Oscillations in Power Systems

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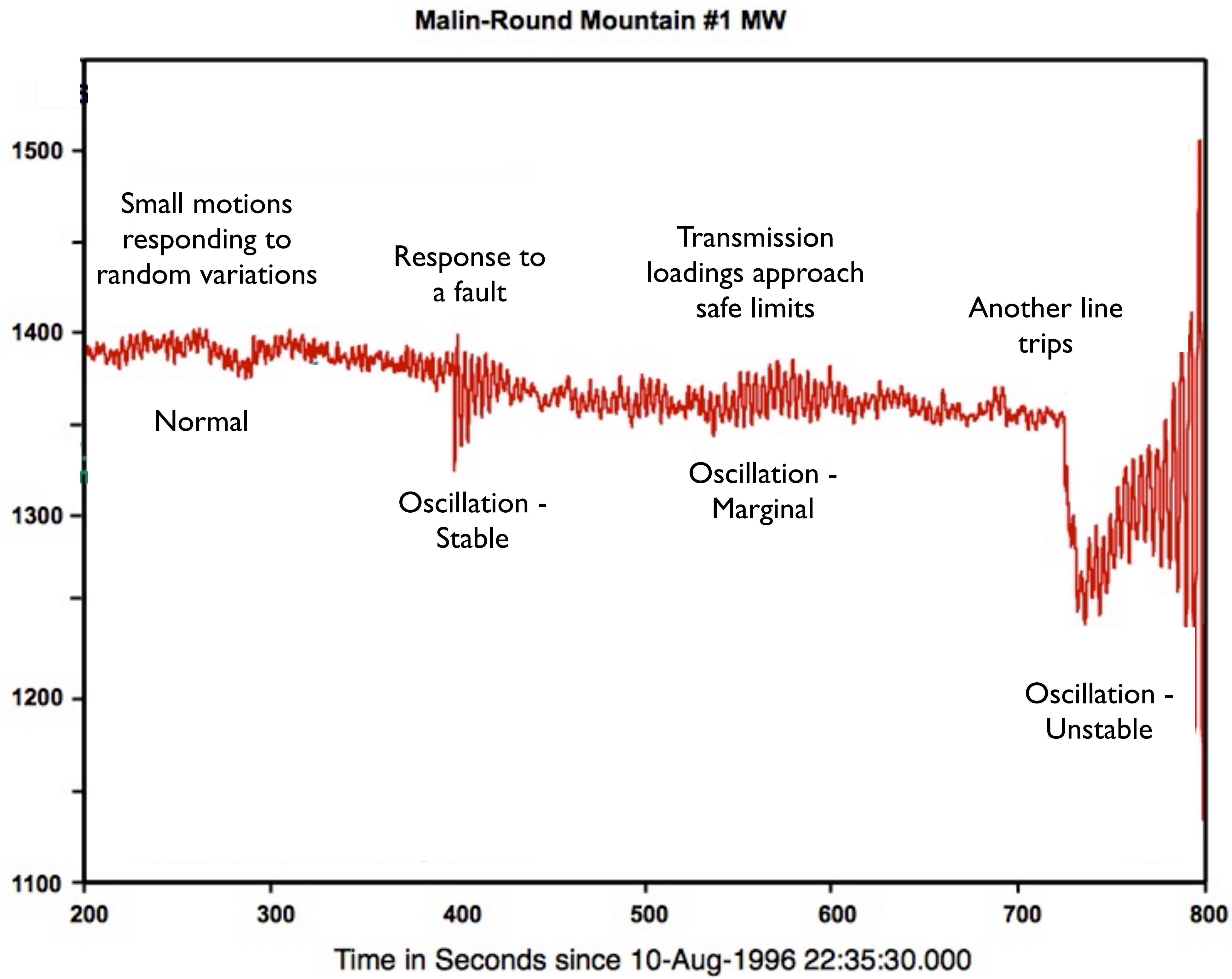
Oscillatory Behavior Is:

- Normal - always present
- Well damped in normal situations
- Mostly visible only to expert 'eye'
- Not a problem when the system is in 'as designed' conditions
- A real problem when system conditions approach operating limits
- A good indicator of an abnormal situation

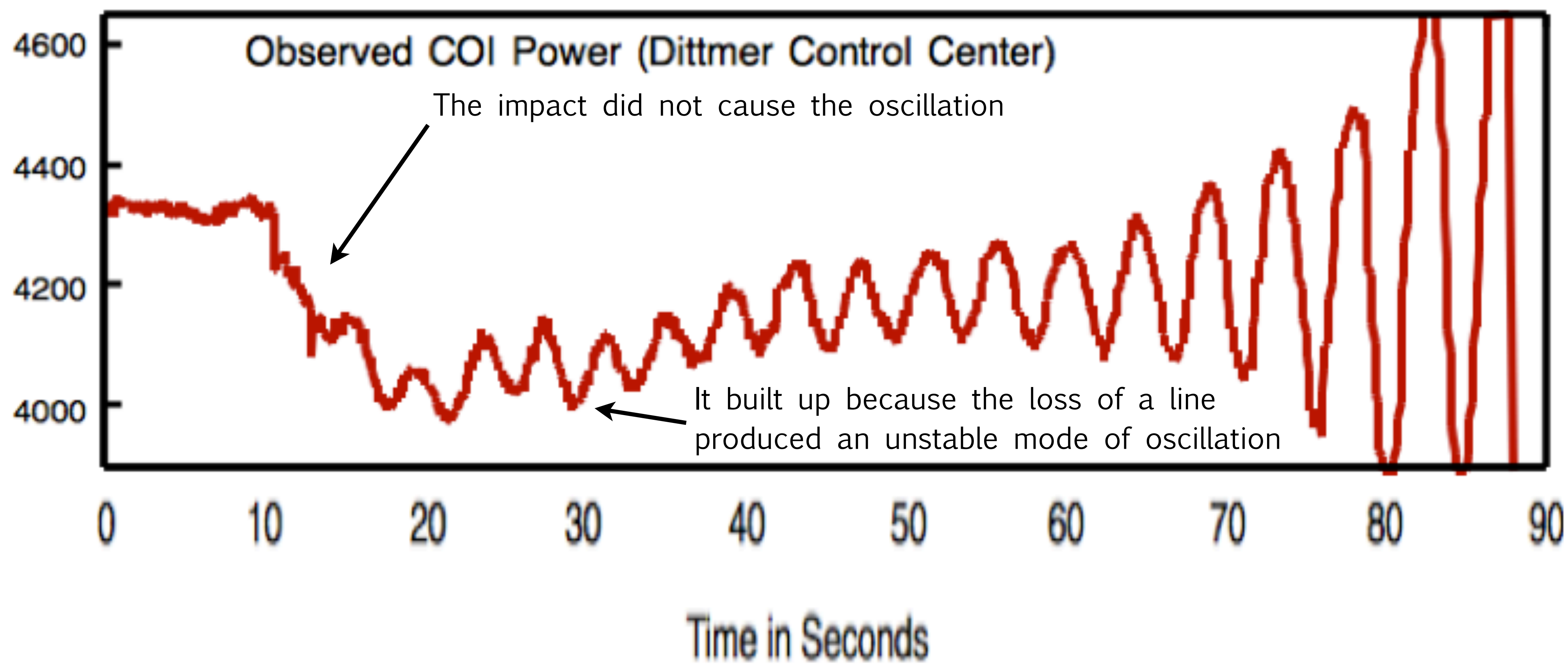
Modes of Oscillation

• Local rotor angle motions	1-2 Hz
• Controller responses	1-20 Hz
• Shaft torsional motions	5-40 Hz
Subsynchronous oscillations	40-5 Hz
• Inter-area power flow oscillations	0.2 - 0.5 Hz
• Boiler / turbine / draft tube	0.05 - .5 Hz


Malin-Round Mountain #1 MW
1500
1400
1300
1200
1100
200
300
400
500
600
700
800
Time in Seconds since 10-Aug-1996 22:35:30.000
Small motions responding to random variations
Normal
Response to a fault
Oscillation - Stable
Transmission loadings approach safe limits
Oscillation - Marginal
Another line trips
Oscillation - Unstable

Unstable Oscillation - Rotor Angle Motion

Caused by Excessive Flow on Interarea Transmission Path



Factors Aggravating Oscillatory Behavior

- In the power plant
  - Voltage regulator
  - Turbine shaft torsional motions
  - Turbine controls
  - Draft tube puslations

- In the transmission system
  - Excessive real power transfer
  - Unfavorable load characteristics - both voltage and frequency
  - Electronic transmission controls
    - DC, FACTS, Wind Power, Photovoltaic Power

- Special situations
  - Series capacitors - subsynchronous oscillations
  - Process issues - cyclic loads

Important Distinction

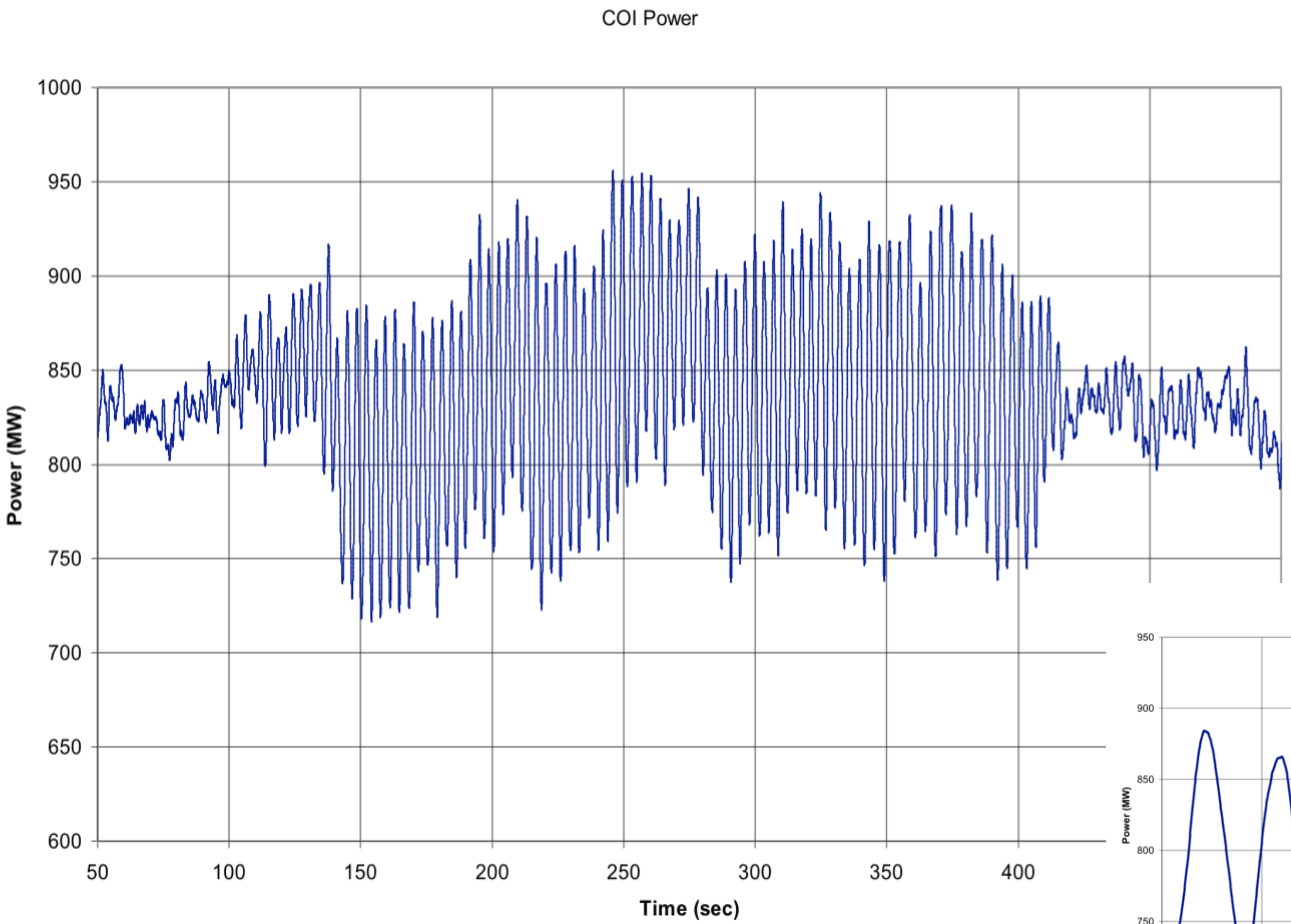
- System is **stable** but oscillates in response to a cyclic driving force
- Small driving force can produce a large response if frequency is close to a natural frequency
- Oscillation dies when driving force is removed

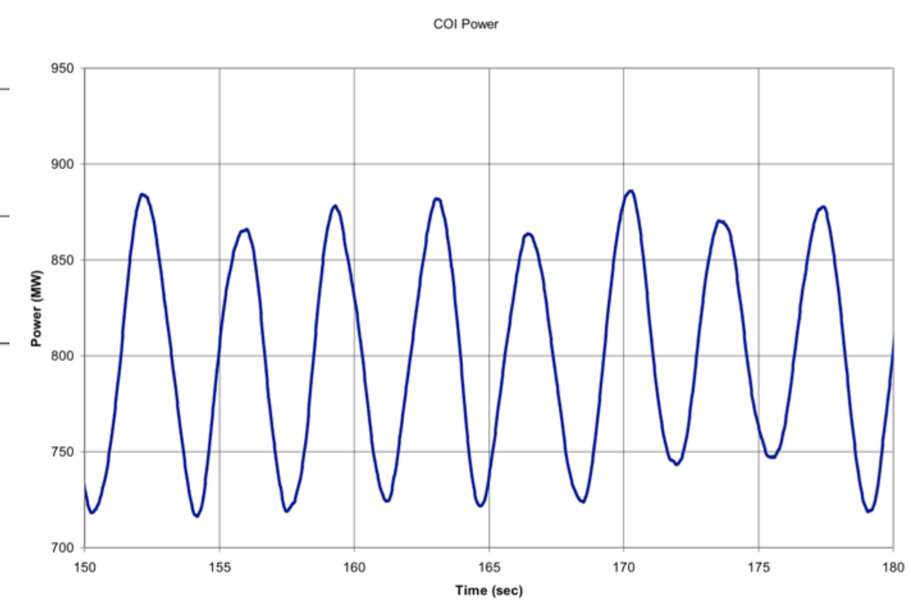
- System has an **unstable** oscillatory natural mode
- Microscopic impulse can initiate an oscillation that grows to damaging level
- Oscillation grows in absence of driving force

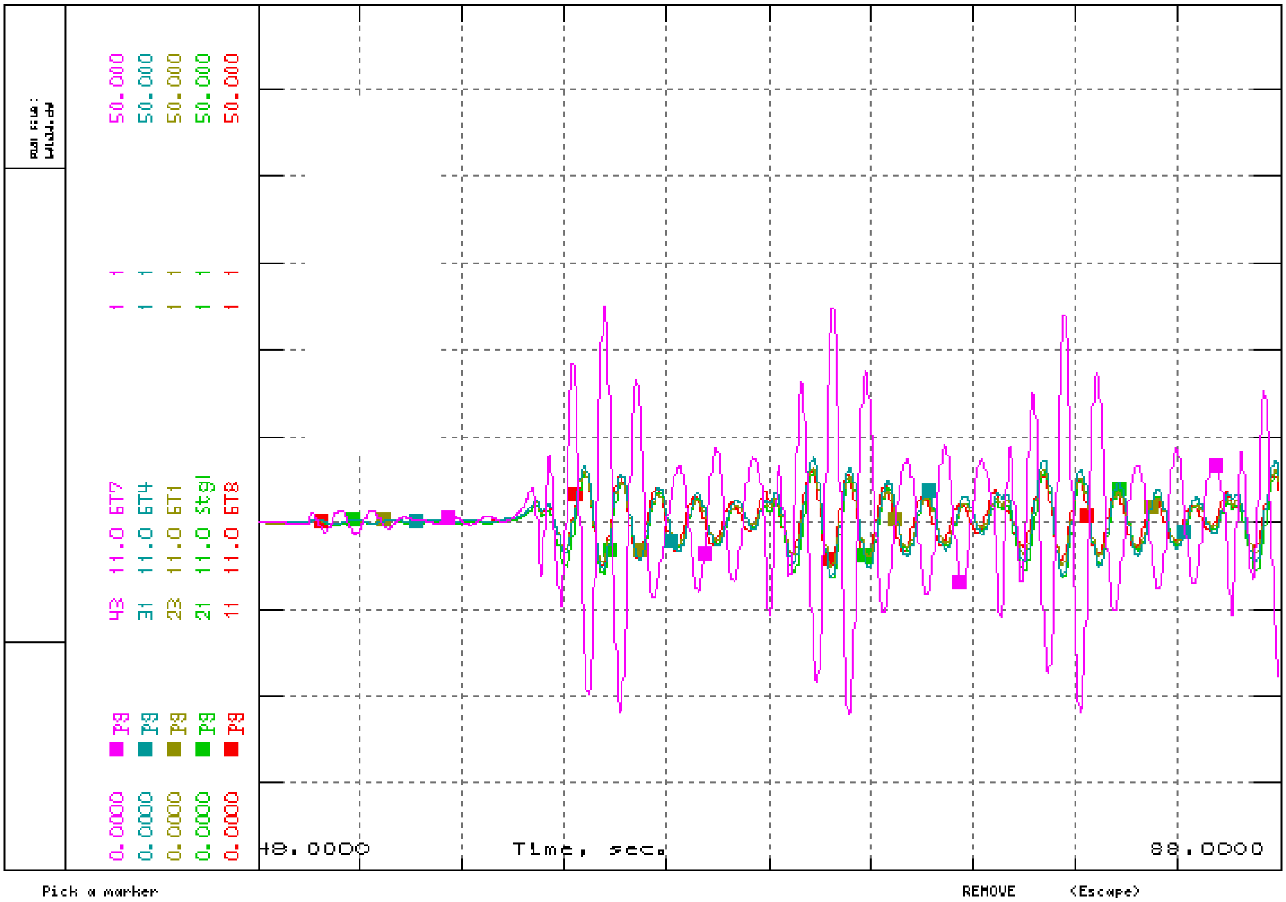
Driven Oscillations

- System is **stable** but oscillates in response to a cyclic driving force
- Driving force is mostly, BUT NOT ALWAYS, local to one plant. (DC malfunctions likely to be drivers at both ends)
- Effect can be local or widespread - depends largely on frequency of the driving force
- Driving force is often but not always a malfunctioning control system
    - Bad contact in electronics
    - Failed capacitor / transistor / diode . . . .
    - Sticky valve in hydraulics
    - Air lock / low oil pressure / broken spring . . . .
    - Faulty software logic
    - Draft tube pulsation

Driven by Malfunctioning Controller







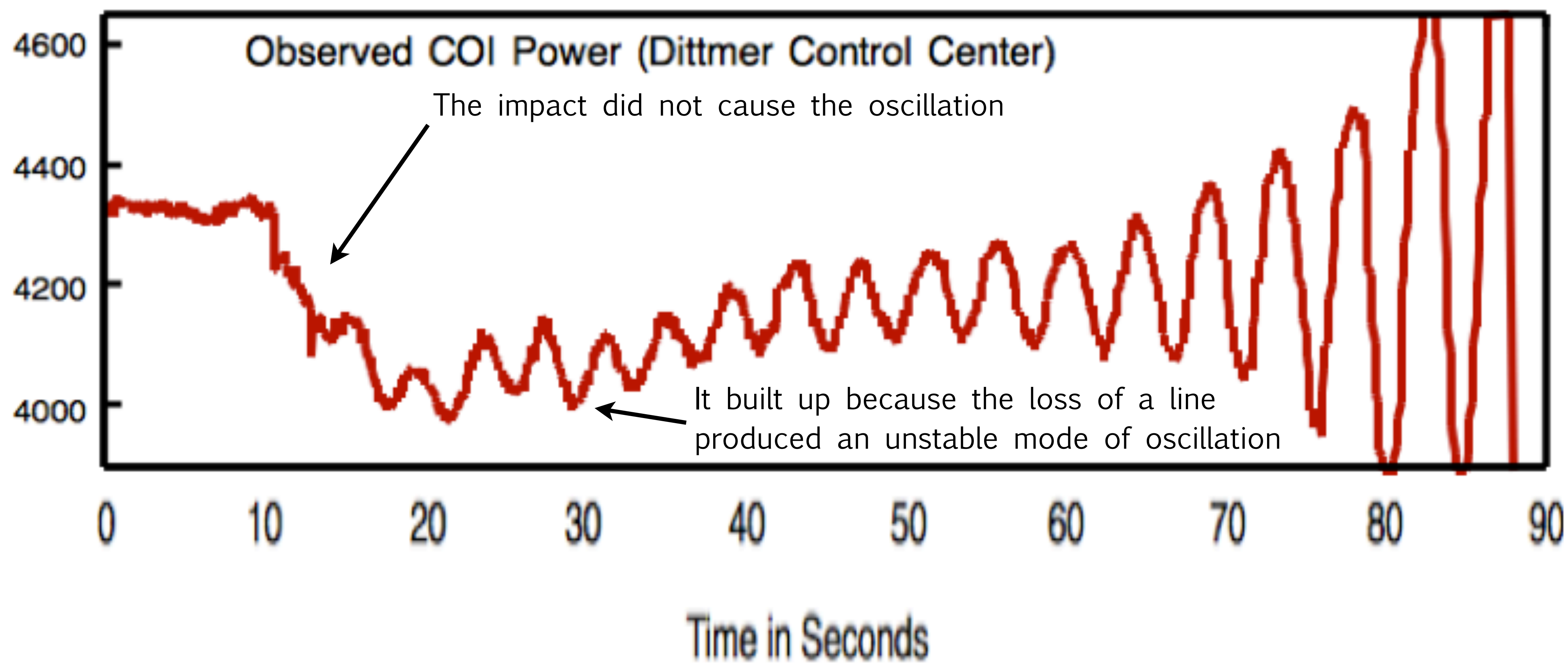
50.000
50.000
50.000
50.000
50.000
43 11.0 GT7
31 11.0 GT4
23 11.0 GT1
21 11.0 Stgl
11 11.0 GT8
0.0000
0.0000
0.0000
0.0000
0.0000
48.0000
Time, sec.
88.0000
Pick a marker
REMOVE
<Escape>

Unstable Oscillations

- System is **unstable** and oscillations grow spontaneously
- Key factor is system condition -
  - not an initiating event
  - not a cyclic driving force
- Condition leading to instability can be the result of a discrete event or can evolve gradually
- Unstable oscillations can be local or systemwide
  - May affect 'everything' -
  - May affect only specific equipment

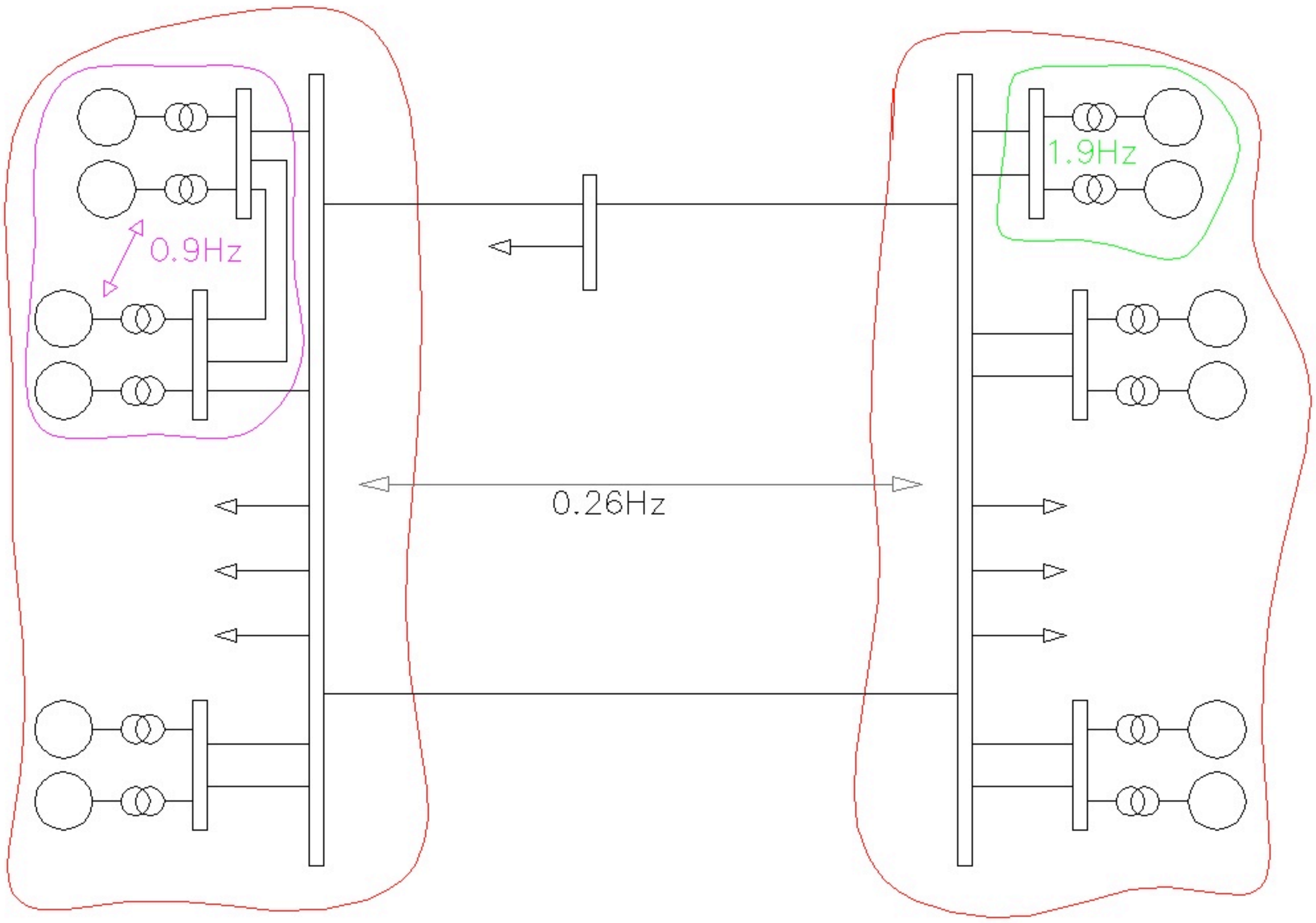
Unstable Oscillation - Rotor Angle Motion

Caused by Excessive Flow on Interarea Transmission Path



Local and Systemwide Modes

Local modes tend to be at higher frequencies
Interarea modes are at lower frequencies

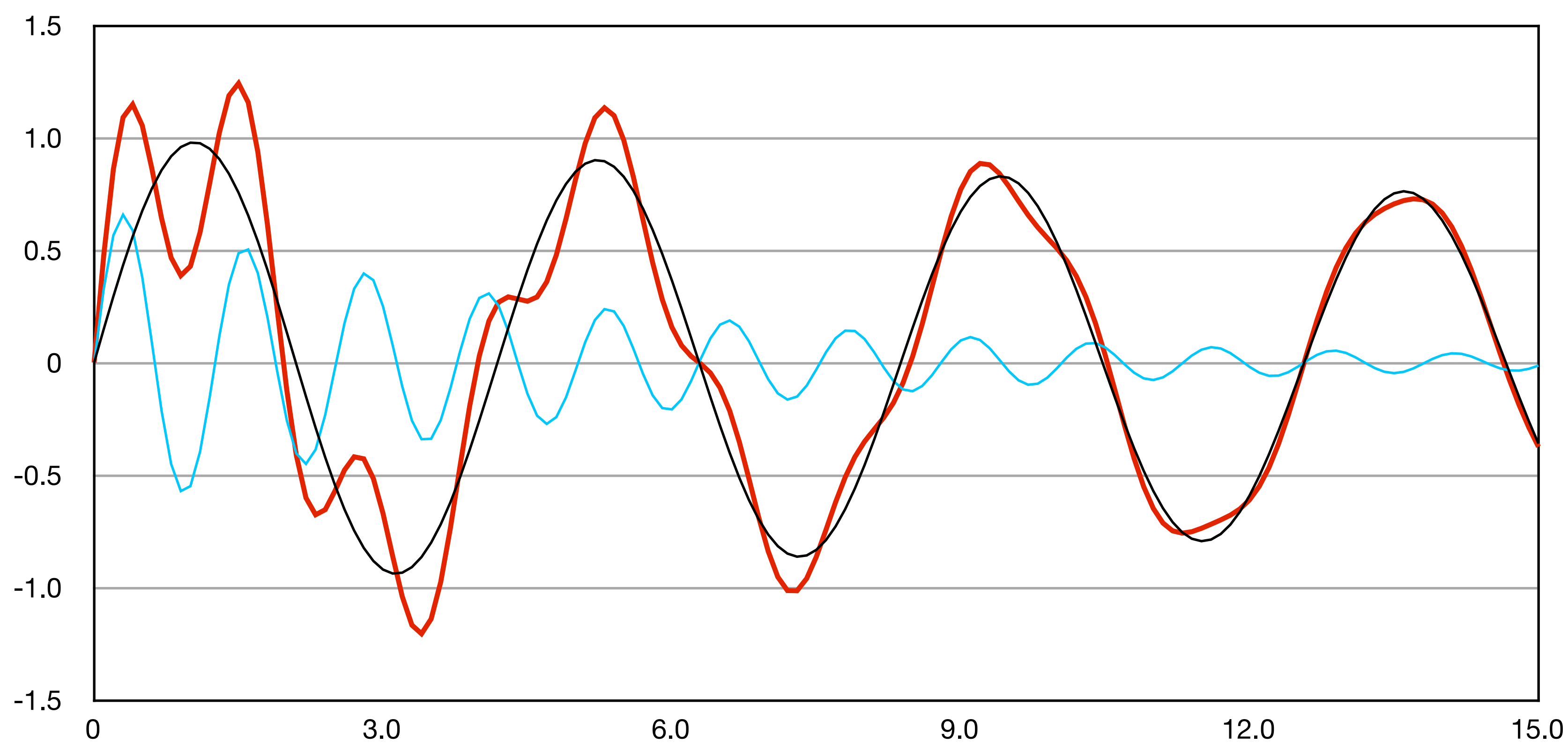


Local and Interarea Oscillations

Measurement is composed of many components (modes)

Local, fast, well damped (blue)
Interarea, slow, poorly damped (black)

PMU measures the red
Signal processing can deduce the blue and black



See that something is happening

Local measurements show frequency of oscillation
But
To know the cause
Need to know which system elements are participating

We have wanted for 50 years to have measurements to show what that something is

Synchronized measurements at widely spaced location show
which elements are / are not participating

Modeling is Imperfect
Effective Monitoring is Essential

Present analytical modeling can anticipate oscillation problems very well with regard to their nature, physical mechanisms, and remedial techniques

But it does not give reliable indication of the boundary lines between satisfactory and unsatisfactory system conditions

Continuous recalibration of study models and study results against measured behavior is essential

Oscillation Detection with SCADA

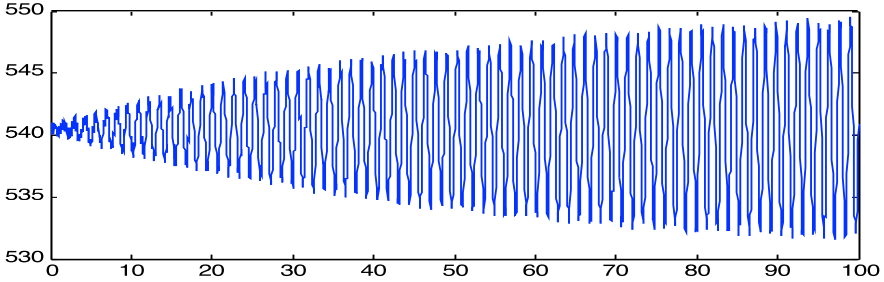
- This is how operators can detect power oscillations with numeric SCADA displays today

Rapidly changing digits on numeric display

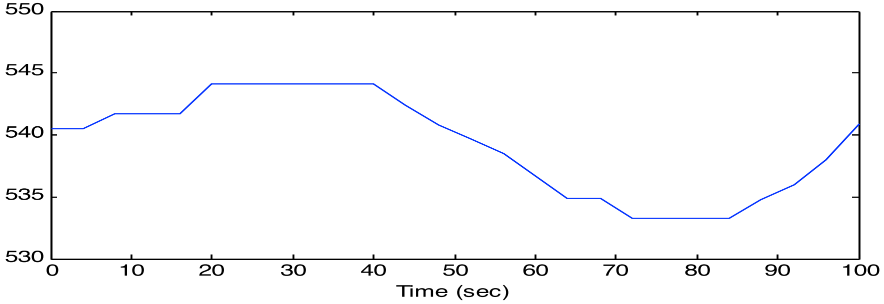
Oscillations Seen by Synchrophasors

SCADA measurements cannot see most oscillation
Worse – they can give misleading impression

Synchro-phasors are needed to observe oscillations because of faster data sampling, greater data resolution, and wide-area synchronization



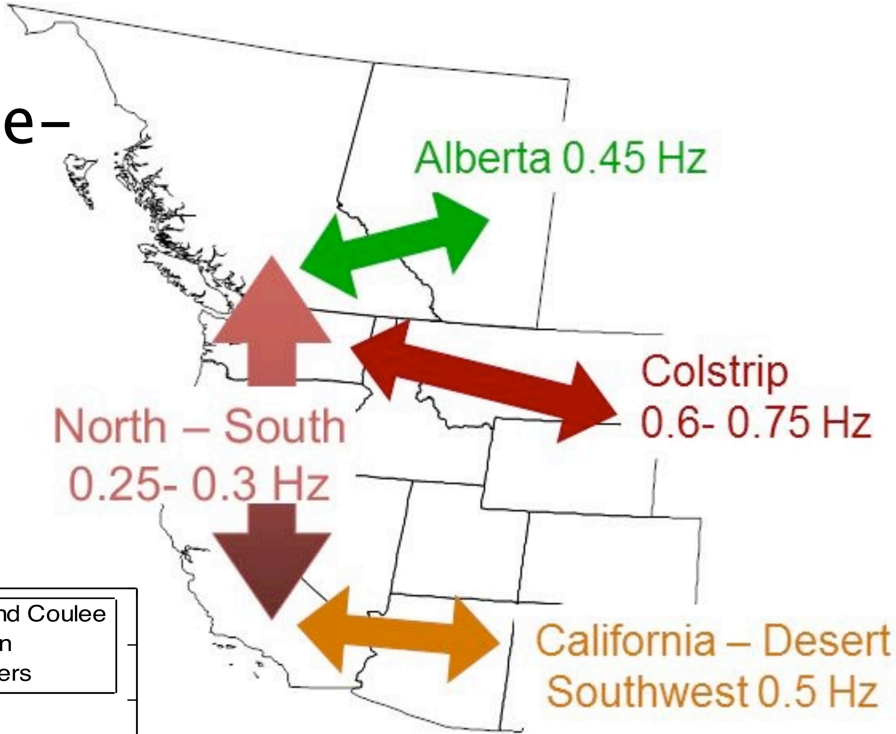
<< Synchrophasors

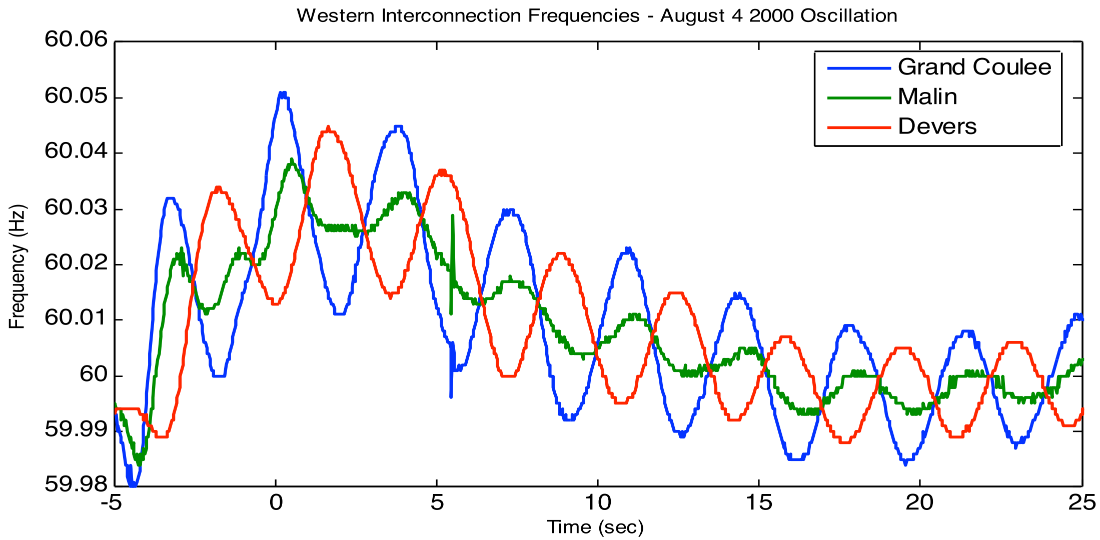


<< SCADA

Wide-Area View of Oscillations with Synchrophasors

Synchro-phasors provide wide-area geographic visibility of power oscillations:
- Is it a local or inter-area oscillation?

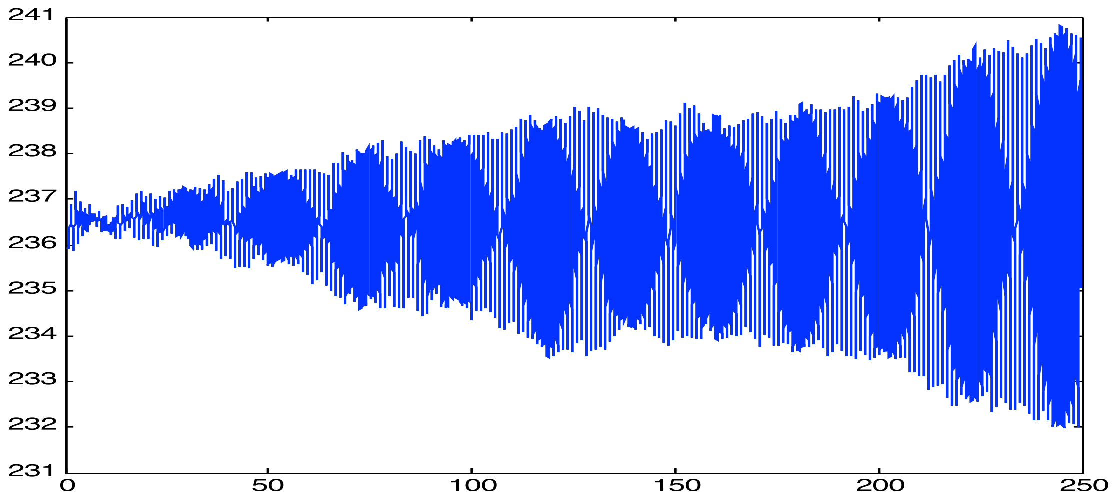




Operational Tools: Oscillation

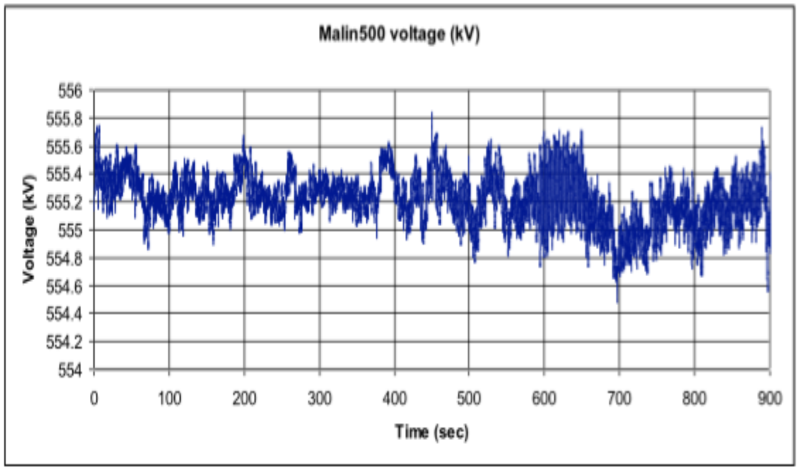
- Scan dozens of signals in real time for growing or sustained oscillations (like MWs of power plants, HVDC lines, frequency, etc.)
- Alarm dispatchers when an oscillation is detected
- Display the oscillation trend to a dispatcher
- Works for detecting oscillations due to system

Example: Boundary power plant oscillation due to line outages, oscillation is building up over 5 minutes

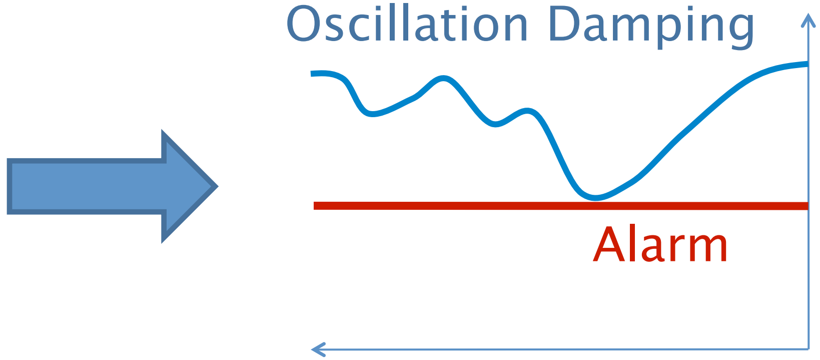


Operational Tools: Mode Meter

- Looks for early signs of deterioration in oscillation damping in the ambient data
- Provides early warning of potential damping problems
- Estimates oscillation damping, frequency and energy from ambient noise



Ambient Data



Time (min)

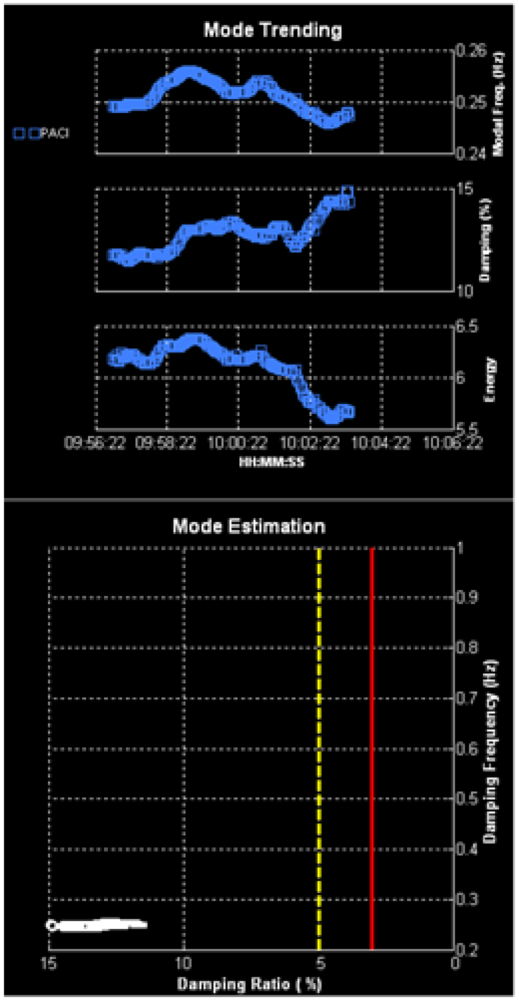
CAISO, BPA and WECC Plan to Operationalize North to South Oscillations in the Control Room

Background:

- Generators in Canada and Pacific Northwest oscillate against generators in Southwest
- Presents a risk to major transmission paths carrying power N-S (e.g. COI, P-26, PDCI)
- N-S oscillations can be observed in large power oscillations at the COI

Operationalizing PMU data at the CAISO:

- Development of operating procedures (ongoing)
  - Monitor damping ratio, BC-NW flow, GC-ML angle diff
- Provide operator training on RTDMS and procedures



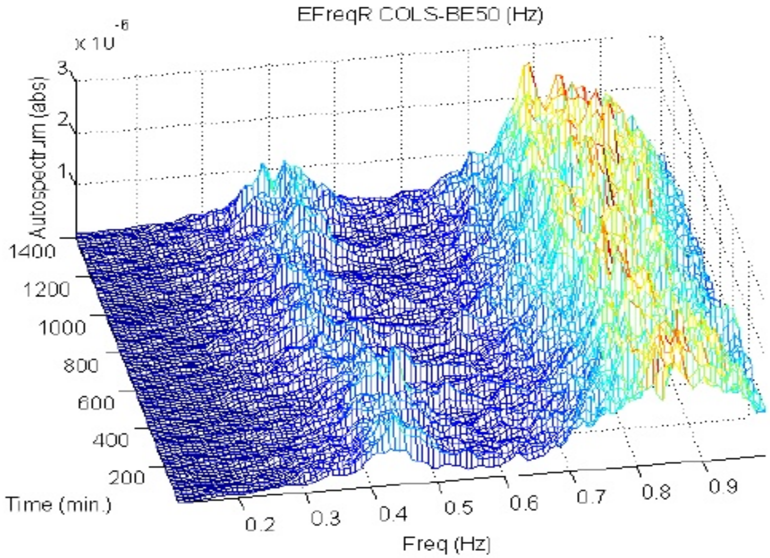
CERTS

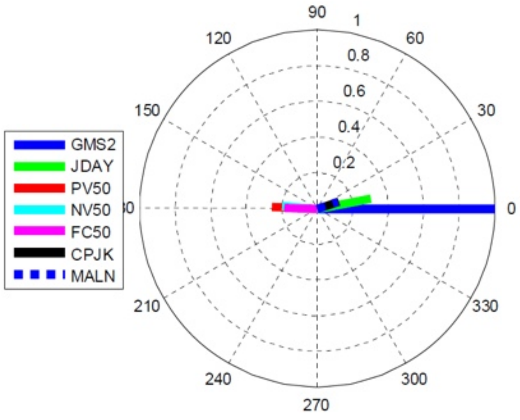
California ISO

Electric Power Group

Planning Tools: Oscillation Baselining

- Develop a baseline of power oscillations – oscillation frequencies, spectrum, energy, shape, etc
- Better understand conditions when the risk of power oscillations is high
- Identify contributors to the power oscillations
- Detect forced oscillations due to mis-tuned or failed





Planning Tools: Event Analysis and Model Validation

- Calculate system performance (oscillation frequencies, damping, energy and mode shapes) from disturbance-initiated oscillations
- Better understanding of the reliability risks
- System model validation – power system models are known to be very deficient in capturing power oscillations (power system models are used for grid investment and operating decisions)