i-PCGRID Workshop 2014

Lessons from System Restoration of NE Blackout - March 26

Summary of August 14th Blackout

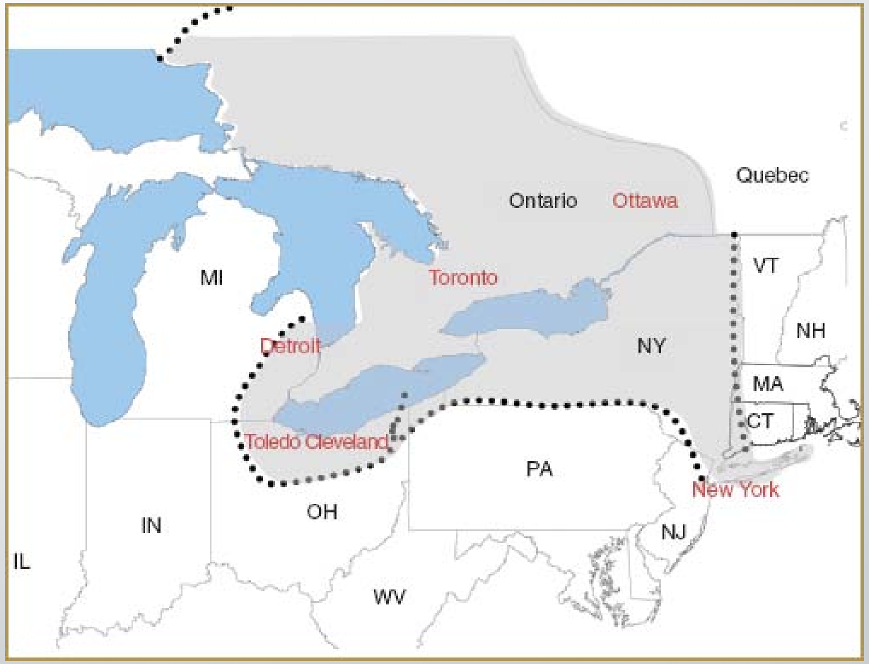
- Three Separate Phases of Blackout
- First Phase – Steady State – Four 345kV lines relay in Central Ohio
- Second Phase – Quasi Steady State – low voltages; many Zone 3 relay trips
- Third Phase – Angular Instability and Voltage Collapse – Southeastern Michigan slipped 4 poles relative to Eastern Interconnection!

High Speed Cascade

- Zone 2 relays trip 345kV lines in SE Michigan separating Detroit and Toledo
- Major flows reverse and go from west to east toward New York
- Tsunami like flows rip thru West. Pennsylvania, N. New Jersey & New York
- Unstable Power Swings separate Ontario from New York, New England from New York and New York from Eastern Interconnection

Aftermath

- 50 Million People Blacked Out
- Over 60,000 MW Interrupted
- 5 Major Islands formed: New York;
  New England; Ontario; Detroit & Cleveland

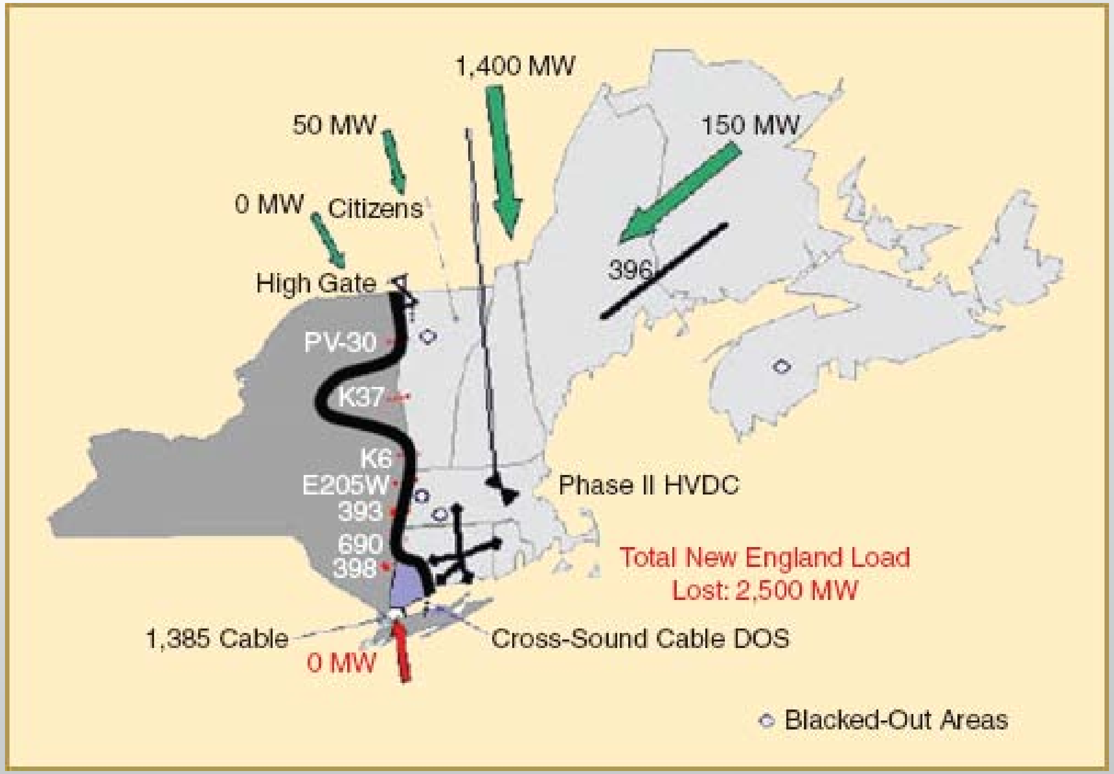


Restoration of New York Island

- NYISO Implemented Restoration Procedures
- Energize New York Grid; Sync to Eastern Grid & restore power to off-site Nuclear Units
- Synch of Gilboa Units Delayed – High Voltage
- Branchburg – Ramapo 500kV line paralleled
- Lessons Learned: Staffing; Physical Communications; Information between transmission and generation owners; Restoration Training Needed

Restoration of New England Island

- NEISO implemented their plan
- Southeastern Connecticut separated with New York; AGC Issues; 140 MW restored
- Overloaded transmission lines & low voltages; 500 MW of manual load shedding
- Lessons Learned: Generators not on AVR; Switch from tie line bias from flat frequency; governor response; frequency & voltage criteria for synchronizing; staffing; and communications



Restoration of Ontario Island

- Independent Market Operator responsible for restoration plan
- Restoration from several islands that remained
- Bruce Nuclear Units energized from Niagra
- Transmission cranking paths built and Northern and Southern Ontario synchronized
- 11 Nuclear Units impacted; rotating outages
- Lessons Learned: Restoration Plans; Training and Simulation; Cooperation with Multiple Entities; Communication

Restoration of Detroit and SE Michigan Island

- Detroit Edison and Consumers Energy responsible for Detroit and SE Michigan
- Severe damage to equipment hampered restoration
- Damaged generators due to ruptured discs
- Restored power from 120kV connected to Eastern Grid; then energized 345kV
- Consumers Energy restored power to SE Michigan too quickly – System Collapsed
- Lessons Learned: DTE's computerized repair log hampered restoration to distribution; Additional spare discs needed

Brief Summary of August 10th, 1996 and September 8th, 2011 Disturbances

- August 10th – 500kV outages in Oregon and inadequate reactive reserve were initiating events
- Unstable power swings on COI caused separation at COB
- Northern California islanded; Southern California islanded with Arizona & Southern Nevada
- 28,000 MW of load lost and 20,000 MW of generation tripped due to out-of-step conditions
- September 8th – Hassayampa – N. Gila 500kV line tripped initiating disturbance
- Overloaded 230/92kV IID transformers tripped; unintended consequences of SPS
- SONGS Separation Scheme operated separating SCE – SDG&E 230kV ties

Restoration Lessons learned from Aug. 14th, Aug. 10th and Sept. 8th Disturbances

- Communication Issues: All three disturbances
- Sound Restoration Plans: All three disturbances
- Assessment of the System: All three disturbances
- Build a cranking path: Primarily Aug. 14th disturbance
- Connect load to maintain voltage and frequency stability: All three dist.
- Availability of a large stable interconnection: All three disturbances
- Prioritize critical load during restoration – All three disturbances
- Restoration to off-site nuclear power plants – All three disturbances

Fundamental Elements of Black Start Restoration Plans

- NERC EEP 005.2 and EEP 006.2
- Physical communication systems; satellite phones and radios
- Communication plan between ISOs, TOs and generators established
- Black Start Generators – isochronous governors – for starting islands
- During initial stages, small amount of load added for frequency stability
- Cold load pickup must be considered when picking up load – 1.5x to 2x

Fundamental Elements of Black Start Restoration Plans

- A cranking path must be established so that other generators and load can be connected
- High voltage a concern when energizing transmission lines
- Relatively high priority to energize voltage control equipment – reactors/sync condensors
- A combination of load and reactive resources to help stabilize voltage
- Priority to energize additional non-black start units early in process
- Attention paid to minimum load of generators: ie Helm PGP at 80 MW
- Off-Site power to nuclear power plants: other high priority critical infrastructure load

Fundamental Elements of Black Start Restoration Plans

- As additional generations come on-line; one generator on control; others on droop; large enough island – AGC
- Important to take a methodical and disciplined approach – 5% load limit
- Reconnect parallel transmission lines to extent possible - redundancy
- Objective as islands are built out is to reach a synchronization point
- After islands have stabilized (load increase has minimal impact on frequency or voltage), synchronize two islands
- Using syncscopes manually versus allowing sync check features of digital relays

Conclusion on Restoration

- Important to have well thought out restoration plans
- No matter how good plans are, system must be assessed – things change
- Staffing must be considered – restoration of a total blackout could take days
- Training and simulation a must; dynamic training simulators even better – ERCOT has one of the most sophisticated training simulators in US
- Dynamic restoration tools should be considered; PG&E has AGORA software tool installed and testing is underway to make operational