Stabilizing the Bulk Power System with a Combination of Virtual and Physical Batteries

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Introduction

- Power system is transitioning to renewable energy
  - Present use examples
    - MN consumes 370,000,000 Million BTU of fossil fuel-22,200,000 tons
    - Water Heating 1 ton of CO^2 /year/home
    - Space Heating 10 tons of CO^2 /year/home
  - Goal economical renewable energy
- Considerations of renewable energy
  - Fast moving fronts and stall create a mismatch of resources and loads
    - Example Polar Vortex
  - 75% of wind energy production is coincident with the heating season
  - Geographic diversity of renewable resources increases Capacity Credit and reduces aggregated volatility of renewable resources

Attributes of Battery Energy Storage

- **Operation Modes**
  - **Multiple partial discharges and recharges-continuous duty**
  - **One big deep discharge with 5-hour recharge and wait time for cooling for a 4-hour battery due to heat in the battery**
- **Limitations**
  - **Number of deep discharges degrades battery capacity and energy ratings over**
  - **Battery temperature is a monitored parameter to consider in dispatching the battery storage-warrantee issue-financing issue**
  - **Battery operated at midpoint and with margin on full charge and discharge-30 to 70% preferred operating range**
    - **Bias operating point to respond to energy needs and capacity-50% more capacity**

Attributes of Thermal Battery for Water Heater

- **Water Heater**
  - **Dual temperature thermostat – controlled to 130 degrees and switched to store energy to 165 degrees- provides 4.5 kw for one hour per 50-gallon heater**
  - **Fast-speed of switching in cycles**
  - **Unlimited switching events**
  - **Need to monitor temperature**
- **Operational parameters**
  - **Need fast two-way communications for dispatch of using temperature to calculate storage capability**
  - **Relay to switch**

Attributes of Thermal Battery for Space Heating

- **Attributes**
  - **Under slab hydronic tube, electric cable or ceramic brick**
  - **Dual temperature thermostat control**
  - **Rating 10-20 kw –daily recharge 10 hours**
    - **Example- store excess, low cost wind energy that would have been curtailed**
    - **Example- also fast switched without switching event limits**
  - **Heating load can be off for a day or more**
- **Operational parameters**
  - **Fast two-way communications with monitor of residual heat for remaining storage**
  - **Relay to switch**
  - **Rotational plans for concentrated load management**

Large Scale Uses for Storage

Uses of Storage Using Large Amounts of Energy

- **Sinking energy what would be curtailed to space heating, water heaters and battery storage is an economical use of storage**
- **Use of storage as a large dynamic brake or batteries for energy injections may be economic or for reliability uses for Distributed Storage**

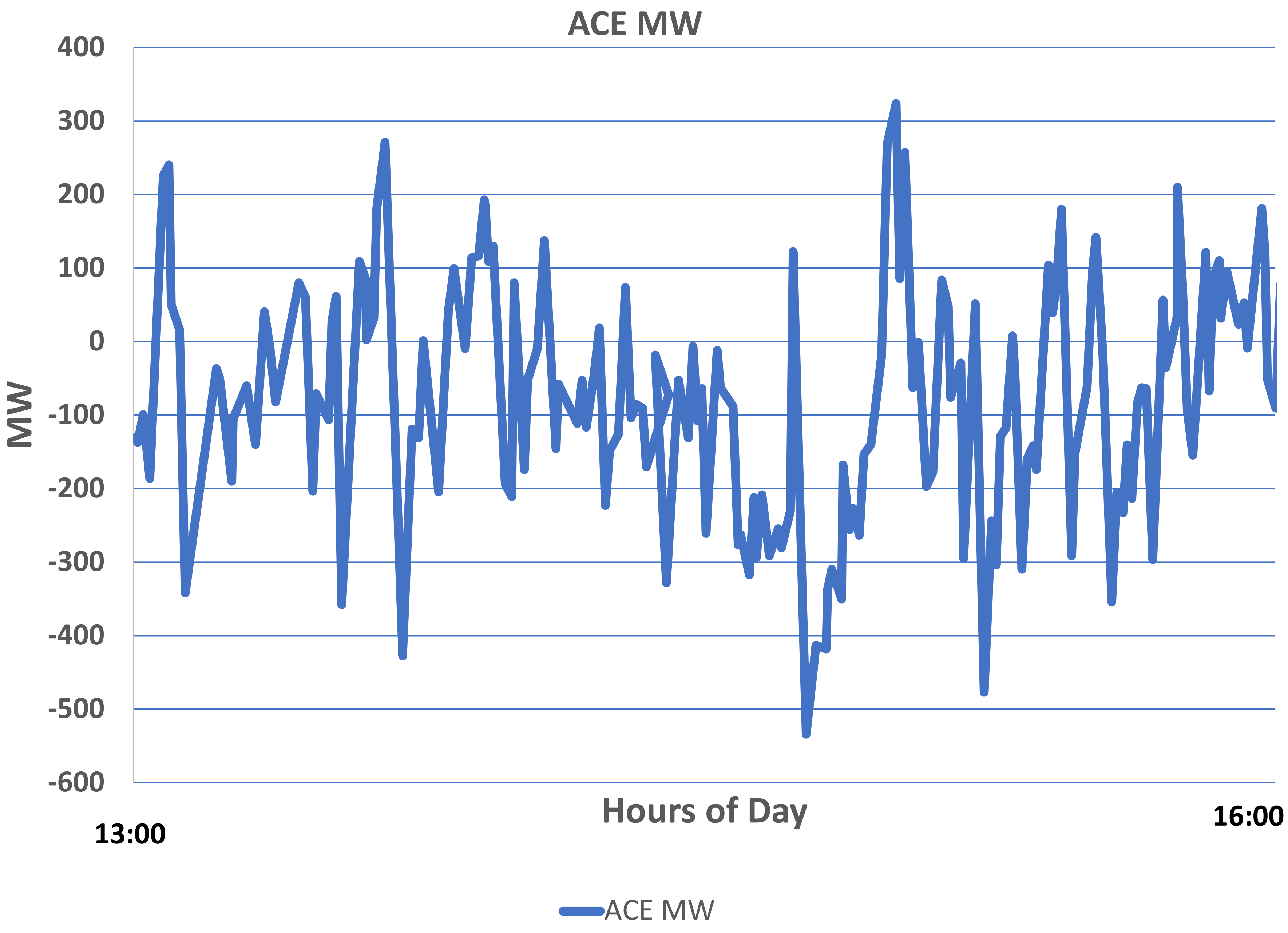
Uses for Energy Storage that is not Resource Adequacy Capacity

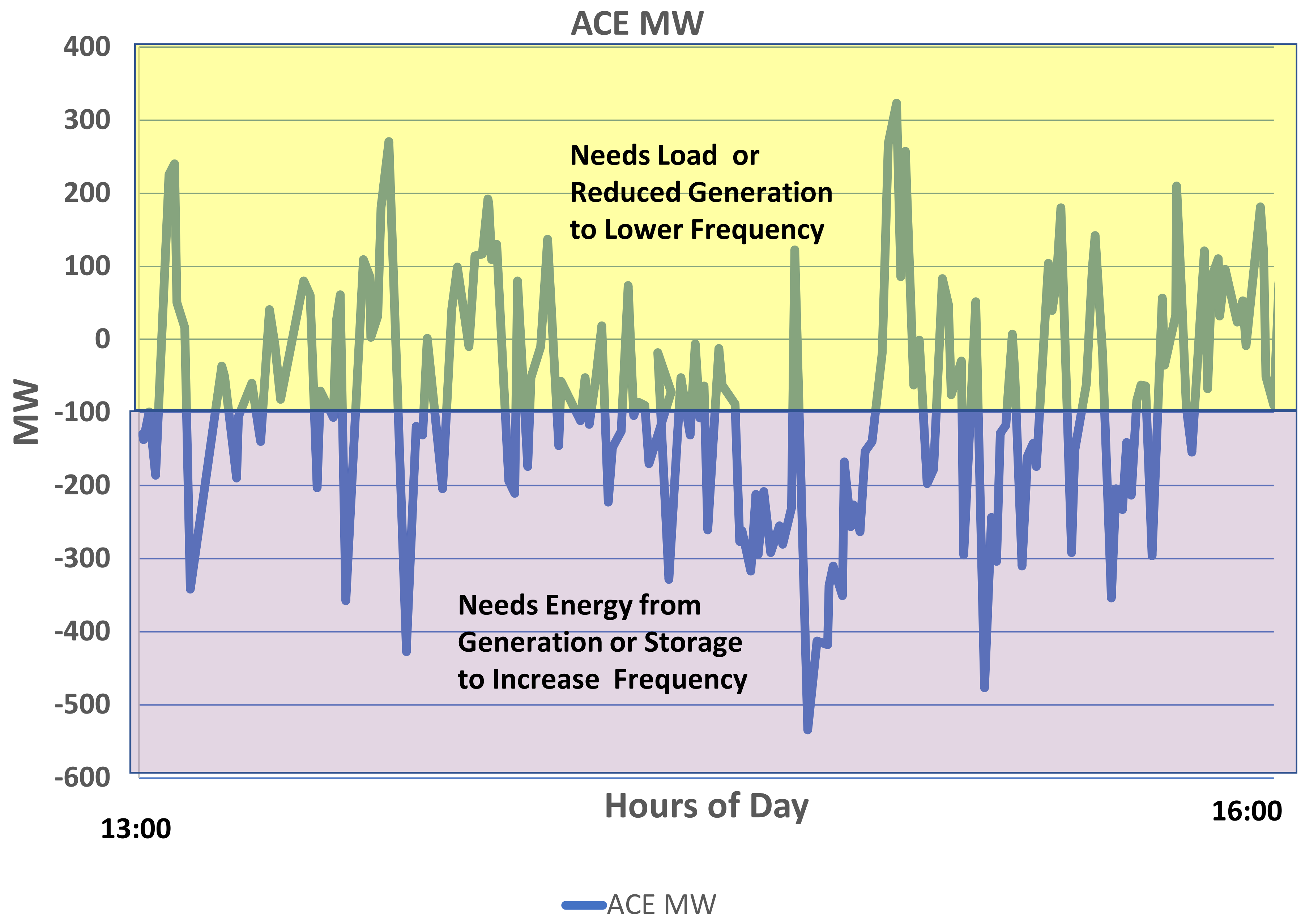
- **ACE to control frequency**
  - **Shovel and Broom-generators, battery systems, water heater and slab heating**
  - **Improve ACE response and reduce Reporting ACE for performance criteria per clock minute**
- **Generation Reserves for Frequency Response**
  - **Fast energy and capacity resource replaced by generation in ten minutes**
- **Power Oscillation Damping**
  - **Use with the Synchrophasor system, fast two way communications, strategically placed Synchophasor Monitoring Units.**
  - **Replace retiring Power System Stabilizers and Power Dampers from coal generators.**
- **Distributed Energy Storage using converters, substations and transmission with Renewable generation used for renewable generation.**
  - **Power System Stability improvement by using nearby storage to absorb accelerating energy and damping oscillations-higher power transfer capability on transmission.**

Bidding Into MISO

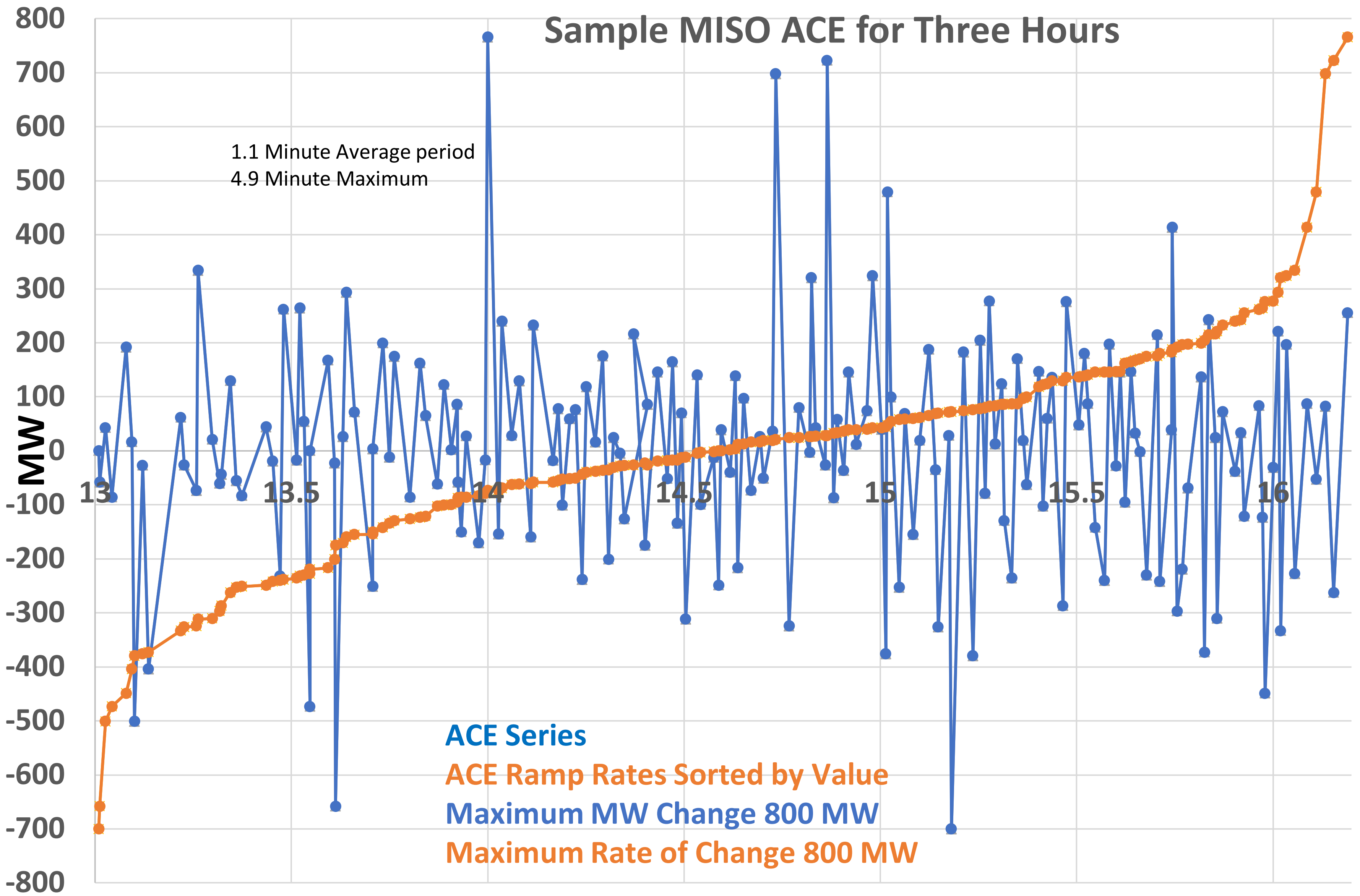
- **Aggregated storage in a utility bid to MISO-updated every 5 minutes**
  - **Battery**
    - **Capacity Available**
      - **Short term**
      - **Long term**
    - **Energy available**
      - **Short term**
      - **Long term**
    - **Rotation of resources managed by the utility arranging the bids**
  - **Thermal Battery**
    - **Capacity Available**
    - **Energy storage**
    - **Energy for long term storage-MISO supplies price curve to utility**
- **Fast Response Storage Resources should not be bid with generation**
  - **Can perform functions at speeds not attainable by generation**
  - **Should not need four hours of storage to have revenues for fast response uses-15 minutes may be sufficient**
  - **Obtain revenue for fast response capacity**
- **Storage management systems would be maintained by utilities for monitored parameters and state estimation**

USE of Storage for ACE Frequency Control


ACE MW
400
300
200
100
0
-100
-200
-300
-400
-500
-600
MW
Hours of Day
13:00
16:00
ACE MW

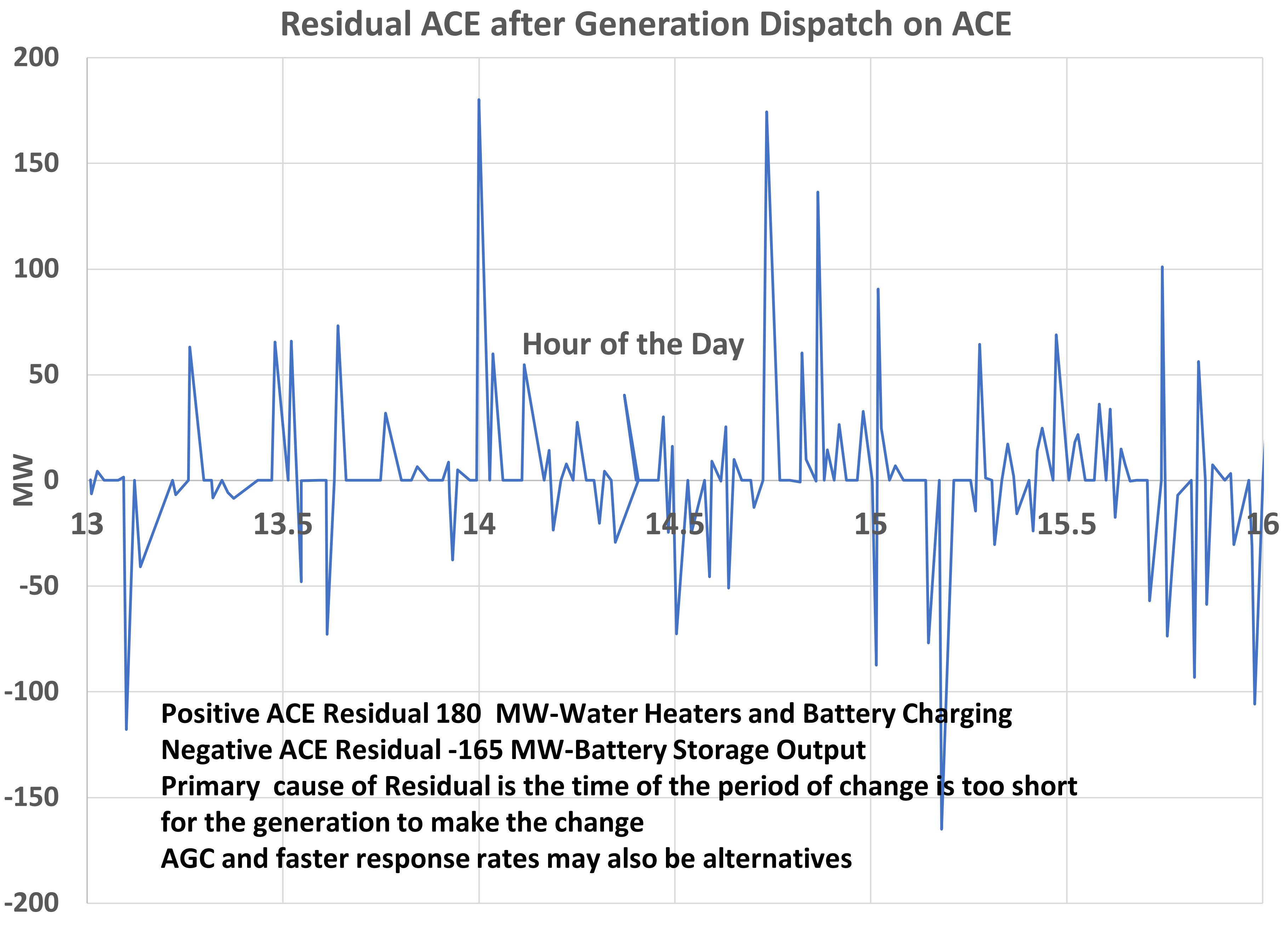


ACE MW
400
300
200
100
0
-100
-200
-300
-400
-500
-600
MW
Needs Load or
Reduced Generation
to Lower Frequency
Needs Energy from
Generation or Storage
to Increase Frequency
Hours of Day
13:00
16:00
ACE MW


Sample MISO ACE for Three Hours
1.1 Minute Average period
4.9 Minute Maximum
MW
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
13
13.5
14
14.5
15
15.5
16
ACE Series
ACE Ramp Rates Sorted by Value
Maximum MW Change 800 MW
Maximum Rate of Change 800 MW

Generator Model for ACE Supply

- **Rated to supply MW and Ramp rates in one minute from the sample data**
- **Errors occur when the time between samples is too short for the generation to supply the change in MW between the sample times**
- **No AGC adjustments included, but AGC and forecasting could be used to dispatch the fast water heater, slab heat and battery storage devices**
- **Fast two-way communication would be necessary to know the state of storage resources and monitor limiting paramers such as temperature and estimated stored or storable energy- faster than 4-6 seconds**


Residual ACE after Generation Dispatch on ACE
200
150
100
50
0
-50
-100
-150
-200
MW
13
13.5
14
14.5
15
15.5
16
Hour of the Day
Positive ACE Residual 180 MW-Water Heaters and Battery Charging
Negative ACE Residual -165 MW-Battery Storage Output
Primary cause of Residual is the time of the period of change is too short
for the generation to make the change
AGC and faster response rates may also be alternatives

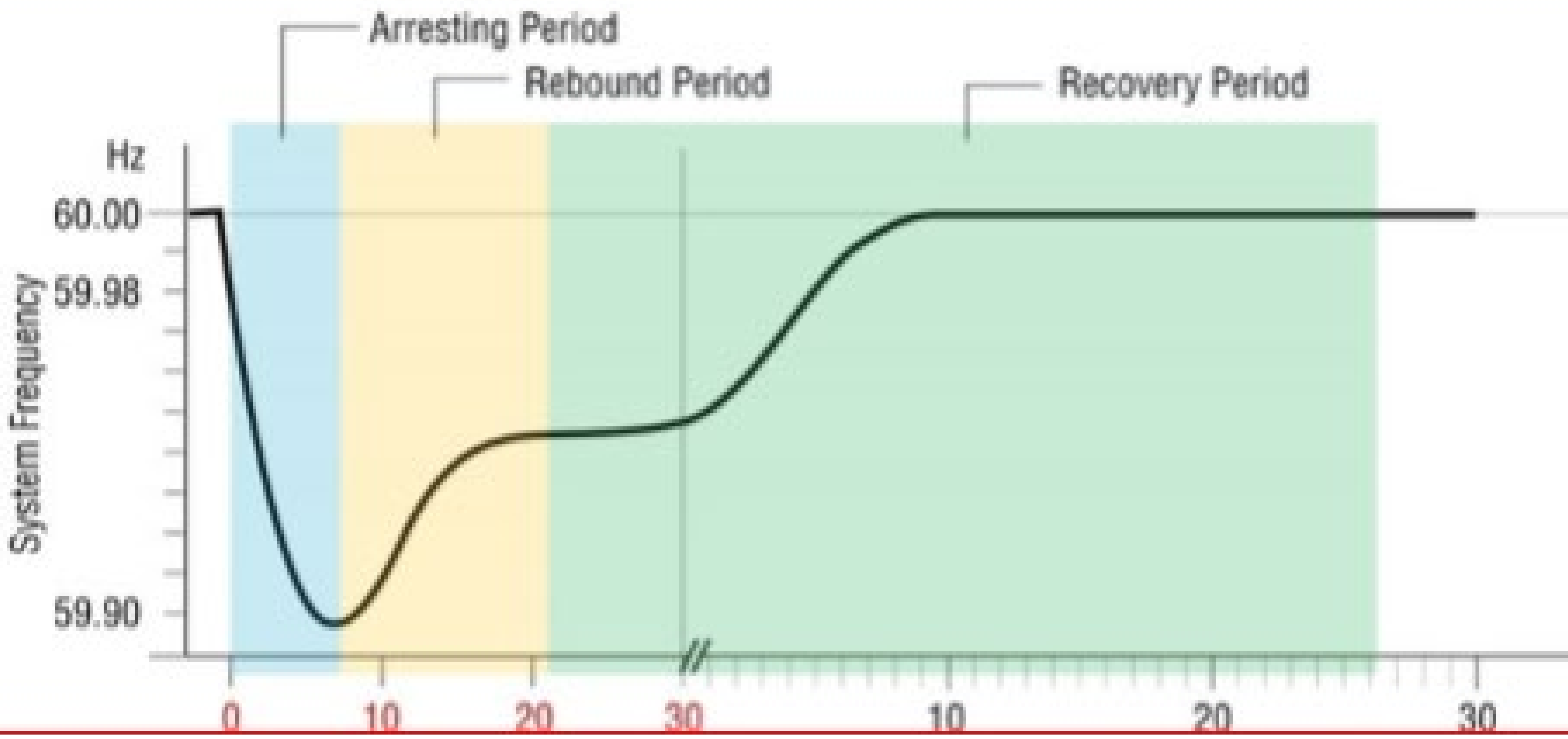
Capacity and Energy Rating for Stored Energy

- **Battery**
  - **165 MW**
  - **260 MWH per Day**
  - **49% Capacity Factor**
- **Water Heaters, Slab Heat, Battery Charging**
  - **180 MW**
  - **343 MWH Per Day**
  - **59% Capacity Factor**
- **Water Heater Potential-150,000 in Minnesota**
  - **675 MWH Available each day**
  - **Rotate the water heaters participating**

Storage Use for Frequency Response

Battery Storage for Frequency Response Reserve

- **840 MW Reserve for MISO**
- **About a 75% Capacity Factor for 10 minutes**
- **Probably would use a 15-minute rated battery**


Arresting Period
Rebound Period
Recovery Period
Hz
60.00
59.98
59.90
System Frequency
0
10
20
30
10
20
30

Battery Storage for Frequency Response

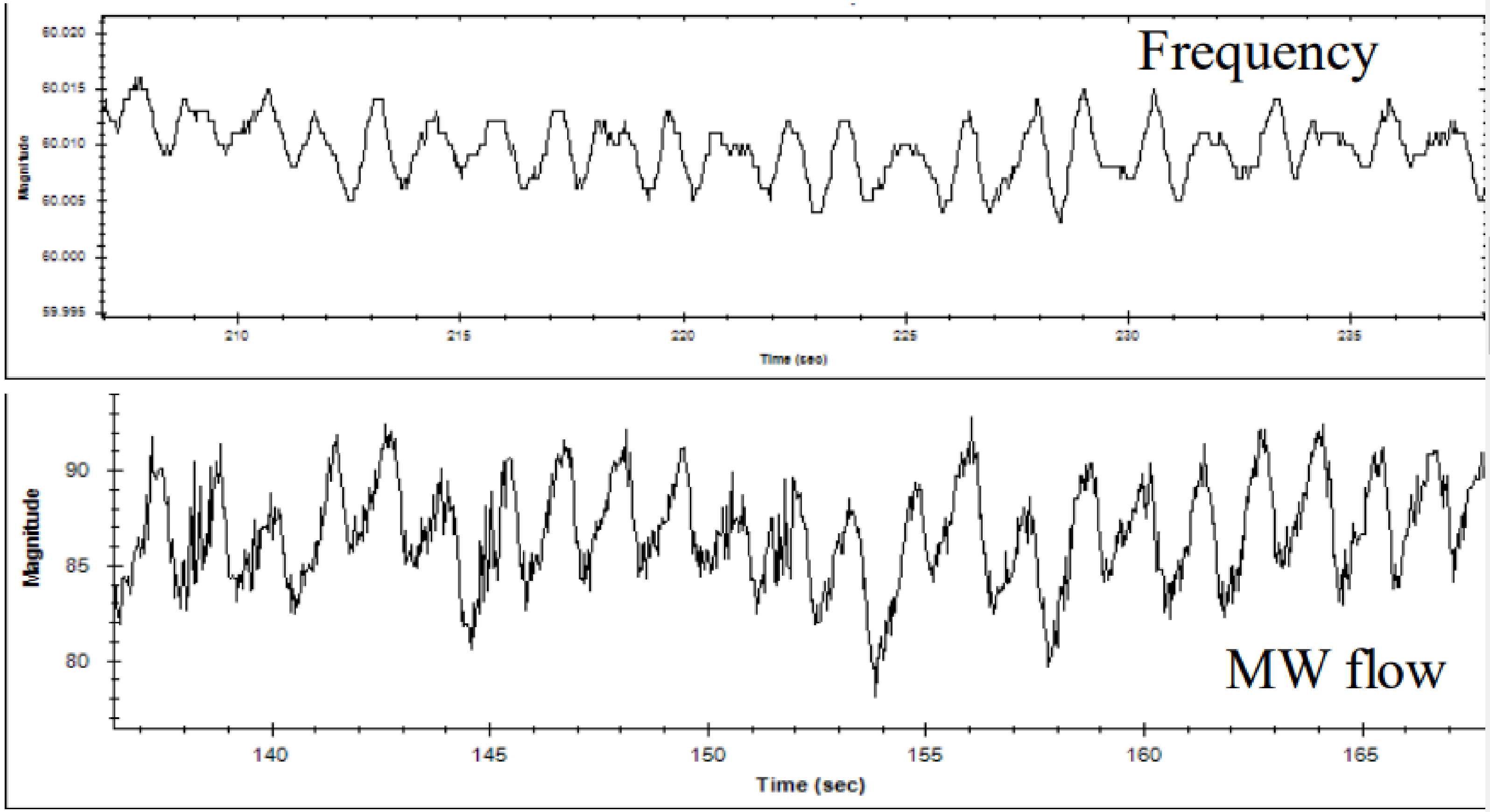
- **Part of the Spinning Reserve -840 MW for MISO from 1500 SR**
- **15-minute energy storage would allow the response of fast start generation and three cycles of dispatch displacing Spinning Reserve**
- **The traveling wave power disturbances from generation loss would be mitigated and the system would be less stressed-more reliable**
- **Four Hours of Storage for this use is over kill**
- **Thermal Storage and Controlled Battery Storage could mitigate power oscillations from the loss of generation events**

Power Oscillation Damping

Power Oscillation Damping and Stabilization

- **Coal plants have power system stabilizers to damp power oscillations**
- **Newer techniques allow dampers to respond to a large frequency range**
- **Synchrophasor networks are capable of providing information for damping systems**
  - **Fast-reliable communications is needed**
  - **Communications are faster than the Frequency signal**
    - **Frequency signals travel at 300 miles per second in the eastern part of the Eastern Interconnection and 1000 miles per second in the western part of the Eastern Interconnection. SynchroPhaser systems can detect and measure the traveling waves of Frequency oscillations.**
    - **Water heaters could absorb the traveling positive wave**
    - **Batteries could mitigate the negative wave**
    - **Wave frequencies are from .25 HZ or 2 second response**
- **Controls and the SynchroPhasor system could identify multiple power oscillations and damp them. Fixed tuned stabilizers are a thing of the past.**

0.73 Hz Forced Oscillation



10 MW oscillations visible in several MISO signals. Present throughout.

Distributed Storage

Method of multiple use of generation facilities to lower total cost of Storage

If Co-Located in Areas with Large Synchronous Generation, May Improve Stability Margins and Power Transfer Capability

Distributed Storage

- **Co-use of electronic power converters, transformers, control buildings, collector systems and transmission systems for solar, wind and battery storage canlower the cost of Distributed battery systems**
- **Applications with low energy demand may provide sufficient revenue to pay the incremental cost of adding battery storage to new combined use systems**
- **If the converters are of the Voltage Source Converter type distributed voltage regulation and black start capability are available for additional revenue. VSCs can operate without the wind or solar generation.**
- **If close enough to largeF synchronous generators with transmission faults, may improve stability margins of the generator and improve transmission power transfer capabilities.**
  - **Energy accelerating the generator could be removed from the area within 30 seconds and minimize first swing power angles of the generator-more reliable.**
  - **Use water heaters, space heating, battery storage and battery energy injection**

Questions?

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