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Power Grid Impacts Resulting From Unintentional Demand Response

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TCIPG Seminar Series on Technologies for a Resilient Power Grid
February 3, 2012

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We deliver solutions to America's most intractable problems in energy, national security and the environment. Through the power of our interdisciplinary teams, we advance science and technology to make the world a better place.

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Washington, D.C.

Energy Mission Business Area: Electricity Infrastructure

- Electric power systems expertise
- Research and development of tools for enhancing electric power system reliability, security, and operational effectiveness
- Electricity Infrastructure Operations Center (EIOC), a national research test bed
- Real-time wide-area situational awareness of the electric grid through an integrated measurement system
- Analysis of large-scale renewable integration to the existing grid
- Advanced information, networking, and cyber security for reliability management services

Outline

- Setting the context: power grid operational issues
- Setting the context: cyber security and the smart(er) grid
- Analyzing the power grid impacts resulting from unintentional demand response
- Recommendations and conclusions

Acknowledgements

- PNNL Colleagues (who did the work)
  - Harold Kirkham
  - Marcelo Elizondo
  - Shuai Lu
- DOE Sponsors (who made it possibe)
  - Hank Kenchington
  - Carol Hawk

Top 20 Engineering Achievements of the 20th Century

- According to the National Academy of Engineering, in their book “A Century of Innovation”

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

The North American Electric Power Grid

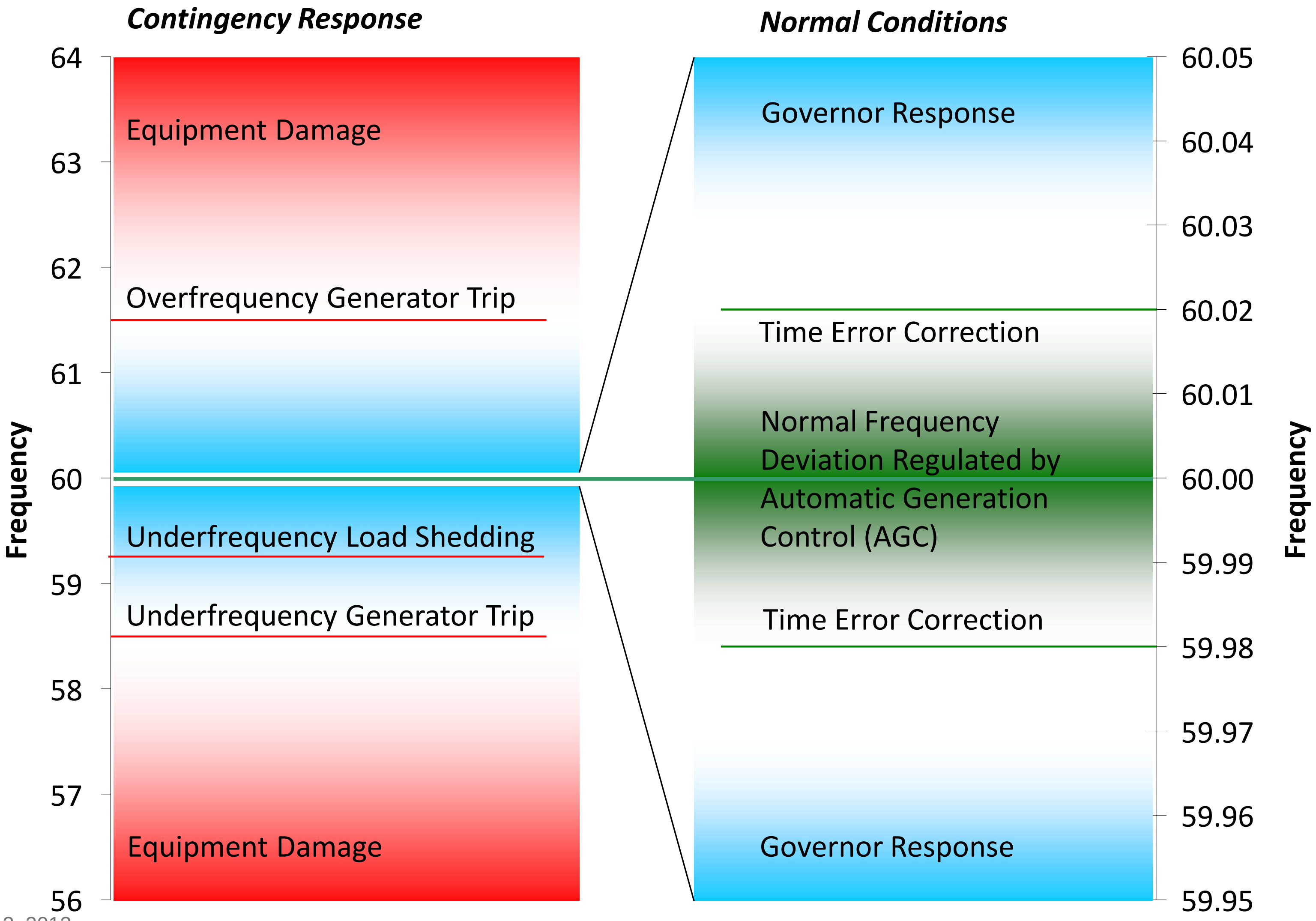
- The biggest machine!

Elements of Basic Control Strategy

- Centralized Control Center
  - Energy Management System (EMS)
  - Telemetry through supervisory control and data acquisition (SCADA)
  - Monitor flows and observe system limits
  - Balance generation and demand (dispatching)
  - Coordinate maintenance activities, emergency response functions
- Localized Controls (Power Plants, Substations)
  - Feedback controls (e.g., governors, voltage regulators)
  - Protection (e.g., protective relays, circuit breakers)
- Key Priorities:

1. Safety
2. Protect equipment from damage
3. Reliability
4. Economics

Frequency Regulation – An Excellent Example of Hybrid Centralized and Distributed Control



Basic Reliability Approach

- "The interconnected power system shall be operated at all times so that general system instability, uncontrolled separation, cascading outages, or voltage collapse will not occur as a result of any single contingency or multiple contingencies of sufficiently high likelihood."

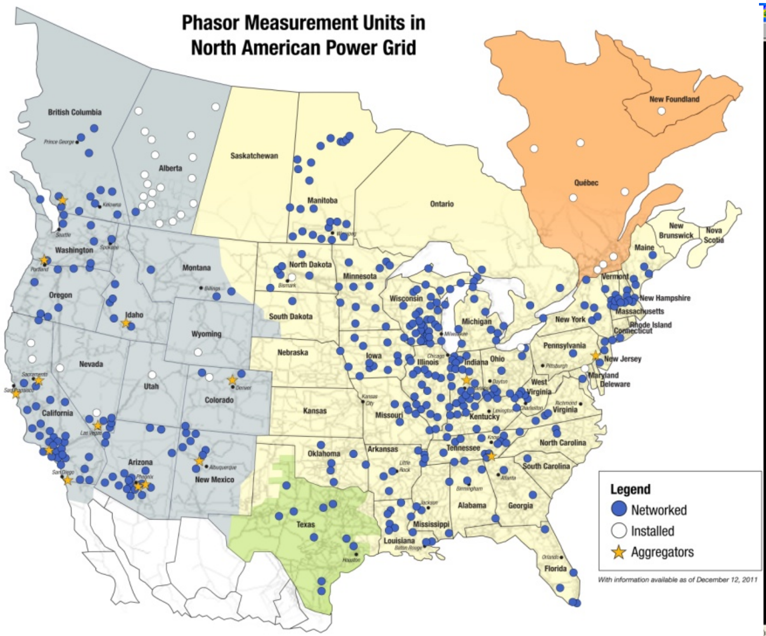
  WECC Minimum Operating Reliability Criteria
- Otherwise known as "N-1"
- Achieved by:
  - Generation having sufficient operating reserve, spinning reserve
  - Strict adherence to transfer capacity limits on the transmission grid
    - Determined through comprehensive planning studies
  - Operations discipline, detailed procedures, coordination
  - When all else fails, rely on emergency controls to limit cascading failure (e.g., under frequency load shedding)
  - If blackout occurs, implement restoration plans (e.g., "Black Start")

Historical Perspectives on Stability

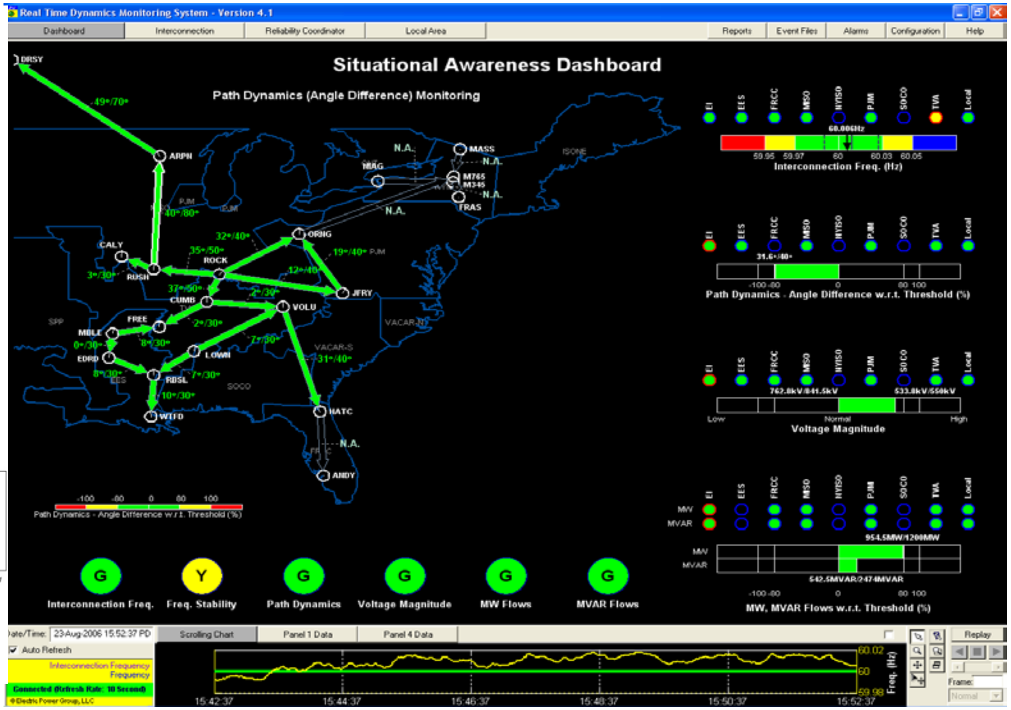
- Early stability problems associated with large power plants separated from metropolitan load centers
  - Papers on this topic published as early as 1920
- Complexity of stability problems increased as systems became interconnected, particularly through 1960s
- As some stability problems were solved with advanced technology, others were introduced
  - Example: fast-acting excitation to solve transient stability issues resulted in greater oscillatory instability
- Computational capability through 1970s-1980s greatly aided ability to study and analyze complex stability problems
  - Control theory, analytical tools, transient stability software
- Large-scale remedial action and special protection schemes introduced to increase interregional power transfer capabilities
- Introduction of wide area time synchronized measurements beginning in 1980s leading to better situational awareness capabilities

North American SynchroPhasor Initiative

DOE and NERC are working together closely with industry to enable wide area time-synchronized measurements that will enhance the reliability of the electric power grid through improved situational awareness and other applications


Phasor Measurement Units in North American Power Grid

With information available as of December 12, 2011



"Better information supports better - and faster - decisions."

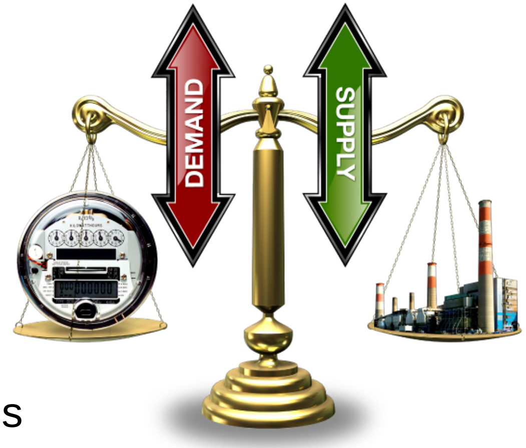
NASPI North American SynchroPhasor Initiative

Smart Grid Defined

- A smart grid uses digital technology to improve reliability, security, and efficiency of the electric system: from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources.
- The information networks that are transforming our economy in other areas are also being applied to applications for dynamic optimization of electric system operations, maintenance, and planning.

Smart Grid Vision

Bring digital intelligence & real-time communications to transform grid operations



- Demand-side resources participate with distribution equipment in system operation
  - Consumers engage to mitigate peak demand and price spikes
  - More throughput with existing assets reduces need for new assets
  - Enhances reliability by reducing disturbance impacts, local resources self-organize in response to contingencies
  - Provide demand-side ancillary services – supports wind integration
- The transmission and bulk generation resources get smarter too
  - Improve the timeliness, quality, and geographic scope of the operators' situational awareness and control
  - Better coordinate generation, balancing, reliability, and emergencies
  - Utilize high-performance computing, sophisticated sensors, and advanced coordination strategies

Smart Grid Cyber Security

- The same information and communication technologies that enhance the resilience of the power system may also present a new set of vulnerabilities relating to communications and information technologies associated with the control layer of the physical infrastructure
- If there are common modes of failure present in these control layers, there will necessarily be challenges to achieving full degrees of resilience in future smart grid deployments
- Because smart grid technologies transcend the scope of the FERC/NERC jurisdiction associated with the bulk electricity system, cannot rely on existing mandatory cyber security standards and requirements

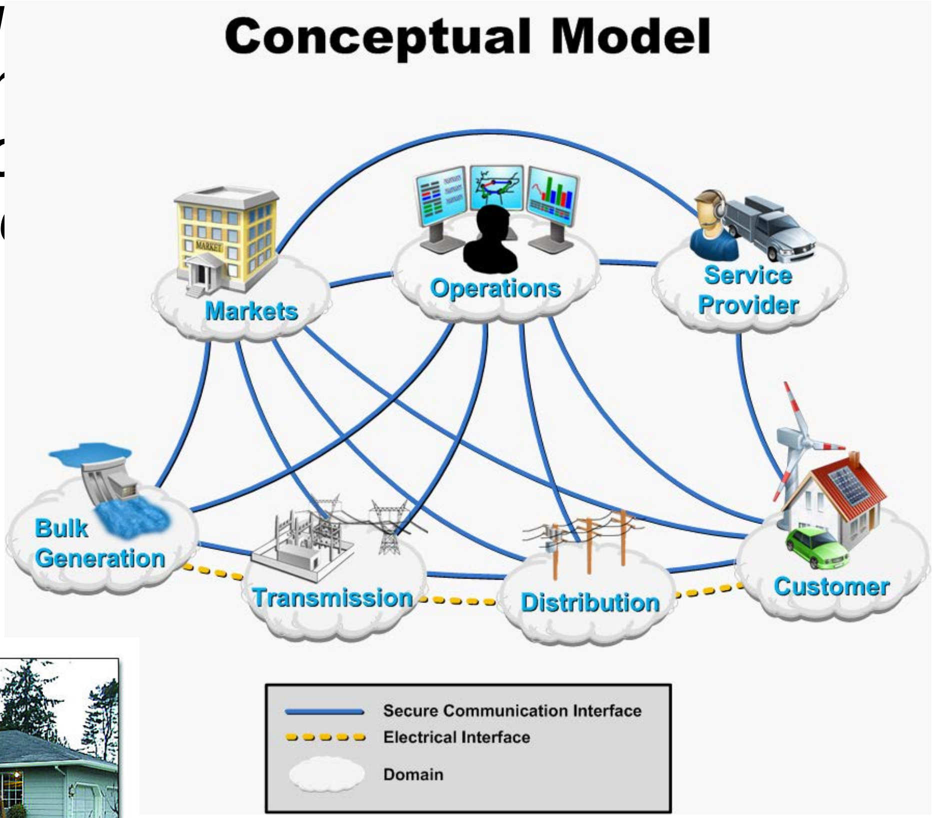
Cyber Security of ARRA Activities are *Critical* to Smart Grid Success

- Organized interagency group (DOE, NIST, FERC, DHS, others) for development of cyber security requirements in the funding opportunity announcement (FOA)
- Cyber security was a factor in evaluating the grant proposals
- Cyber security plans were required, and evaluated by a team of subject matter experts
- Site visits underway with all smart grid investment grant recipients to review cyber security plan implementation

> ***"DOE may not make an award to an otherwise meritorious application if that application cannot provide reasonable assurance that their approach to cyber security will prevent broad based systemic failures in the electric grid in the event of a cyber security breach."***
>
> **Smart Grid FOA**

www.ARRASmartGridCyber.net

*Provide a resource enabli
Smart Grid Investment Gr
and Demonstration Projec
to understand the baselin
principles and practices
necessary to implement
cyber security in the
deployment of smart grid
technologies*

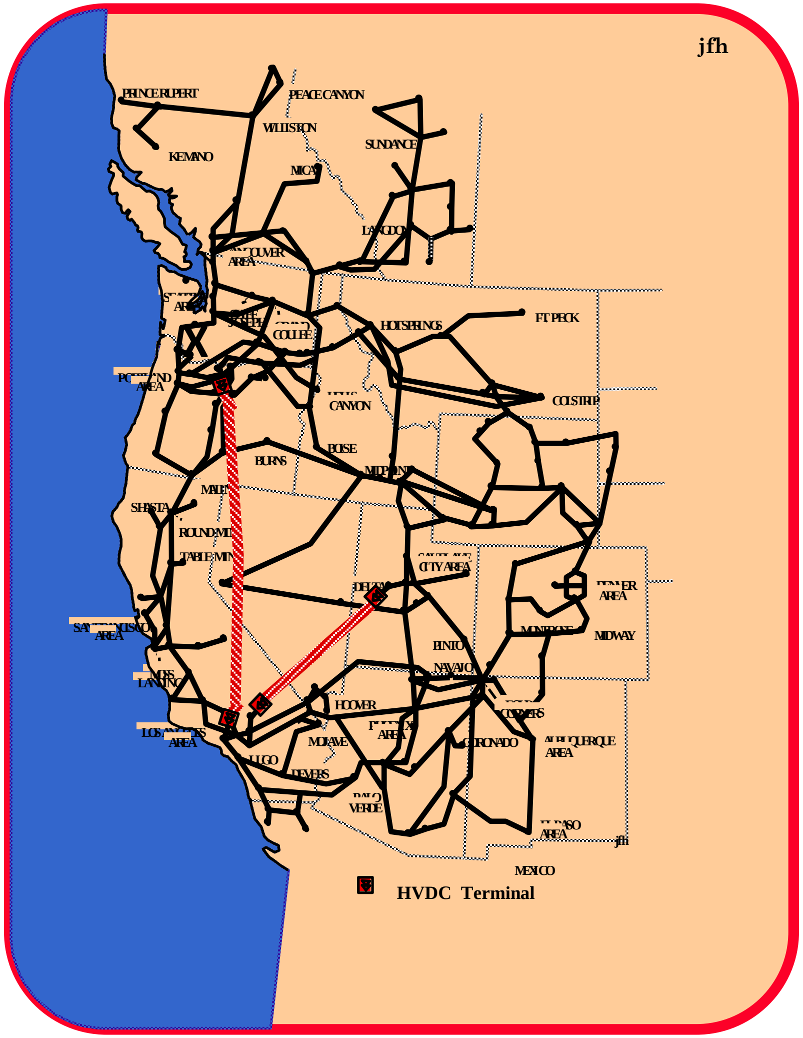


Final Interim Smart Grid Roadmap, prepared by the Electric Power Research Institute (EPRI) for the National Institute of Standards and Technology (NIST)

Analyzing the Power Grid Impacts Resulting From Unintentional Demand Response

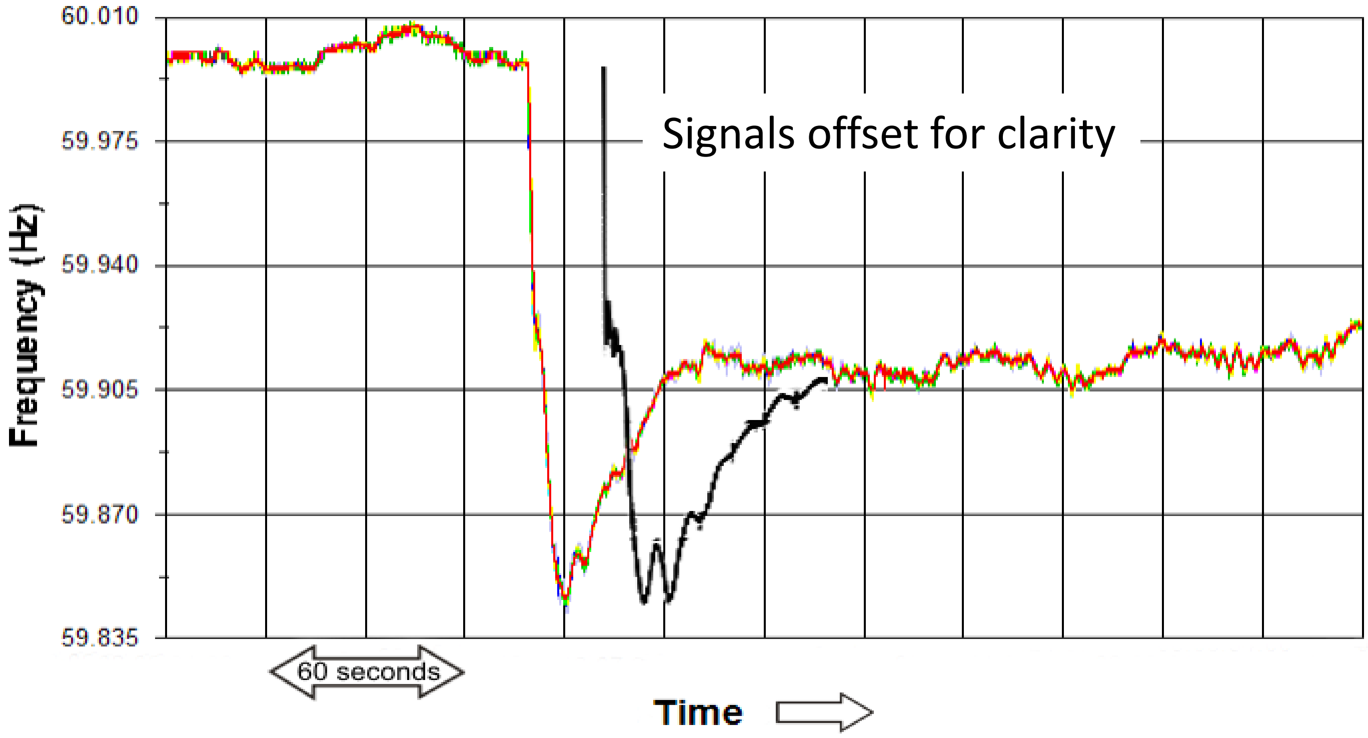
Model of the Western Interconnection

- WECC Summer Case
  - Buses 16,791
  - Branch Sections 14,524
  - Transformers 6,665
  - Generators 3,346
  - Loads 8,284
  - Shunts 1,279
  - Static VAR devices 973
  - DC buses 12
  - DC lines 9
  - DC converters 8
  - Areas 21
  - Zones 421
  - Owners 446
  - Generators 174,316 MW 23,517 MVAr
  - Loads 168,255 MW 31,591 MVAr
  - Losses 6,060 MW



Reality Check

Loss of major generator in WECC, actual and modeled

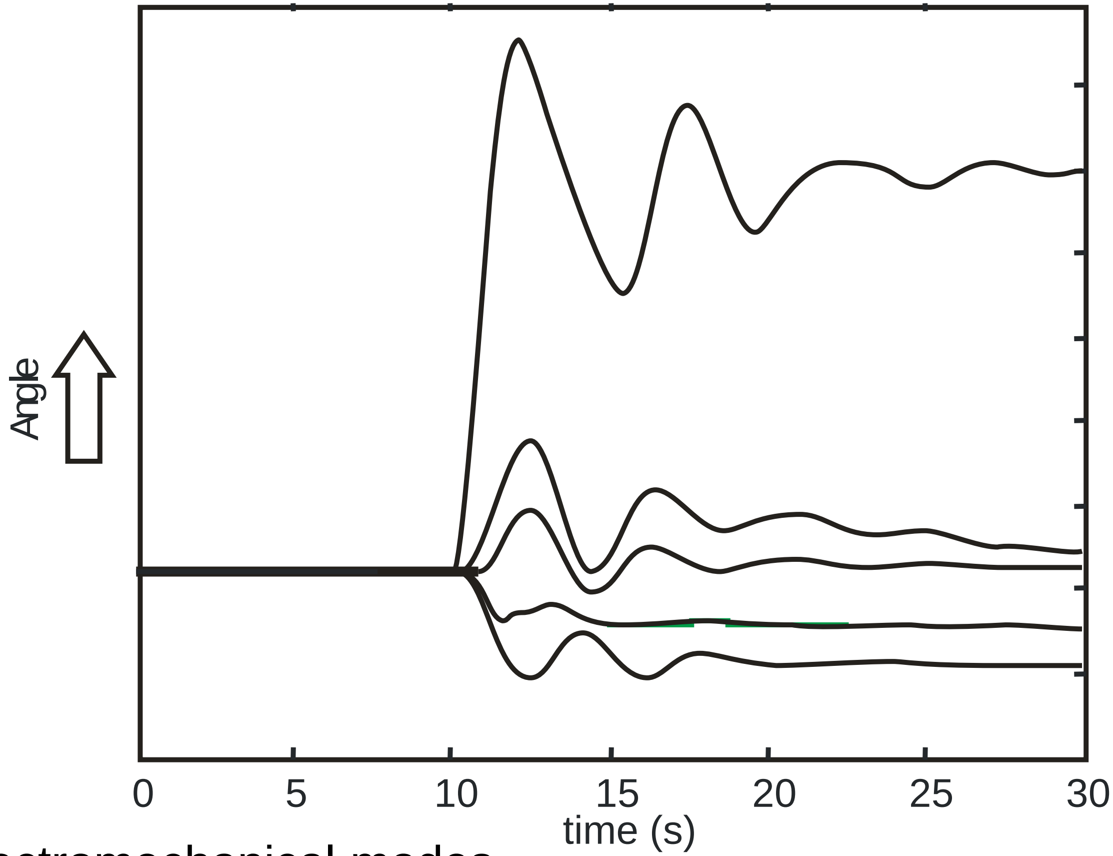


Study Methodology

- Analyze locational sensitivity of dropping load
- Find threshold at which power system stability is compromised
- Explore other means of creating stability impacts
  - Cyclic load manipulation to excite interarea modes of oscillation
  - Trying to trick voltage controls
- Repeat for a different WECC basecase (winter vs. summer)

Locational Sensitivity

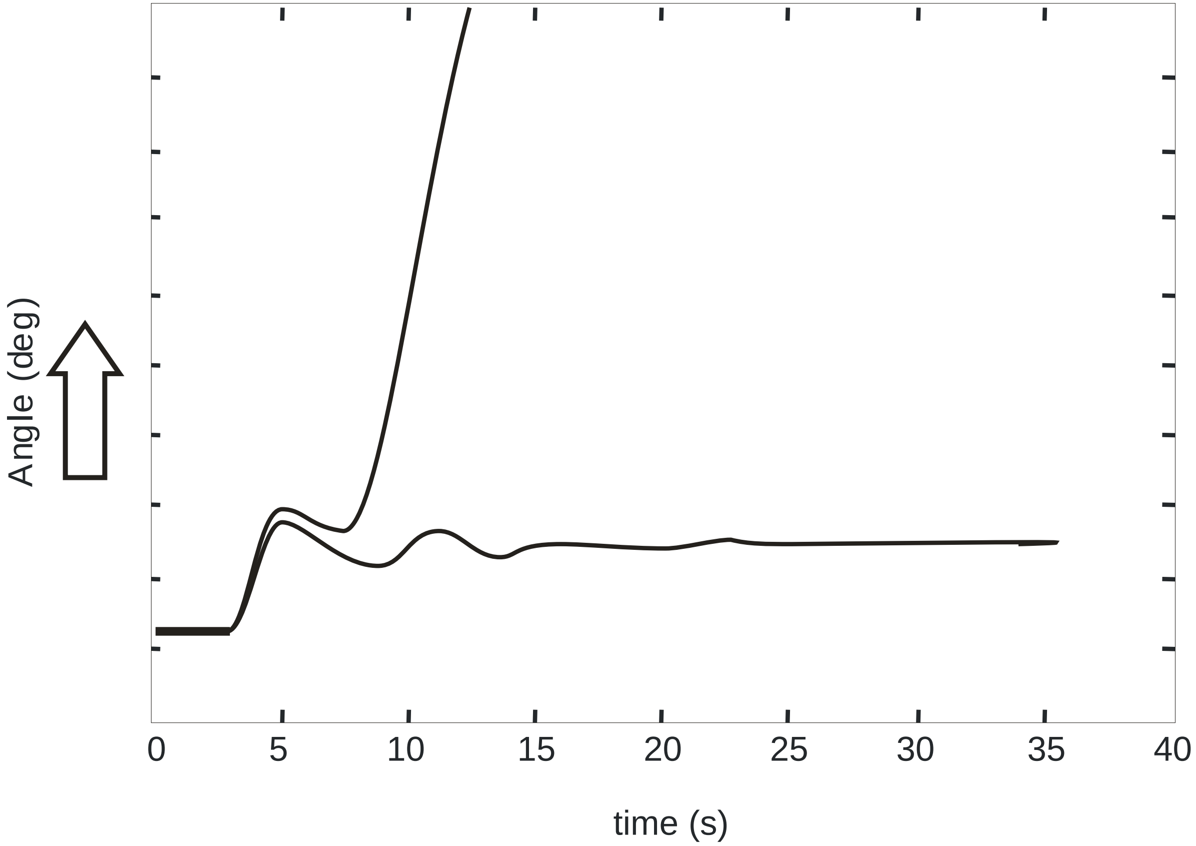
- Looking at the impact of the same amount of load shedding at various locations in the grid



Note that different electromechanical modes of oscillation are excited in different regions

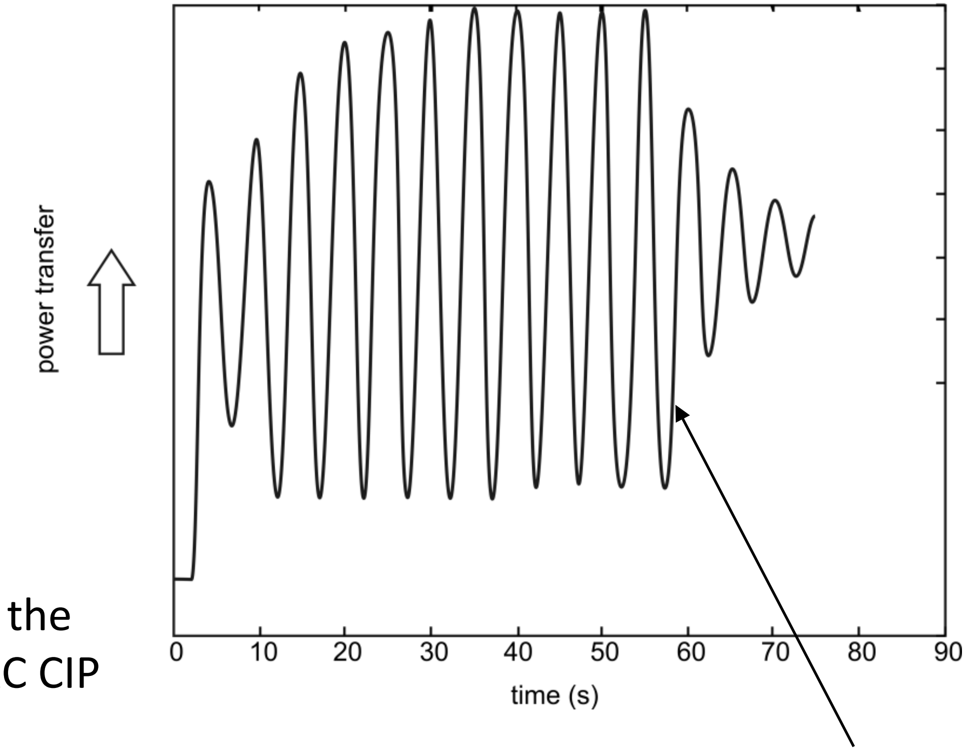
Threshold of Stability

- Increasingly large amount of load shedding until system instability is observed
  - The total load shed (focused in one region) is > 1500 MW
  - The difference between these two plots is 100 MW



Cyclic Load Manipulation

Effect of 300MW cyclic stimulus on inter-regional power transfer, tuned for maximum effect

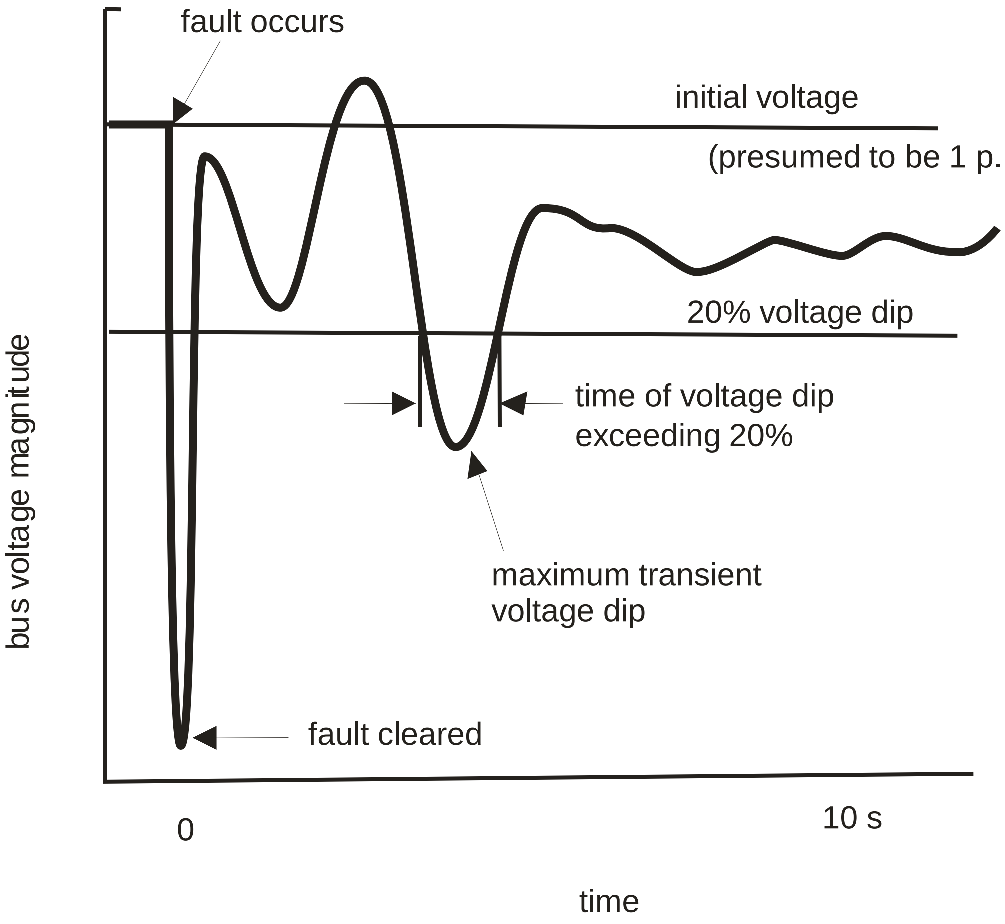


Note: 300 MW is the threshold for NERC CIP requirements

Damping acceptable, no long-term effect observed

Voltage Collapse Analysis

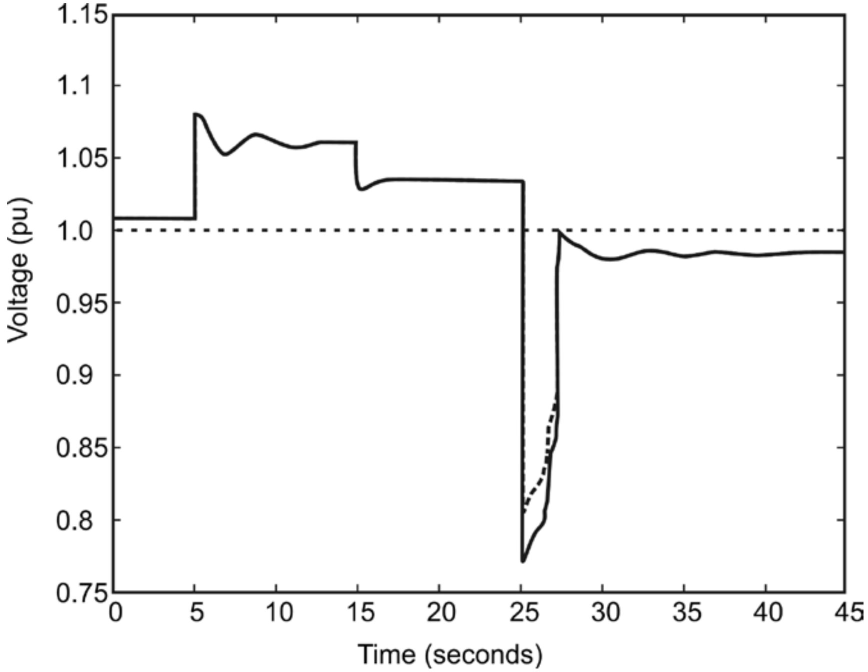
- WECC Disturbance Performance Standard on Bus Voltages



Voltage Scenario Results

- Shed load, allow voltage controls to re-stabilize at a new equilibrium, then restore the load
- Focused in an area known to have voltage stability concerns

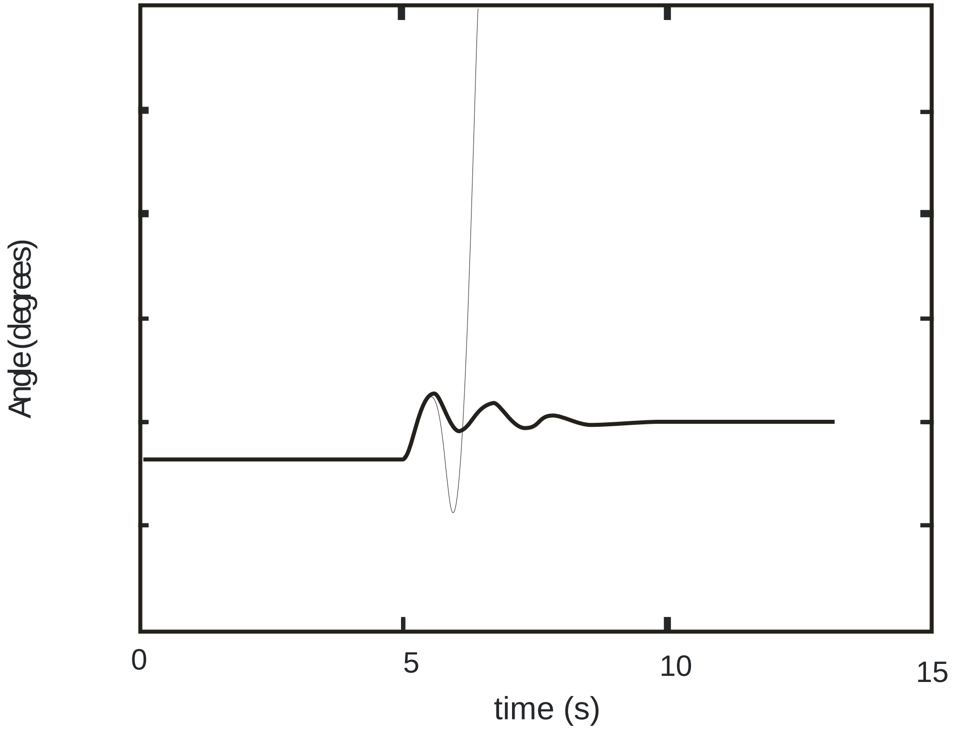
Voltage profile following simulated drop/restore sequence



Under-voltage relay timers start, but do not cause trip

Analysis Repeated for Winter Case

- General observation: significant differences from the summer case because of the different loading profiles, generally found to be more sensitive to uncommanded load shedding in different regions
  - The total load shed (focused in one region) is > 1000 MW
  - The difference between these two plots is 100 MW



Recommendations

- Now that it is becoming possible for large amounts of load to be simultaneously manipulated, it is important for utilities to consider this as a “credible contingency” in the context of planning and operational contingency analysis
- Measures should be taken to limit the amount of load that can be controlled from a single point of access (need segmentation, isolation)
  - This threshold needs to be designed through comprehensive contingency analysis studies
  - Envisioned to be uniquely specific for various regions and/or system conditions
- Cyber security measures to prevent malicious (or accidental) triggering of unintended load changes remains of paramount importance
  - Although our study indicated that the grid is relatively resilient to this method of attack

Concluding Remarks

- The power grid is exceptionally complex, and extraordinarily reliable
  - Most customer outages are due to issues with radial distribution feeders vs. the networked transmission grid
- Hierarchal control strategy provides good tradeoff between reliability and efficiency
- Blackouts provide good opportunity to study and apply lessons learned to further enhance reliability
- As advanced technology is being considered for deployment, need to consider unintended consequences (e.g., cyber security)
- Robustness and resiliency are enhanced by considering all threats to the power system
  - An “all-hazards” approach
- Historically little attention has been given to addressing multiple contingency scenarios
  - Need to consider cost-effective risk mitigation solutions

A Final Word on Resilient Infrastructure

- Resilience is the ability to reduce the magnitude and/or duration of disruptive events
- A resilient infrastructure can anticipate, absorb, adapt to, and/or rapidly recover from a disruptive event
- It is best when all-hazard “disruptive events” include the unenvisioned
- It is also important to be imaginative when considering possibilities

While our study concluded that the impact of unintended demand response was easier to cope with (from a grid stability standpoint) than unanticipated loss of generation, there nevertheless remains a need to be vigilant to prevent this technology from becoming an exploitable vulnerability in the future.