Loss of Synchronous Generation Impacts and Mitigation

MEPPI
Power Systems Engineering Division (PSED)

for EE500E Energy & Environment Seminar,
University of WA,
October 5, 2017
Agenda

1. An Active Industry Issue: Loss of Synchronous Generation

2. Impacts from Loss of Synchronous Generation
   a) Reduced fault duty
   b) Reduced inertia

3. Mitigation Options
   a) Comparative overview of mitigation options
   b) Examples

4. Examples of Simulating Impacts and the Relative Performance of Mitigation Options

5. Extract from a NERC Inverter Performance Task Force report on the Blue Cut Fire related 1,200MW PV Loss Related System Disturbance
1. **SONGS Nuclear Shutdown**
   2,500 MVA generation capacity loss, with associated –66 kA Amps (at 22 kV) reduced system fault current contribution & -13.5 MW-s reduced system inertia contribution

2. **Diablo Canyon Nuclear Shutdown**
   2,640 MVA generation capacity loss, with associated –61 kA Amps (at 25 kV) reduced system fault current contribution & -12.5 MW-s reduced system inertia contribution

3. **Coastal Once Through Cooling (OTC) Gas Fired Generation Shutdown**
   ~ 5 GVA generation capacity loss, with associated –325 KA Amps reduced system fault current contribution & -15 MW-s(H) reduced system inertia contribution

4. **Western Coal Shutdown, IPP, other Rocky Mountain States’ Coal Plants**
   1,982 MVA generation capacity loss with future IPP shutdown, with associated –44 KA Amps reduced system fault current contribution & -5.7 MW-s(H) reduced system inertia contribution

*Increased risk of loss of protection coordination.*

*Diminished frequency deviation recovery.*

*Reduced stability-criteria-compliance margin.*

*Reduced total import capability into California.*
Selected Impacts for Discussion

1. “Generators that use inverters to interface to the grid ... can only supply relatively small amounts of short circuit current. Typically, inverter short circuit current is limited to a range of 1.1 to 1.4 per unit. As the penetration levels of these generators increases and displaces conventional synchronous generation, the available short circuit current on the system will decrease. This may make it more difficult to detect and clear system faults. “

2. “… as DER displaces synchronous generation, there may be times when there is insufficient system inertia and primary frequency response to arrest frequency decline and stabilize the system frequency following a contingency.”

(emphasis added)

From “Potential Bulk System Reliability Impacts of Distributed Resources”, NERC, August 2011
Reduced SCD Impact Mitigation, How Much Replacement Fault Current Needed? DER Models to Simulate Impact and Mitigation?

For the most effective use of an inverse-time relay characteristic, its pickup should be chosen so that the relay will be operating on the most inverse part of its time curve over the range of values of current for which the relay must operate. In other words, the minimum value of current for which the relay must operate should be at least 1.5 times pickup, but not very much more.

From “Distribution System Feeder Overcurrent Protection”, GET-6450, GE
Lack of DER Models:
A Challenge to Understanding Fault Current Impacts

**System Protection Considerations**
As DER penetration increases, the impact of the DER on system protection requirements of the bulk power system should be evaluated. However, it can be challenging to incorporate these effects into the bulk power system planning tools, due to often limited data available about the capacity and power production profile of the DER and the behavior during disturbance conditions.

From “Potential Bulk System Reliability Impacts of Distributed Resources”, NERC, August 2011
Inertial Response

- The magnitude of inertial response depends on the amount of synchronous generation and motors online.
- The greater the number of synchronous generation and load online the larger the inertial response resulting in a smaller decrease in system frequency deviation.

\[ M_{sys} = \sum_{i \in I} H_i \cdot MVA_i \]

- \( M_{sys} \) = System inertia
- \( H_i \) = Generator/motor inertia constant (seconds on MVA rating)
- \( MVA_i \) = Generator/motor MVA rating

From “ERCOT Essential Reliability Services Tutorial: Frequency Support”
Figure: Example Frequency Response to an “Event”
Example Frequency Response in WECC

Frequency response showing the simulated loss of two Palo Verde units for WECC 2014 peak (blue) on July 1, 2014, and the WECC 2014 low load (Red) on November 2, 2014 cases. This figure highlights the impact of system loading on frequency response.

Figure: Example Frequency Response in WECC to a loss of 2750 MW

Example Inertial Response in ERCOT: Impact of Renewables

- Approximately 24,000 MW of system load
- Total wind generation

**Figure:** ERCOT historical kinetic energy boxplots (2010-2017)

**Figure:** Calculated system frequency after 2750 MW generation trip during nonsynchronous generation peak in ERCOT (years 2010-2014)

Overview of XMSN Mitigation Options

<table>
<thead>
<tr>
<th></th>
<th>SC</th>
<th>SVC</th>
<th>STATCOM</th>
<th>BESS (w/inverter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVA Range</td>
<td>100-500</td>
<td>1-250</td>
<td>1-250</td>
<td>1-50</td>
</tr>
<tr>
<td>Operating Quadrants</td>
<td>+/- Q</td>
<td>+/- Q</td>
<td>+/- Q</td>
<td>+/- P (State of Chg &gt;0) +/- Q</td>
</tr>
<tr>
<td>Overload Capability,</td>
<td>8X</td>
<td>1X</td>
<td>2.0X</td>
<td>1.2X</td>
</tr>
<tr>
<td>Multiples of full load A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inertia</td>
<td>Medium, Rapid decay</td>
<td>n/a</td>
<td>n/a</td>
<td>Synthetic, High, 4X equivalent damping/MVA</td>
</tr>
<tr>
<td>Min. Response Time*, ms</td>
<td>1,200 for Q</td>
<td>20 for Q</td>
<td>10 for Q</td>
<td>100 for P 100 for Q</td>
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<tr>
<td>Max. Ramp Rate (MVA/s)</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Output vs Control, Accuracy/Lag</td>
<td>Low/High</td>
<td>Med./Low</td>
<td>High/Low</td>
<td>0</td>
</tr>
<tr>
<td>Typical Unit Cost, $/KVA</td>
<td>$250/kVAR, &gt;50 MVA</td>
<td>$150/kVAR, &gt;50 MVA</td>
<td>$175/kVAR, &gt;50 MVA</td>
<td>$500/kVA power &gt;10 MVA, &gt;1-hr</td>
</tr>
</tbody>
</table>

*Response time from receiving control signal to reaching target power output level
Conclusions

- An Energy Source Power System Stabilizer has been installed on the 10 MW, 40 MWH Battery Energy Storage System at SCE’s Chino substation.
- The ESPSS is operating satisfactorily.
- The ESPSS senses system frequency deviations from the nominal 60 Hz and regulates power output of the batteries to provide damping to these system swings.
Project Examples Synthetic Inertia (F/R) thru Full Peaker Replacement Capabilities

Mitsubishi Electric Designed and Built BESS, 50 MW 300MWh
## Synthetic Inertia & SCD Solution Example, Distributed Resource/Distribution PRODUCT

### MEPPi D-STATCOM

**Grid CoRe Series**
- 2-Quadrant “buck and boost” Voltage Regulation (CVR)
- Volt/VAR Optimization (VVO)
- Harmonic Mitigation ($5^{th}$ and $7^{th}$)
- Voltage Phase Balancing ±5% *(patent pending)*
- Transient Voltage Overvoltage and Sag Mitigation
- Improvement of Voltage Regulation and Control
- Short Term Voltage Stability

**D-STATCOM Product Family Configurations**

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Rating (kVAR)</th>
<th>Product Generation</th>
<th>Cell Bypass</th>
<th>Harmonic Mitigation</th>
<th>Voltage Phase Balancing</th>
<th>Transformer Type</th>
<th>TX Voltage (High Side)kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>500</td>
<td>A</td>
<td>B - Yes</td>
<td>H - Yes</td>
<td>P - Yes</td>
<td>Air Insulated - AI</td>
<td>#.#</td>
</tr>
<tr>
<td>GP</td>
<td>1000</td>
<td></td>
<td>0 - No</td>
<td>0 - No</td>
<td>0 - No</td>
<td>Oil Insulated - OI</td>
<td>0 if 7 is 0</td>
</tr>
<tr>
<td>GM</td>
<td>1500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Customer Supplied - 0</td>
<td></td>
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<tr>
<td>GM</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Fast Reaction Time (ms)
- Dynamic Functionality (not stepped)
- Self Protecting (cannot be overloaded)
- Lower System Losses
- Increase System Reliability
- Support Renewable Integration
- Improve Transient Stability
- Reduce Temporary Overvoltage’s
- Increase other T&D assets’ life and utilization
Simulation for Information
“Studies for Battery Energy Storage Systems (BESS)”

February 2016
Revision #01

Prepared by:
Mitsubishi Electric Power Products, Inc. (MEPPI)
Power System Engineering Services Department
Warrendale, Pennsylvania
Customers Have Asked Us to Examine the Following Topics

• Understanding the impact of batteries on the power system.
  – Maintain, create, and validate models in various software suites (PSS/E, PSLF, DigSilent, PSCAD, EMTP, CYME, OpenDSS, Gidlab-D, etc.).

• Adding a BESS into a utilities solution tool-kit.

• Computer simulation allows the utility to understand the impact of BESS’ on their power system. The following are examples of types of studies that can be performed:
  – Determining the impact of the BESS and the inverter control system on the electric power system.
  – Interaction with other power electronic devices.
    • Controls interaction, anti-islanding detection concerns.
  – Black start studies
  – BESS sizing and optimal location.
Customer Problem: Investigate BESS as an Alternative for Black Start Studies Power

- BESS’ can be utilized in a power system black start scheme.
- Utilizing both time domain and positive sequence analysis tools the ability of the BESS to start a cranking path and conventional generation can be confirmed.

![Diagram of power system with BESS location and black start scheme](image-url)
Voltage Response During Black Start

- It was observed that the BESS provided better regulation of the voltage at the 69 kV bus than a traditional peaker unit and it’s associated excitation system.
  - The BESS resulted in reduced voltage dips and overshoot at the regulating bus regardless of the size of the started generator.
Frequency Response During Black Start

- It was observed that the BESS provided better regulation of the frequency at the 69 kV bus than a traditional peaker unit and its associated excitation system.
  - The BESS resulted in reduced frequency dips at the regulating bus regardless of the size of the started generator.
Ideas on Future Informative Studies

1. **DER Penetration Impact Study Concepts**
   - Develop ‘aggregate’ DER models for implementation in bulk power system studies
   - Develop Bulk System Cases: IEEE1547-2003 compliant DER that Anti-island (drop off), 20%, 30, 40%, 50%
   - Develop Bulk System Cases: 1547 Revision/UL-1741-SA Compliant DER that Ride Thru, 20%, 30%, 40%, 50%

2. **Evaluate System Performance Benefits From BESS Advanced Functionality**
   - Impact of implementing FRR capability for inverter or FACTS connected resources
   - Impact of H-equivalent active damping from inverter or FACTS connected resources
   - Impact from (need for?) short term overload capability for inverter and FACTS connected resources
   - Develop study methodology to determine fault duty contribution needed to preserve legacy ToC based protection coordination, through distribution level
   - Other?
SELECTED NERC SLIDES, from
BLUE CUT FIRE PV INTERUPPTION
DISTURBANCE REPORT
1200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Rich Bauer
Associate Director Reliability Risk Management / Event Analysis
Joint OC/PC Meeting
June 6, 2017


Source, NERC
Source, NERC
Source, NERC
Data gathering

- 26 different solar developments
- All utility scale
- Majority connected at 500kV or 230kV
- 10 different inverter manufacturers
- Reported causes of “trips”
  - Under frequency
  - Under voltage
  - Over voltage
  - DC overcurrent
  - 1 loss of synchronism

Source, NERC
<table>
<thead>
<tr>
<th>#</th>
<th>Date/Time</th>
<th>Fault Location</th>
<th>Fault Type</th>
<th>Clearing Time (cycles)</th>
<th>Lost Generation (MW)</th>
<th>Geographic Impact</th>
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<tbody>
<tr>
<td>1</td>
<td>08/16/2016 11:45</td>
<td>500 kV line</td>
<td>Line to Line (AB)</td>
<td>2.49</td>
<td>1,178</td>
<td>Widespread</td>
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<tr>
<td>2</td>
<td>08/16/2016 14:04</td>
<td>500 kV line</td>
<td>Line to Ground (AG)</td>
<td>2.93</td>
<td>234</td>
<td>Somewhat Localized</td>
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<tr>
<td>3</td>
<td>08/16/2016 15:13</td>
<td>500 kV line</td>
<td>Line to Ground (AG)</td>
<td>3.45</td>
<td>311</td>
<td>Widespread</td>
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<tr>
<td>4</td>
<td>08/16/2016 15:19</td>
<td>500 kV line</td>
<td>Line to Ground (AG)</td>
<td>3.05</td>
<td>30</td>
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<tr>
<td>5</td>
<td>09/06/2016 13:17</td>
<td>220 kV line</td>
<td>Line to Ground (AG)</td>
<td>2.5</td>
<td>490</td>
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<td>6</td>
<td>09/12/2016 17:40</td>
<td>500 kV line</td>
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<td>3.04</td>
<td>62</td>
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<tr>
<td>7</td>
<td>11/12/2016 10:00</td>
<td>500 kV CB</td>
<td>Line to Ground (CG)</td>
<td>2.05</td>
<td>231</td>
<td>Widespread</td>
</tr>
<tr>
<td>8</td>
<td>02/06/2017 12:13</td>
<td>500 kV line</td>
<td>Line to Ground (BG)</td>
<td>2.97</td>
<td>319</td>
<td>Widespread</td>
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<tr>
<td>9</td>
<td>02/06/2017 12:31</td>
<td>500 kV line</td>
<td>Line to Ground (BG)</td>
<td>3.01</td>
<td>38</td>
<td>Localized</td>
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<tr>
<td>10</td>
<td>02/06/2017 13:03</td>
<td>500 kV line</td>
<td>Line to Ground (BG)</td>
<td>3.00</td>
<td>543</td>
<td>Widespread</td>
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<tr>
<td>11</td>
<td>05/10/2017 10:13</td>
<td>500 kV line</td>
<td>unknown</td>
<td>unknown</td>
<td>579</td>
<td>Somewhat Localized</td>
</tr>
</tbody>
</table>

Source, NERC
Largest block of loss (~700 MW) was due to underfrequency tripping
Inverter sensed a near instantaneous frequency of <57 Hz and tripped instantaneously

Source, NERC
2nd largest block of inverter loss (~450 MW) was attributed to low voltage
What was the voltage?

Source, NERC
What’s been done?

- Frequency tripping
  - Manufacturer is adding tripping delay
- Simulations to identify momentary cessation risk
  - ~7200 MW potential
  - Specify maximum delay and ramp rate for Restore Output
Finding 4
GOs installing inverter connected resources, as well as the inverter manufacturers, are often facing potential inconsistencies in requirements with NERC Standards, IEEE 1547, UL 1741, National Electrical Code, GIAs, and other applicable references. Many inverter manufacturers are using the existing IEEE 1547 Standards, originally meant for generators less than 10 MW and connected to the distribution system, as a default for inverter control settings. Further, generator owners are supporting this as they are required to obtain a UL listing for their equipment. If a new standard for inverter-based operation is successfully promulgated, coordinate with UL such that it can now use this standard, written for inverter-based generation interconnected to the transmission system, as the basis for testing to obtain a UL listing.

Source, NERC
**NERC Alert issued 6/20/2017**

**Industry Recommendation**
Loss of Solar Resources during Transmission Disturbances due to Inverter Settings

Initial Distribution: June 20, 2017

NERC identified a potential characteristic exhibited by some inverter-based resources, particularly utility-scale solar photovoltaic (PV) generation, which reduces power output during fault conditions on the transmission system. An example of this behavior has been observed during recent BPS disturbances, highlighting potential risks to BPS reliability. With the recent and expected increases of utility-scale solar resources, the causes of this reduction in power output from utility-scale power inverters needs to be widely communicated and addressed by the industry. The industry should identify reliability preserving actions in the areas of power system planning and operations to reduce the system reliability impact in the event of widespread loss of solar-resources during faults on the power system.

For more information, see the 1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

About NERC Alerts >>

**Status:**
- Acknowledgement Required by Midnight Eastern on June 27, 2017
- Reporting Required by Midnight Eastern on August 31, 2017

PUBLIC: No Restrictions
More on handling >>


Source, NERC
Thank you, and for more information:

Charlie Vartanian P.E., Western Generation
Charlie.Vartanian@meppi.com

Rob Hellested, Section Manager, PSED
Rob.Hellested@meppi.com
MEPPI is a MELCO-owned American Company combining the best of Japanese and American business practices to bring high quality products to our local customers.

- **Incorporated in December 1985**
  - 50/50 Joint Venture of Westinghouse Electric and Mitsubishi Electric
  - Named WM Power Products, Inc.

- **Became 100% subsidiary of Mitsubishi Electric in 1989**
  - Named Mitsubishi Electric Power Products, Inc.
  - Supporting the Energy and Electrical Systems Group of MELCO

- **Local capabilities**
  - Headquartered in Warrendale PA
  - Manufacturing, product integration, project management, service, NPD, sales & marketing
MEPPI USA locations

Warrendale, PA

- 520 Bldg
  - MV Breakers
- 530 Bldg
  - Headquarters, PSES (Studies), Diamond Vision
- South 512 & North 510 Bldg
  - HV Circuit Breakers

Memphis, TN

- Transformers

Lake Mary, FL

- Generation

- 547 Bldg
  - Substations, GIS, FACTS, BESS
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- Step and Touch Voltage
- Harmonics and Frequency Scans
- Geomagnetic Induced Current
- Distributed Energy Resources
- Blackstart Analysis
- Gas Insulated Substations
- Transient Recovery Voltage
- Capacitor Bank Switching
- Ferroresonance
- Temporary Overvoltages
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- Power Quality
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- Power Factor Correction
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