Preventing Blackouts

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Panel Session on Major Grid Blackouts of 2003
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Suddenly, knowing a lot about the U.S. power grid became sexy at cocktail parties.

*The Oregonian*, 24 August 2003
Summary — How to prevent blackouts

- Compliance with NERC Planning Standards
  - Good start on defining best practices

- **Automatic** load shedding in major load areas

- Prioritized substation, and control and protection upgrades:
  - Excitation equipment including limiters
  - Backup relays
  - Communications and protection equipment
  - Capacitor banks with modern controls
Summary — Longer-term improvements

- **Coordinated voltage control design:**
  - High, flat voltage profile
  - TEPCO presentation

- **CAPS (advanced capacitor banks)**

- **SPS/WAMS/WACS**

- **Automated direct load control for reliability**

Bottom Line: Defense in depth
NERC Planning Standards

- Sections II and III define industry best practice in modeling, and control and protection

- Developed because of 1996 power failures

- WECC and others proactive in partial enforcement
  - Reliability Management System
  - Generator testing
NERC Planning Standards — Examples

■ NERC Planning Standard III.C.S1: All synchronous generators connected to the interconnected transmission systems shall be operated with their excitation system in the automatic voltage control mode unless approved otherwise by the transmission system operator.

■ NERC Planning Standard III.C.S2: Generators shall maintain a network voltage or reactive power output as required by the transmission system operator within the reactive capability of the units. ...
NERC Planning Standards — Examples

- NERC Planning Standard III.C.G2: Generators and turbines should be designed and operated so that there is additional reactive power capability that can be automatically supplied to the system during a disturbance.

- NERC Planning Standards III.A.G17: Application of zone 3 relays with settings overly sensitive to overload or depressed voltage conditions should be avoided where possible.
August 14, 2003 Voltage Profile

- FE Eastlake 5 unit tripped at 13:31 loaded at 630 MW, 370 MVAr (because of exciter problems)

- Low voltages increase $I^2R$ heating by $1/V^2$, contributing to transmission lines sagging into trees

- Desired voltage for high, flat profile is ~1.03 p.u. or 355 kV
August 14, 2003 Voltage Profile

FE Eastlake 5 tripped at 13:31, 630 +j370 MVA

Source: U.S.-Canada Power System Outage Task Force final report, April 2004
Undervoltage Load Shedding

- Installed by many power companies

- **Automatic** control takes burden off operators
  - In new or evolving situation operators require 20 minutes or longer to make tough decisions.

- **Complements underfrequency load shedding universally installed after 1965 blackout**
  - New digital relays can be used for both UV and UF load shedding with common trip circuits. Voltage measurement on unregulated (transmission) side.

- **Settings should be 8-10% below voltage during heavy load conditions with system normal**

- **Time delays should be around 1 second for summertime**

- **All three phases must be depressed**

- **Wide-area automatic load shedding more sensitive**
Backup Relays

- Most blackouts involved undesirable operation of zone 3 and other backup relays
- BPA stopped using zone 3 relays in 1970, but....
- Multi-phase faults not involving ground are very rare
- Not a proper means of overload detection
- If deemed necessary, use modern digital relays with restricted reach for load, or use blindingers
- Other substation and protection upgrades may be required:
  - Redundant local protection and communications circuits for EHV transmission
  - Eliminate three-terminal lines, etc.
Prioritized Control and Protection Upgrades

- Modern digital control and protection more reliable and higher performance
- Low cost and fast installation compared to transmission additions
- Example: many generator voltage regulators use obsolete technology, especially for overexcitation limiters
- May need main equipment replacement such as generator exciter (Eastlake 5?)
- Substation upgrades such as bus arrangements may also be desirable (Brazil 1999 blackout)
- Built-in monitoring
- Upgrades should go in rate base
## Western Interconnection Failures: 1994–1996

<table>
<thead>
<tr>
<th>Date and Time</th>
<th>Pacific Intertie Flow</th>
<th>Number of Islands</th>
<th>Load Loss MW&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Generation Loss MW</th>
</tr>
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<tbody>
<tr>
<td>17 Jan. 1994</td>
<td>S to N</td>
<td>5</td>
<td>7500</td>
<td>6400</td>
</tr>
<tr>
<td>14 Dec. 1994</td>
<td>S to N</td>
<td>5</td>
<td>9336</td>
<td>11,300</td>
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<tr>
<td>2 July 1996</td>
<td>N to S</td>
<td>5</td>
<td>11,743</td>
<td>9909&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>10 August 1996</td>
<td>N to S</td>
<td>4</td>
<td>30,489</td>
<td>25,578&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1. Mostly controlled underfrequency load shedding.
2. Includes intentional tripping of NW hydro of AC intertie loss.
3. 175 units excluding intentional tripping of NW hydro. Some units loss because of transmission line outages.
Reasons for (Unnecessary) Generator Trips

Generators *in no danger of damage* have tripped during cascading outages for:

- Loss of excitation relay operating for high voltage!
- Volts per hertz relay not coordinated with V/Hz limiter
- Stator impedance relay, other backup relays
- *Over/under voltage* — main bus or auxiliary bus
- *Over/under frequency*
- Overcurrent
- Exciter protection
- Drum level, other boiler problems
10 August 1996, Northern Calif. Frequency

~1% overshoot

Moss Landing Units 6 & 7 Trip

Blocks 9 & 10 Trip San Francisco

Blocks 7 & 8 Trip

Contra Costa Units 6 & 7 Trip

Ties Open Diablo Canyon Trips E20 & Blocks 1-6 Trip

Lowest Frequency: 58.3 Hz

* Frequency Readings from Contra Costa Sub

11 minutes
Coordinated Voltage Control

- Install transmission-level shunt capacitor banks to keep reactive power reserves at generators
  - Modern fuseless banks are low cost and zero loss
  - BPA installed three large banks within 9 months of August 10, 1996
  - TEPCO experience with microprocessor controls
BPA Shunt Capacitor Banks

BPA has many 550-kV capacitor banks up to 460 MVAR
Coordinated Voltage Control

- **Generator line drop compensation and/or high side voltage control for tighter control of transmission voltage and reduced reactive power losses**
  - LDC cost is low (part of voltage regulator, just connect)
  - Advanced high-speed high side voltage control available from Mitsubishi (field tested at BPA)
  - TEPCO control

- **Control of all area generators should be similar**
High-Speed High Side Voltage Control

230-kV voltage for switching 168-MVAr capacitor bank

Reactive power from two 95 MVA generators with HSVC, 6% high side droop

Control is about six times more effective than terminal voltage control
**CAPS (CAPacitor bank Shorting)**

- Compensate for reduced capacitor bank output during low voltage emergencies by reducing bank reactance:

\[
Q_c = \frac{V^2}{X_c}
\]

- Two-step capacitor bank with either continuous or short-term (30 min.) rating in shorted condition:
  - Up to 50% boost — e.g. 100/150 MVAr rating
Shorted Section, typically comprises 20% to 33% of the bank.

![Diagram of a capacitor bank system with a shunt capacitor bank, discharge impedance, unshorted section, and shorting switch. The diagram includes a graph showing the relationship between bus voltage and capacitor bank reactive power. The graph is labeled 'Normal' and 'Shorted'.]
BPA Olympia Substation Installation

241.5/B3

14 series groups, 20 parallel capacitors/group. 168-MVAR total.
9.96-kV, 200-kVAR.

Discharge MPT

Shorting switch
Current limiting reactor
PT for voltage differential relays
TVA is installing fuseless CAPS banks at 161-kV.
Special Protection Systems

- First upgrade basic control and protection, and add undervoltage load shedding

- Controlled separation difficult in meshed system

- Out-of-step relaying basics:
  - Impedance relays used
  - Don’t use out-of-step blocking without out-of-step tripping that causes complete separation

- Remember: Next blackout will be different
BPA Wide-Area voltage and stability Control System (WACS)

- Phasor measurements as inputs, and special protection system trip circuits for discontinuous control actions at power plants and substations
  - On-line demonstration in progress
  - One algorithm based on voltage measurements from many substations
  - Second algorithm combines voltage measurements and generator reactive power measurements at many substations and power plants

- Flexible platform for capacitor bank switching, generator/load tripping, and direct load control
Flexible Platform for Control

- **GPS**
- **voltage phasors**
- **current phasors**
- **frequencies**
- **fiber optics**
- **SCADA control center LAN**
- **BPA control center(s)**
- **power system**
- **generator/load tripping**
- **reactive power switching**
- **Other actions**

**control computers**
Direct Load Control for Stability

- Painless load shedding

- IEEE Task Force on Direct Load Control for Price and System Stability has held three panel sessions
  - Papers available
  - Example: turn-off air conditioners during emergency

- Actuation methods such as pagers are existing:
  - 10 second response

- Automated activation such as WACS is best
How to Prevent Blackouts?

■ Defense in depth:
  • Tree trimming of course
  • Operations
  • Capacitor banks and other substation additions
  • Control and protection upgrades — power plants and substations
  • Maybe even build a line (not mentioned in August 14 final report)

Panelists and audience will discuss lessons learned from past blackouts and how to prevent blackouts in future
Bibliography


Panelists and Program

- Jeff Dagle, “Data Management Issues Associated with the August 14th, 2003 Blackout Investigation”*
- Paulo Gomes, “New Strategies to Improve Bulk Power Systems Security: Lessons Learned from Large Blackouts”*
- Shinichi Imai, “TEPCO Observations on August 14 Blackout and Recommendations to Prevent Future Blackouts Based on TEPCO’s Experience”
- Panel–audience discussion and debate

*Paper in proceedings