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- Report 3.4 -

State-of-the-Art in the Prevention of the Widespread Outages in North-America and France

Executive Summary

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State-of-the-Art in the Prevention of Widespread Blackouts

- Part I: Recent Cascading Outages
  - in WSCC: Western Systems Coordinating Council
  - in NPCC: Northeast Power Coordinating Council
- Part II: Remedial Action Scheme
  - California/Oregon Intertie AC Remedial Action Scheme
  - British Columbia
  - Ontario
  - France
- Part III: Recommendations for the Brazilian Interconnected System

Recent Cascading Outages in WSCC

Date and time	Pacific Intertie Flow	Number of Islands	Load Loss [a]	Generation loss
January 17, 1994 0431 hours	S to N	5	7,500 MW	6,400 MW
December 14, 1994 0125 hours	S to N	5	9,336 MW	11,300 MW
July 2, 1996 1424 hours	N to S	5	11,743 MW	9,909 MW [b]
August 10, 1996 [d] 1548 hours	N to S	4	30,489 MW	25,578 MW [c]

a. Much of load loss by controlled underfrequency load shedding.

b. Includes intentional tripping of NW hydro generation for Pacific intertie outage.

c. 175 units excluding intentional tripping of NW hydro generation for Pacific intertie outage (some units lost due to loss of transmission lines).

d. The total cost of the outage was over US$ 1 billion

WSCC remedial action scheme for the AC COI (California Oregon Intertie)

- Purpose
  - To prevent overload, low voltages and instability in the WSCC interconnected system, should one or more specific 500Kv lines in BPA and/or in PG&E trip for whatever reason
- Functions
  - Controlled Islanding - Automatically splits the WSCC system into two AC islands (northern & southern) preserving the two HVDC links
  - Other remedial actions of lesser impact
- Cost
  - US$10 million to US$20 million
- Decommissioned in 1995 and Re-commissioned after August 10, 1996

California/Oregon Intertie - AC Remedial Action Schemes

- Remedial Actions
  - Tripping armed generation in the northwest US and Canada
  - Tripping PG&E and the California Dept. of Water Resources generation
  - Applying braking resistor at Chief Joseph (BPA)
  - Suspending AGC at BPA and BCHA
  - Inserting mechanically switched capacitors and shunt reactors
  - Bypassing series capacitors
  - Removing shunt capacitors and shunt reactors
- Controlled Islanding
  - Automatically splits the WSCC system into two AC islands (northern & southern) preserving the two HVDC links

Common Features of the Remedial Action Scheme

- Redundancy
  - Largely redundant: failure of any one component will not cause a failure of the scheme
  - Components can be removed from the scheme for test or repair while the rest of the scheme remains in service
- Security Against Misoperation
  - Supervision by power rate relays
  - Use of voting logic of at least 2 of 3 signals before providing a tripping signal
- Testing
  - Functional test is performed once a year
  - Communications tests are performed semi-annually
  - The testing procedure is updated and adjusted periodically

General Observations

- The computational tools used in the investigations are of good quality in modeling the various facilities and simulation.
- The system model represents all the relevant system components including distance relays, under-frequency relays, under-voltage relays and other remedial protection devices. The level of modeling is reasonable for the purpose of the study.
- The experience and skills of the staff conducting the studies are of the highest caliber and measure up to the best in North American standards
- Some of the people we interviewed commented that the number of remedial measures at Itaipu is excessive. We do not believe that such a number (14) is excessive.

Recommendations for the Brazilian Interconnected System

- Time Frames based on the urgency of the required measure and the expected lead time required
  - Measures to be implemented immediately
  - Measures to be implemented in the short time frame
    - » few months to a year
  - Measures to be implemented in the medium time frame
    - » one to two years
  - Long Term Measures
    - » beyond two years

Measures to be Implemented Immediately

- Initiate the development of a Reliability Management System (RMS)
  - Develop **standards** (Planning and Operation) through a consensus of stakeholder self regulating body with an independent governance
    - » Limits on frequency deviation and Area Control Error (ACE)
    - » Operating reserve availability
    - » Appropriate settings of generator AVR's and PSS's
    - » Adequate reactive power capability for new generation, including non-utility generation (e.g. 0.9 power factor capability at the high side of the generator step-up transformer could be required)
  - Develop an **enforcement** of the standards through sanctions against the violators
  - Develop a **compliance** monitoring through control area operators, security coordinators and ISO
    - » Including a central reliability authority to provide oversight of EHV and power plant relay operation and the resolution of the problems

Measures to be Implemented Immediately

- Through **switching changes,** rearrange the bus configurations so as to minimize the impact of bus faults on the system security
  - It should be noted that the feasibility of such rearrangement has to be checked from protection modification requirement and operating flexibility
    - » Bauru
    - » Cabreúva
    - » Ilha Solteira
    - » Jupiá
- Review the application of Zone 3 and other backup distance protection on EHV and the upper end of the HV networks throughout the system
  - Replace them with improved relaying, where appropriate

Measures to be Implemented Immediately

- Explore and determine feasible local SPS which can be implemented immediately to improve system security under multiple contingencies
  - E.g. generation shedding at Ilha Solteira and Jupiá
- Review the condition of the facilities critical to the restoration process immediately
  - Fix whatever is possible on the spot
- Model protection devices and schemes in dynamic simulation programs having user-defined modeling capability
  - PLC-based special protection schemes
  - Model Zone 3 and backup protection

Measures to be Implemented Immediately

- Create a team to audit current conditions of the facilities affecting system reliability using a checklist plan. Many items could be checked such as:
  - control and protection schemes,
  - nameplate ratings,
  - power plant or substation electrical diagrams,
  - communication capability with control centers,
  - black-start capability,
  - operator training/experience, etc.
- Consider the implementation of a professional press release staff to contact press personnel after major disturbances

Measures to be Implemented in the Short Time Frame

- Implement a legislated Reliability Management System (RMS)
- **Rearrange** the substations further to improve the operating flexibility
  - By making changes to the physical terminals of the connection points
  - Each bus section should have bus differential protection
  - Revising the protective relaying philosophy
    - Bauru
    - Cabreúva
    - Ilha Solteira
    - Jupiá

Measures to be Implemented in the Short Time Frame

- Determine all feasible SPS
  - Begin implementing them in priority order according to a well structured emergency security and control strategy
  - PLC-based SPS could also be used for controlled islanding where separation logic and locations can be defined
    - » Such special protection schemes help provide the defense in depth required to mitigate effects of infrequent and unpredictable multiple outages
  - Consider an SPS to trip São Paulo area load or insert capacitor banks for over-excitation limiter pickup, or for sustained field current or reactive power above continuous ratings

Measures to be Implemented in the Short Time Frame

- Investigate overload on the key interface transformers in the system
  - E.g. 500/440 kV transformer at Água Vermelha
  - Determine the necessary short and long term solutions
- Implement over-excitation limiting devices on the critical synchronous condensers and generators which play major role in maintaining voltage stability
  - Should be verified whether they are feasible

Measures to be Implemented in the Short Time Frame

- Update restoration plans
  - Review restoration plans following ownership changes
  - Power system restoration in an emergency should be planned on a one-system basis, without regard to commercial factors
  - Capability for blackstart could be an ancillary service
  - Review the types of load connected initially, concerning most about those with significant voltage and frequency sensitivity.
  - Energization of large motor loads disconnected following the outage should be avoided because of the high starting currents.
    - » An example might be a large residential area with connected air conditioning.
- Establish drills involving many companies, field tests, and simulator training to improve restoration practices

Measures to be Implemented in the Short Time Frame

- Ensure compatibility between the General Electric and ABB primary protection relays, utilized in the Itaipu transmission system
  - Note also that misoperation of the 1970 GE relays have caused problems in other power systems
  - Relay replacement should be considered if the relays from the two manufactures do not show sufficient compatibility
- Consider the PSS replacements at Itaipu 60 Hz to improve damping of several oscillation modes

Measures to be Implemented in the Short Time Frame

- Establish a national guide for out-of-step relaying
  - Practices vary from company
  - In a meshed network such as the south–southeast network, out-of-step relaying with preplanned controlled separation/islanding locations presents difficulties.
  - One option is to simply rely on separation by distance relays.
  - Trip “on-the-way-in” is preferred for EHV lines to avoid a zero voltage condition equivalent to a three-phase fault.
  - Circuit breaker out-of-step tripping capabilities should be verified.
  - Possible out-of-step-tripping should be modeled or monitored in dynamic simulation.

Measures to be Implemented in the Medium Time Frame

- Improve reactive power compensation in the South and Southeastern systems by installing series and/or shunt capacitors
  - Additional switchable shunt capacitor banks should be considered to increase reactive power reserves of generators, condensers and SVCs
- Implement a system wide emergency control plan based on wide applications of SPS
  - Should be implemented to prevent system collapse following multiple contingencies
  - It may be called upon to respond to lower contingency levels until a permanent fix is implemented
- Improve the stability of the North and Northeast systems by proper analysis and installation of stabilizing measures

Measures to be Implemented in the Medium Time Frame

- Modernize the excitation systems of the critical power plants at or close to the load centers especially
  - Henry Borden
  - Luiz Carlos Barreto
  - Porto Colômbia
- Implement a system wide time synchronous monitoring and data logging system to capture valuable information for assessing the system performance on a continuous basis
- Implement an operator training and certification strategy
  - Implementation of Operator Training Simulators
- Review on-load switching capability of EHV shunt reactors
  - Switching devices may improve emergency operation and restoration following a blackout

Measures to be Implemented in the Medium Time Frame

- On-line, near real-time analysis capability should be developed
  - Implement a reactive power reserve monitor at control centers to improve voltage security
  - Implement computational tools to enhance the ability of the system operators to assess the system capability in or near real time
  - The first and most difficult step is working state estimation/on-line power flow
  - Thousands or tens of thousands of “debugged” SCADA measurements and status indicators are required

General Consideration for the Long Term

- The load growth is expected to consume most of the remaining margins within the next few years
- SPS could serve securing the system on temporary basis
- Network reinforcements using hard measures must be planned and implemented

Measures to be Implemented in the Long Time Frame

- **Rearrange** the substations further to improve the operating reliability
  - By making changes to the physical layout to employ breaker-and-one-half bus configurations
    - » Bauru
    - » Cabreúva
    - » Ilha Solteira
    - » Jupiá
    - » and others...
- Further improve the on-line, near real-time analysis capability
  - New technologies such as substation automation, synchronized digital positive sequence phasor measurements, fiber optic communication, and cellular and low earth orbit satellite communication may facilitate the measurements.

Measures to be Implemented in the Long Time Frame

- Reinforce EHV transmission to the São Paulo and Rio de Janeiro load centers
- Consider the strengthening the interconnection between the Southeastern and the South Systems
- Consider the strengthening the transmission within the Southeastern system to:
  - remove the critical bottlenecks
  - reduce the burden on the SPS
  - improve the performance of the North-South interconnection
- Consider that insertion breaker resistors proved to be unreliable and should be phased out if possible
  - This will require a review of the system response to switching actions and may have to be substituted by other means of surge suppression