- **t2**: STATCOM blocked because of undervoltage
- **t3**: Fault is clear, STATCOM is unblocked
Introduction to the SVC

**Static VAR Compensator**

A device which regulates voltage by injecting or removing reactive power using:

- **TCR**: Thyristor Controlled Reactor
- **TSC**: Thyristor Switched Capacitor

![Light Triggered Thyristor](image)
Introduction to the SVC

Static VAR Compensator
A device which regulates voltage by injecting or removing reactive power.
**SVC RTDS Tests**

System Verification Tests
- Operation and static/dynamic characteristics

- Start up & shut down
- Protection
- V-I characteristics
- Faults
SVC – VC Mode

V (pu)

A

Vsys1

Vref

I (pu)

Capacitive

Inductive

System load line A

System load line B

Linear Control Range

SVC Dynamic Characteristic

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**SVC RTDS Tests**

Performance of SVC in phase to ground fault under voltage-control mode

- **t1**: L-G fault applied
- **t2**: SVC injects Q to increase V
- **t3**: Fault is clear; SVC’s Q briefly increases to regulate voltage to 1 pu
- **t4**: SVC injects less Q as voltage is boosted to reference value
SVC RTDS Tests

Performance of SVC in phase to ground fault under susceptance-control mode

Qref = 50 Mvar

t1 : System voltage change; SVC responds dynamically

t2 : System voltage settles; SVC’s reactive power begins to move to reference value

t3 : SVC’s reactive power returns to Qref value
RTDS Tests – Conclusions

1) Real STATCOM & SVC controllers can be tested using hardware-in-the-loop technology on RTDS racks.
2) Verified the functionality and operation of Dominion Energy’s new controllers per the manufacturers’ specifications.
3) Understand the controllers and able to predict the response of the controllers in various scenarios.
4) Further tested the functionality of the controllers by performing more protection sequences and various kinds of faults in the simple model.
Interaction of the STATCOM and SVC
Interaction Assessment of the STATCOM and SVC

Dynamic interaction - voltage recovery time during faults

![Graph showing voltage recovery time for different locations with and without STATCOM and SVC.]
Progress

- Individual simulations of the real SVC and STATCOM controllers are completed using the RTDS simulation equipment and hardware-in-the-loop functionality.
- Operational and dynamic performances of the STATCOM and the SVC are tested and meet the criteria from vendor reports.
- Using an equivalent system model of an urban area, the STATCOM and the SVC controllers are successfully included in the same simulation. No negative interactions are found between the SVC and STATCOM when in close proximity.
- All tests procedures & results obtained are documented; documentation can be used for training purposes.

Future work

(1) Build virtual STATCOM or SVC models in RTDS that emulate the real controller.
(2) Use the virtual models to study the interactions of multiple devices in the same network.
Thank you!
Appendicies
Dominion Energy’s SVC - Hardware

- SVC Hardware Components:
  - TCR: -200 to 0 Mvar
  - TSC: +200 or 0 Mvar
  - 5th & 7th HF: +50 Mvar
  - 3rd HF: +72 Mvar

- System Parameters:
  - 250 MVA
  - 500 kV : 25 kV
  - 500 kV bus
  - 25 kV bus

- QCOMPONENT vs. Q_SVC
  - Quadrants for Inductive and Capacitive components
  - Q_SVC values range from -200 to +250 Mvar
Using Reactive Power for Voltage Regulation

Resistor

Capacitor

Inductor

POWER IN A RESISTOR

POWER IN A CAPACITOR

POWER IN AN INDUCTOR

VOLTAGE

CURRENT

POWER

VOLTAGE

CURRENT

POWER
Reactive Power for Voltage Regulation

Original

\[ \vec{V}_g \quad \Delta \vec{V} \quad \vec{V}_L \quad \vec{I}_L \]

Capacitive compensation

\[ \vec{V}_g \quad \Delta \vec{V} \quad \vec{V}_L \quad \vec{I}_L \]

Inductive compensation

\[ \vec{V}_g \quad \Delta \vec{V} \quad \vec{V}_L \quad \vec{I}_L \]