Quanta Technology

Blackouts and Defense Systems

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Blackouts
Blackouts

Contents

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  – Blackouts in the USA
  – Italy

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Ingredients for Blackouts

Sequence of **low probability** events difficult to accurately predict

**Multiple contingencies** at various locations

Operators cannot act fast enough for a fast developing disturbances

- Low level of investment in recent years
- **Not in my backyard syndrome!**
  - Lack of reactive power reserves
- New ways the grid is being used.
  - Tight operating margins with less redundancy
Before we Start…

**Common Threads Between Recent Blackouts**

And what we learned from each one… *or maybe not?*
November 9, 1965: Northeast Blackout
The first “Big” Blackout in the US

- Load Loss: 20 GW
- Population affected: 30 M
- Duration: 13 h

- Affected areas: NY, CT, RI, parts of PA & NJ and Ontario,

Resulted in the formation of NERC
Resulted in a push for underfrequency load shedding

- Caused by backup protective relay operation on one of five 230-kV lines from a generating plant in Ontario.
- Remaining lines tripped in a total of 2.5 seconds.
- The resultant power swings resulted in a cascading outage.
- A 4 minute underfrequency conditions
July 13, 1977: New York City Blackout

- Load Loss: 6 GW
- Population affected: 9 M
- Duration: 26 h
- Affected areas: NYC

- Triggered by a lightning strike to a double circuit 345-kV line in Northern Westchester.
- Consolidated Edison system separated from surrounding systems and collapsed.
### December 22, 1982: West Coast Blackout

<table>
<thead>
<tr>
<th><strong>Load Loss:</strong> 13 GW</th>
<th><strong>Caused by a mechanical failure of a 500-kV transmission tower due to high winds which led to a mechanical cascade of two lines and contact with 230 kV lines.</strong></th>
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<tbody>
<tr>
<td><strong>Population affected:</strong> 5 M</td>
<td><strong>Problems with coordination of protective schemes were identified (generator tripping and separation schemes operated slowly or did not operate).</strong></td>
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<td><strong>Duration:</strong> several hours</td>
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<tr>
<td><strong>Affected areas:</strong> Many states in the West</td>
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July 2 and 3, 1996: West Coast Blackout
The “formal” introduction of transmission lines to trees!

- Load Loss: 11 GW
- Population affected: 2 M
- Duration: Several hours
- Affected areas: Several states in the West, Canada and Mexico

- July 2, caused by tree contact of a 345-kV transmission line in Idaho. Also action of a protective relay (zone 3) tripping a line incorrectly
- Nearly identical conditions for July 3, but was arrested by operator action shedding loads manually.
August 14, 2003 Blackout
The “Big” Blackout

- Load Loss: 28 GW
- Population affected: 50 M
- Duration: several hours
- Affected areas: Several states in the West, Canada and Mexico
- According to The Wall Street Journal, blackout cost New York City alone an estimated $1B.

- Failure to maintain adequate reactive power support
- Improper operation of Zone 3 relays
- Failure to ensure operation within secure limits
- Inadequate vegetation management
- Inadequate operator training
- Failure to identify emergency conditions and communicate that status to neighboring systems
- Inadequate regional-scale visibility over the bulk power system.

The August 14 2003 Blackout from Above

Source: NOAA
U.S. Northeast Heat Wave, July 6, 1999

A close call!

Source: PJM.com
A close Look at the Italian Blackout of 2003

A Nightmare for Every System Operator!
The “Approximate” Three Phases of the Event on September 28, 2003
Description of the Event

- Tripping of the tie lines to the UCTE created an extreme overload.
- The overload immediately caused an underfrequency which resulted in the tripping of about 2000 MW of generators on the sub-transmission system.
- Voltage collapsed in the north before the separation from France (due to increased reactive power demand and the separation in angle between Italy and the UCTE).
- Wide voltage and power swings.
- One minute out of step between Italy and net UCTE (Slovenian side).
Analysis Of The First Transient Phase

- Cascading outages of the tie lines
- Exceeded planning guidelines
- Different phenomena beating the grid:
  - Under excited operation of some generators due to light conditions
  - Extreme overload after the loss of ties
  - Voltage collapse before the ties to France tripped
  - Incipient out of step operation

The “Perfect Storm”

A system planner, and operator, nightmare!
Characteristics of the Third Phase of the Event

Load shedding steps & remaining generators capabilities are depleted

- Fast frequency collapse
- Large voltage and power transients
- Remaining plants trip when frequency reaches 47.5 HZ

The unavoidable system collapse
Reactive Power

*The Sleeping Giant*
Voltage Related Concerns Are on The Rise

- More and more electric utilities are facing voltage concerns, and hence imposed voltage limits.

- Voltage instability and collapse have resulted in several major system failures (blackouts) in the US and overseas.

- Reactive losses are on the rise due increased line and system loading.
Transmission lines can either absorb reactive power (under heavy loading conditions), or provide reactive power (under light loading conditions).
Reactive Power Sources and Sinks

- **Sinks**
- **Sources**
- ** Loads**
- **Generation**
- **Transmission Line Charging**
- **Capacitors**
- **Shunt Reactors**
- **Transmission Line Reactive losses**

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Effect of Tripping of Adjacent Lines
Conclusions.....
How to Prevent Blackouts

- Main idea: *Defense in Depth*
- Mandatory planning/operating standards based on best practices
- Tree trimming, real-time thermal ratings
- Control and protection upgrades (prioritized)
  - Transmission and power plant
  - Digital/optical
  - Example: Digital PSS allows higher gain for more damping
  - Example: single-pole switching adds defense in depth
- Modeling and simulation validation
- On-line security assessment
- Wide-Area monitoring and control (WAMS/WACS):
  - Example: Generator reactive power monitoring as part of EMS
Defense Plans
Contents of Defense Plans

- Definitions
- Classic Defense Plan
- Integrated Defense Plan Concept
Defense Plan

• The most rudimentary definition of a Defense Plan could be “the collection of steps that a utility can take during extreme emergencies to prevent system breakup and widespread blackouts”.
  – Basically it provides ride-thorugh capability for extreme emergencies.
Some Definitions

- **Stability**: the continuance of intact operation of the power system following a disturbance

- **Reliability**: the probability of satisfactory operation over the long run
  - denotes the ability to supply adequate electric service on a nearly continuous basis, with few interruptions over an extended period

- **Stability** and **security** are time-varying attributes; **Reliability** is a function of time-average performance
Power System Security

- **Security**: the degree of risk in the ability to survive imminent disturbances (contingencies) without interruption of customer service
  - depends on the operating condition and the contingent probability of a disturbance
- To be secure, the power system must:
  - be **stable** following a contingency, and
  - settle to operating conditions such that no physical constraints are violated
- The power system must also be secure against contingencies that would not be classified as stability problems, e.g. damage to equipment such as failure of a cable
Integrated Defense Plan

- Planning
- Operation (including Maintenance)
- Ride-Through
- Restoration
Integrated Defense Plan
Selected Elements

- Cyber Protection
- Voltage Optimization
- Load Curtailment
- UFLS UVLS
- Restoration
- Vegetation & Bird Control
- Special Protection Systems
Required Qualities of the IDP

• The IDP should provide a “ride-through” capability for:
  – Fast developing disturbances
  – The operations beyond design limits
  – Contingencies that stretch beyond the planning criteria
  – Multiple contingencies with complex interactions (with low probability of occurrence) which are difficult to predict or simulate accurately
Areas Covered

- Areas (existing and planned) which will be addressed by the IDP will be:
  - Substation Emergency Preparedness plans and philosophy
  - Special protection systems
  - Out-of-step protection
  - System margins
  - UFLS/UVLS
  - Islanding schemes
  - Sufficiency of control and real-time information from generators connected to the grid
Areas Covered

- Restoration plans
- Black start capability and certification of generators
  - Black start plans
  - Re-synchronisation procedures
- Training of system operators for severe contingencies
- Use of wide area measurements for the IDP
  - Communication requirements
  - Local vs. centralized schemes
  - Real-time measurements
IDP FACTS

• It would have to cover a number of existing (and planned) defensive systems against specific disturbances.

• The severity of a contingency is greatly influenced by system conditions at the time the contingency occurs, including:
  – Line loading
  – Generation patterns
  – Amount of generation reserve and its location relative to the area where the contingency originates
Steps to Assure System Security and Provide Reliable Electric Power

- The provisions made in **planning** the system to allow for contingency operation
- The **operator awareness/actions** to assure that the system does not reach a state where a predictable contingency could result in widespread outages
- The **automatic actions** that respond to extreme emergencies that could be envisioned
- **Coordination of protective** measures to limit the probability that unforeseen emergencies may result in cascade tripping until blackouts occur.
- **Provisions to restore** the system in case it does collapse.
- Continuing revision of the above plans in response to **changes in the network** and in the **technology** for measurement, control and protection.
Automatic Actions

- Planned actions to prepare the system to withstand severe contingencies and to minimize effects of extreme contingencies need to be updated as the system expands and as the technologies for control and protection change.

- Operator awareness of stressed grid conditions and proactive actions to prepare for critical contingencies can be as important (or even more) in minimizing their effect as the automatic protective actions during the contingency.
Special Protection Systems
Special Protection Schemes

- Wide area schemes to detect abnormal system conditions
- Pre-planned, automatic, and corrective actions based on system studies
- Restoration of acceptable performance
- NERC defined standards of acceptable SPS Performance

Most Common SPS Types

Source: IEEE PSRC, WG C6 report
Use of Special Protection Systems

• A special protection system solution should only be considered when other operating procedures cannot solve the problem (or substantially more expensive, or longer to implement).

• Some US utilities prefer to avoid the use of special protection system except as a short term measure to meet reliability requirements.

SPS’s should also be always reviewed for relevance and need.
Philosophy of Special Protection System
Sample Attributes

• Simple overall design
• Operators at its heart (to the extent possible)
• All automatic measures should be simple and reliable
• System security should not be compromised
• Automatic remote load shedding must be minimized
• Preferably based on the detection of local variables and perform actions locally

It must be considered as a continuous process
It will never be concluded! But refined!
Coordination of the Various Defensive Actions

- It is necessary for each measure to have clearly defined tasks to perform, given the many situations and system behaviors that could occur.
- Each system must be able to act on its own inputs, and the combination of actions should make it possible to preserve the power system’s stability.

It should not be assumed that different measures are independent from each.
Stages of Dealing with System Emergencies

• The first stage is localization and elimination of a primary disturbance to avoid undesirable development of the emergency situation.
  – Involves relay protection and generation excitation, etc.
• The second stage deals with survivability of the system.
  – Ability of a system to ride through/resist the disturbances
  – Not to allow their cascade development and mass interruption of the electric power supply
• The third stage deals with the system restoration, assuming some part of the system has collapsed

The aim of this document is to handle the last two stages.
Studies Needed for Special Protection System Applications

Studies needed *before* and *after* installation.
Planning Studies for the SPS

- Studies should support the need of the SPS.
- It is not adequate to only analyze the SPS against historical events, but it is recommended that SPS be evaluated for all possible system configurations.
- Any significant problems identified in studies need to be avoided, first by operating procedures, then by an SPS.

- By product of the studies: identification of significant problems w or w/o an SPS.
- Any issues identified in the studies must be resolved prior to beginning the specific SPS design.

- The SPS system should not be operated in an un-studied configuration.
Planning Studies for the SPS - Continued

- Identification of the critical contingencies and disturbances for which the SPS would be needed
  - Generator patterns, Transmission line loadings, Load patterns, Reactive power reserves
- Identification of actions and grid locations that are most effective for the SPS
- Deciding on the maximum time available for the SPS to operate
- Setting bounds within which the SPS must operate
  - The location and number of elements required for the SPS to operate successfully
- Identification of the effects of the SPS misoperations
SPS Design Studies

• Identification/selection of the initiating or "trigger" signal(s)
• Assessment of the trigger signals for both dependability and security
• Finalizing the arming criteria
• Finalizing the SPS logic and the algorithms
• Finalizing the SPS communication requirements and communication links between remote sites.
• Specification of any margins to cover system modeling and instrumentation inaccuracies
Highly recommended

Studies need to be periodically performed if:
- Major components or system configurations are implemented
- SPS input (or output) locations are added or removed
- The SPS functionality changes
- Significant modifications are made to the SPS

It is always recommended to keep evaluating the need of the SPS, and possibly retiring them if they are not needed, since they are a reliability concern, no matter how well designed they are.
SPS Failure Modes

• **Undesirable operations**
  – Unintended, due to a hardware, software, or human error.
  – Intended according to the design, but still undesirable due to a flaw in the design logic (perhaps due to lack of detail in studies design studies)

• **SPS failure to operate**
  – Due to hardware failure, faulty design, software failure (e.g., faulty vendor written embedded, applications).
  – Problems associated with construction, operation, or maintenance of the SPS.
Activation Times of the Special Protection Systems
Effect Of Special Protection Systems Not Operating When Required
Underfrequency Load Shedding
Comparison of Actual UFLS Systems
Cyber Security
Cyber Security

• A survey of 100 information security professionals at U.S. electric companies found that more than half of respondents handle some 150 serious cyber attacks each week and two-thirds responded to at least 75 attempted intrusions per week on corporate systems.

• The vulnerability from a cyber attack increases as the power grids are run with tighter tolerances (less safety margin).
Cyber Security

• Requires a new way of looking at risk and vulnerability to the system, taking into account the potential for simultaneous impact to many grid assets across the system.

• At risk are:
  – Real time platforms used in the operation of the power grid
  – Communication and tele-tripping systems
  – Centralized processing and control, especially those which constitute single points of failure
  – Distributed platforms that perform operations concurrently, but can be accessed remotely.
Need of UVLS
Why UVLS

- UVLS has been successfully deployed in many systems throughout the world to protect local systems from voltage collapse.
- For low probability events and extreme contingencies, UVLS may be the most economical solution in preventing voltage collapse.
- UVLS is usually NOT helpful for mitigating transient instability
Goals of UVLS

• Automatic load-shedding measures are designed into the power system, because shedding some load in a controlled fashion is preferable to the uncontrollable loss of a large amount of load.

• The goals of a ULVS scheme are the following:
  – Shed load in order to restore reactive power relative to demand
  – Prevent voltage collapse
  – Contain a voltage problem within a local area rather than allowing it to spread in geography and magnitude.
**UVLS as a “Safety Net”**

- UVLS: as a safety net
- Be utilized to reduce the severity of low probability and unforeseen events with high consequence events
  - Loss of an entire substation
  - Multiple co-incident loss of major transmission circuits
  - Loss of an entire power generating station
  - Should not affect the system transfer capability
UVLS vs. UFLS

- The concept of Safety Net is used in UFLS for outages that propagate into large system islands, and UFLS schemes may trip over 30% of customer load.

- While UFLS applies load tripping for problems involving large system islanding, UVLS uses load tripping to address reactive or VAR problems that are local.
Load Modeling

- Load models and their parameters are probably the most difficult and important representation data to obtain.
- For the voltage collapse time period, frequency sensitivity is not usually a concern, but load sensitivity to voltage and time are always important.
THANK YOU!

For Questions

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