Simulation of a Dynamic VAr Compensator as a Solution to a Large Motor Start Problem

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One quick aside: Wayne Knabach

- Wayne Knabach died on Aug 5 of this year.
- Wayne was in the US Army Field Artillery, then at Northwest Public Service Co.
- Wayne joined the faculty of SDSU in 1957 and was there until he retired in 1995.
- From 1971 to 1995, Wayne was the coordinator of the SDSU Center for Power System Studies.
- Even after retiring, Wayne actively mentored students and faculty.
- There is now a scholarship fund in his name at SDSU.
Motor starts on high-impedance circuits

• Induction machines look almost like faults when they first start. (Also, large synchronous machines are started as induction machines.)

• The bigger the motor the worse it is.

• If a large industrial motor is installed on a feeder with high impedance, the voltage drop during the large starting current can cause the motor to stall, or other problems.
Problem studied in this paper

• 84 mile long, 69 kV feeder feeding a 25 kV substation

• Proposed new load includes:
  • Three 4650 hp (3.5 MW) brushless synchronous motors driving compressors, supplied via RVATs.
  • One 2200 hp (1.6 MW) brushless synchronous motor driving a compressor, supplied via an RVAT.
  • Four 1500 hp (1.1 MW) induction motors driving pumps, supplied via SSVRs.
  • Two 800 hp (0.6 MW) induction motor driving compressors, started directly across the line.
RVAT: Reduced Voltage AutoTransformer

SSVR: Solid-State Voltage Reducer

Image from: http://www.eaton.com/ecm/groups/public/@pub/@electrical/documents/content/ap03902001e.pdf
Possible solution: dynamic VAr compensator

• Most of the current drawn by a motor during startup is reactive (mostly reactive line impedance and mostly reactive motor impedance).

• If the needed VAr could be sourced locally, there’d be much less voltage drop.

• Capacitors are often employed but they are on-off devices (no fine control) and are usually fairly slow to switch.

• A Dynamic VAr Compensator (DVC) is a power electronics device that can meet this need.
DVC
The DVC proposed for this project has two fixed capacitors under its control. Thus, the DVC unit has both continuous (fine-tuning) and coarse discretized control, to give it a wide VAr output range. The power electronics section can respond much more quickly than switched capacitors, which often reduces the overall VAr demand.
Procedure

• Built a detailed transient model of the feeder, motors, motor starters, other loads, and DVC (MATLAB/SimPowerSystems).
  • Z + PQ load used for the 25 kV feeder loads.
  • One 69 kV site had significant motor loads; those were modeled explicitly.

• Validated the model against available data and physical expectations.

• Ran tests on each motor in two cases:
  • First to start;
  • Last to start.

• Compared results with and without DVC.
Feeder model
Zoomed in view of the motor and DVC site

- Feeder 1
- Feeder 2
- Feeder 3

- 69:25 kV transformer
- 69 kV source
- 69 kV Thevenin Z

- New motor load site
- Switched capacitors controlled by the DVC
## Summary of results

<table>
<thead>
<tr>
<th>Motor</th>
<th>Position in starting order</th>
<th>DVC on?</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 hp</td>
<td>First</td>
<td>No</td>
<td>Start</td>
</tr>
<tr>
<td>800 hp</td>
<td>First</td>
<td>Yes</td>
<td>Start</td>
</tr>
<tr>
<td>800 hp</td>
<td>Last</td>
<td>No</td>
<td>Fail</td>
</tr>
<tr>
<td>800 hp</td>
<td>Last</td>
<td>Yes</td>
<td>Start</td>
</tr>
<tr>
<td>1500 hp</td>
<td>First</td>
<td>No</td>
<td>Start</td>
</tr>
<tr>
<td>1500 hp</td>
<td>First</td>
<td>Yes</td>
<td>Start</td>
</tr>
<tr>
<td>1500 hp</td>
<td>Last</td>
<td>No</td>
<td>Fail</td>
</tr>
<tr>
<td>1500 hp</td>
<td>Last</td>
<td>Yes</td>
<td>Start</td>
</tr>
<tr>
<td>2200 hp</td>
<td>First</td>
<td>No</td>
<td>Start</td>
</tr>
<tr>
<td>2200 hp</td>
<td>First</td>
<td>Yes</td>
<td>Start</td>
</tr>
<tr>
<td>2200 hp</td>
<td>Last</td>
<td>No</td>
<td>Fail</td>
</tr>
<tr>
<td>2200 hp</td>
<td>Last</td>
<td>Yes</td>
<td>Fail</td>
</tr>
<tr>
<td>2200 hp, adjusted RVAT</td>
<td>Last</td>
<td>No</td>
<td>Fail</td>
</tr>
<tr>
<td>2200 hp, adjusted RVAT</td>
<td>Last</td>
<td>Yes</td>
<td>Start</td>
</tr>
<tr>
<td>4650 hp</td>
<td>First</td>
<td>No</td>
<td>Start</td>
</tr>
<tr>
<td>4650 hp</td>
<td>First</td>
<td>Yes</td>
<td>Start</td>
</tr>
<tr>
<td>4650 hp</td>
<td>Last</td>
<td>No</td>
<td>Fail</td>
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<td>4650 hp</td>
<td>Last</td>
<td>Yes</td>
<td>Start</td>
</tr>
</tbody>
</table>
Summary of results

• All first to start cases were successful without the DVC.
• Without the DVC, none of the last-to-start cases was successful.
• For two last-to-start cases, we needed the DVC, and an adjustment to the RVAT settings. With those changes, all cases started successfully.
Case: 1500 hp motor, first to start, no DVC.

Result: successful start.
Case: 1500 hp motor, first to start, no DVC.

Result: successful start.
Case: 1500 hp motor, last to start, no DVC.

Result: fails to start.
Case: 1500 hp motor, last to start, with DVC.

Result: successful start.
Case: 1500 hp motor, last to start, DVC outputs
Case: 4250 hp motor, last to start, no DVC.

Result: fails to start, and causes other motors to stall.
Case: 4250 hp motor, last to start, with DVC.

Result: other motors no longer stall, but still fails to start.
Problem is in the RVAT

• The threshold for fully bypassing the RVAT is never reached, so full voltage is never applied.

• Part of the reason is the RVAT’s own impedance.

• Solution: adjust the RVAT thresholds.
Case: 4250 hp motor, last to start, with DVC and adjusted RVAT.

Result: successful start.
DVC outputs during 4650 hp start, last to start
Conclusions

• Without the DVC, the system was not able to start any of the motors when they were last to start. In some cases already-running motors stalled.

• Overall solution involved adding the DVC, and adjusting the RVATs on the two largest motor sizes. With these changes, all motor starts were successful.

• Transient simulation was used to:
  • Gain a quantitative understanding of the problem being faced
  • Quantify the expected effectiveness of the solution
  • Develop interconnection requirements (i.e., adjusting RVAT settings)
Thank you!

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