Operating Procedures for Oscillation Monitoring and Mitigation in RC West

Urmila Agrawal
CAISO (RC West)

09/27/2023

Outline

- Introduction
  - Natural oscillations
  - Forced oscillations
- Tools and Operating procedures in RC West
- Operational challenges
- Examples of wide-area forced oscillations

Power Systems Oscillations

- Oscillations are inherent to a power system due to its electromechanical nature
- From a system reliability perspective, two types of oscillations are of concern to system operators
  - Natural oscillations: System's natural response to transient event and small-signal random disturbances
    - Function of overall system dynamics
    - Determined by the frequency and damping ratio of system modes
  - Forced oscillations: System's forced response to periodic disturbance, such as cyclic load, malfunctioning control valve and incorrectly tuned inverter-based controls
    - Forced response of a system given by transfer function of the system from the input location to the measurement location
    - Response dependent on input frequency and location

Natural Oscillations

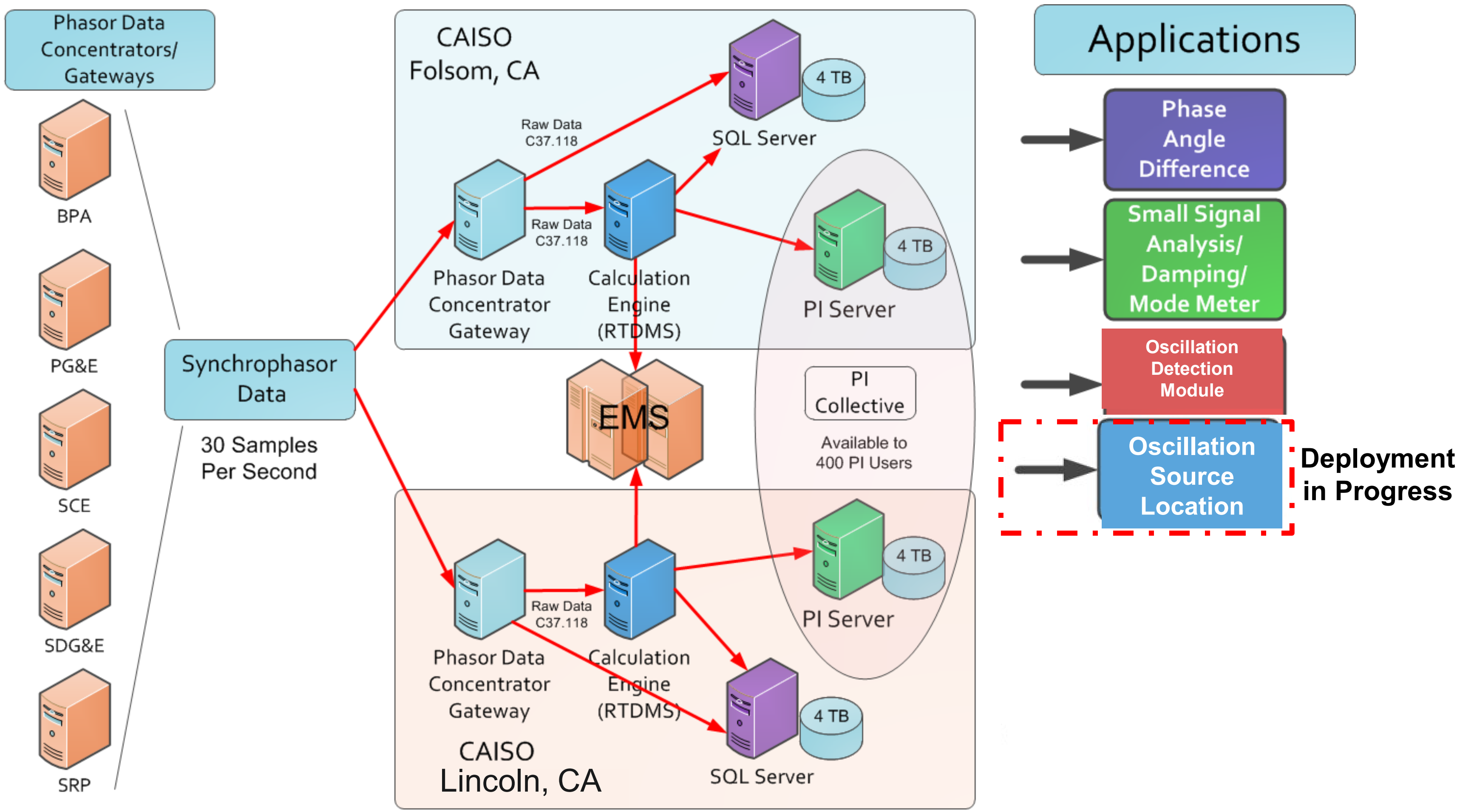
- Natural oscillations always present in a power system
  - Ambient noise: System’s natural response to random small-signal disturbances such as load variations
  - Ringdown oscillations: System’s natural response to transient event
- Well-damped system modes critical to maintaining secure and reliable system operations
  - Requires continuous monitoring of damping ratio of system modes using ambient data
  - When the damping ratio of a mode reaches a critical level, operators are required to take mitigation actions that usually involve changes to the system operating conditions

Forced Oscillations

- Forced oscillations caused by an input source injecting periodic disturbances to a system
- Frequency and amplitude of the forced input determine the severity of forced oscillations
  - Frequency of the forced input determines if the forced oscillations are localized or observed across a wide-area
  - Both amplitude and the frequency of the forced input determine the magnitude of the power swings observed at other locations
  - High amplitude power swings observed across a wide-area are of major concern (“Resonance” condition)
- Mitigation involves locating the source of forced oscillations and taking corrective actions, such as shutting down the source unit

Tools and Operating Procedures in RC West

CAISO Synchrophasor Architecture/Applications



Tools for Monitoring and Locating Source of Forced Oscillations

- Oscillation Detection Module (ODM)*
  - Detects sustained oscillations within the RC area in real-time and provides RC Operators with wide-area analysis, monitoring and visualization across the Western Interconnection (WI)
  - Generates alarms to alert the RC Operator to conditions that might indicate oscillations occurring in the system
- Oscillation Source Location (OSL) tool*
  - Currently working toward deploying OSL in the control center

*RTDMS, ODM and OSL are registered products of Electric Power Group, LLC (EPG)

Tools for Monitoring Natural Oscillations

- Modemeter engine developed by Montana Tech
  - Continuously monitors damping ratio of the dominant modes observed in the WI
    - North South A (NS-A)
    - North South B (NS-B)
    - British Columbia (BC)
    - East West (EW)
    - Montana Northwest

Operating Procedures for Mitigation of Forced Oscillations

- Determine the extent of impact
  - Identify the general area affected by the oscillations and the affected BA/TOP(s) and other RC(s)
- Determine the severity of the impact
  - Obtain the frequency and the magnitude of the forced oscillations
- Identify the source
  - Co-ordinate with the affected entities
  - Monitor the MW and Mvar output of units in the affected areas for fluctuations
- Discuss potential mitigation options with affected entities
- Evaluate the effectiveness of the mitigation actions being taken by the affected entities
  - Issue Operating Instructions to affected entity(s) in the RC Area, including the specific mitigation actions and timeframe, if needed

Operating Procedures for Mitigation of Natural Oscillations

- For low damping ratio alerts, several mode-specific mitigation strategies outlined in the procedure
- Coordinate with neighboring RCs and other affected entity(s) to implement existing procedures for mitigating inter-area oscillations
  - Curtailing power flow across path that is critical to the mode of interest
  - Raising system voltages to upper end of voltage schedules
  - Restoring higher voltage lines that were out of service
- Evaluate the effectiveness of the mitigation actions being taken by the affected entities
  - Issue Operating Instructions to affected entity(s) in the RC Area, including the specific mitigation actions and timeframe, if needed

Operating Procedures During Resonance Condition – New Updates

- Alerts are issued in the both ODM and Modemeter tools
- Determine if the alerts are because of critically damped natural oscillations or forced oscillations
  - Likely corresponds to forced oscillations if the damping ratio trend for the triggered system mode shows a sudden decrement to zero over a short time and no corresponding large system event

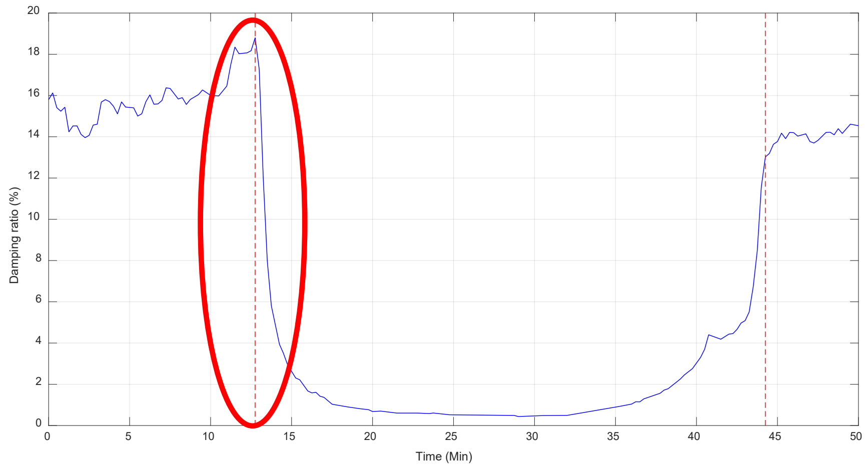


Figure: The damping ratio trend and no major system event indicates the 0% damping ratio is most likely caused by the presence of forced oscillations during resonance condition

Operational Challenges

- Incomplete situational awareness
  - Not having complete information can delay mitigation actions, such as locating the source of forced oscillations
- Lack of confidence in the use of tools
  - Too many inaccurate or false alerts leads operators to ignore results
- PMU data quality
  - Bad PMU data quality can disrupt results and in some cases add to confusing results
  - Persistent data quality issues may lead to insufficient PMU coverage

Wide-area Forced Oscillations – Examples

Wide-area Forced Oscillations – Example-1 (1)

- A wide-area forced oscillation event occurred in the Western Interconnection in January 2022
  - Disturbance source was a battery storage system in Southern California
  - Frequency of forced oscillation close to that of NS-A mode and the disturbance source in the area participating in the NS-A mode
  - Damping ratio estimate of the NS-A mode biased toward 0%
  - Forced oscillations lasted for close to 15 minutes and were observed across a wide-area

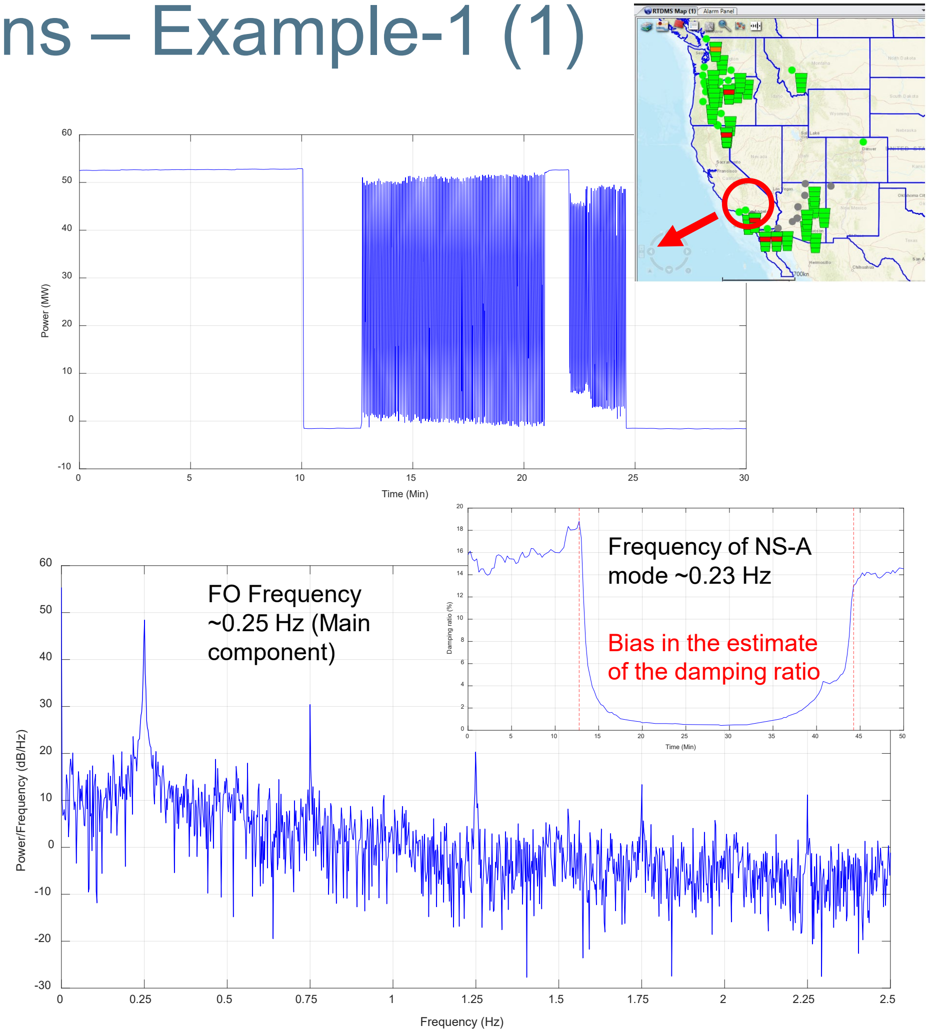


Figure: Example of wide-area forced oscillations in Western Interconnection that originated in Southern California. Figure shows PMU measurement and the calculated periodogram spectrum for the oscillation originating unit.

Wide- area Forced Oscillations – Example-1 (2)

- Battery output of only the source units showed fluctuations
- Several synchronous units oscillated based on the participation of those units in NS-A mode

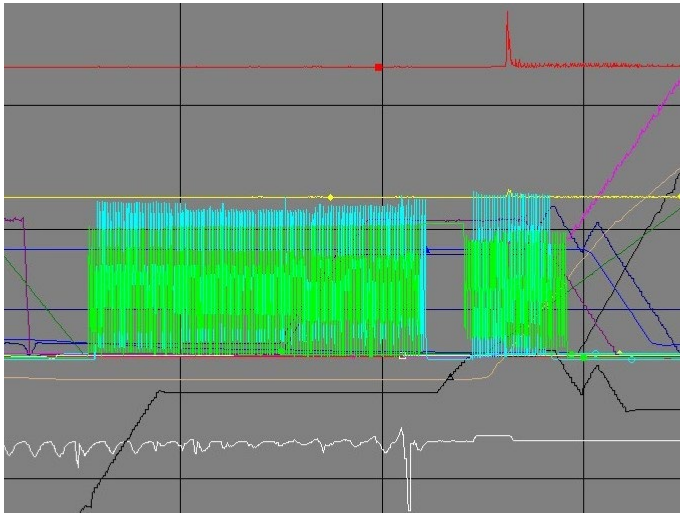


Figure: Power output (SCADA measurements) of several large battery units in CAISO footprint that were online during the event. The oscillating unit outputs in the plots are of the source battery units. (X-axis and Y-axis represent time in minutes and power output in MW respectively)

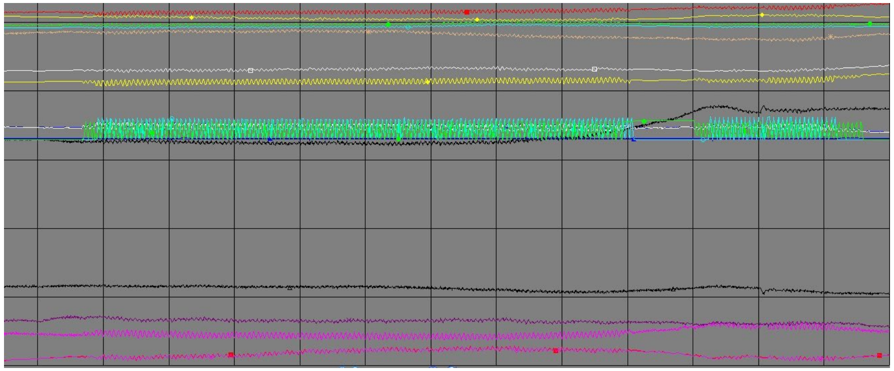


Figure: Power output (SCADA measurements) of some synchronous generation units in WI that were online during the event.

Wide-area Forced Oscillations – Example-2 (1)

- Another wide-area forced oscillation event recently occurred in the Western Interconnection on 20th September 2023
  - Disturbance source was a battery unit in Arizona – Controller issue caused oscillations during unit testing
  - Frequency of forced oscillation close to that of NS-A mode - Alerts triggered for NS-A mode in Modemeter due to the mode estimate biasing
  - Forced oscillations lasted for close to 16 minutes
  - Issue quickly identified and actions taken
  - Control of the source unit set to local mode

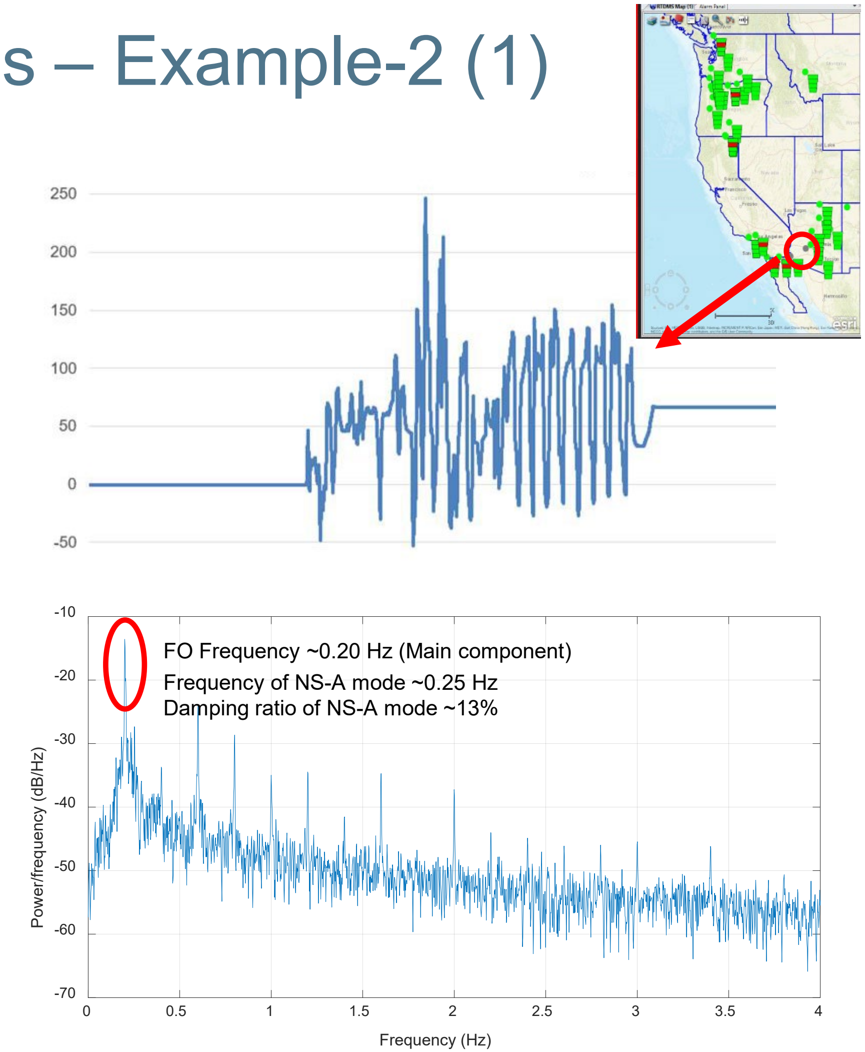
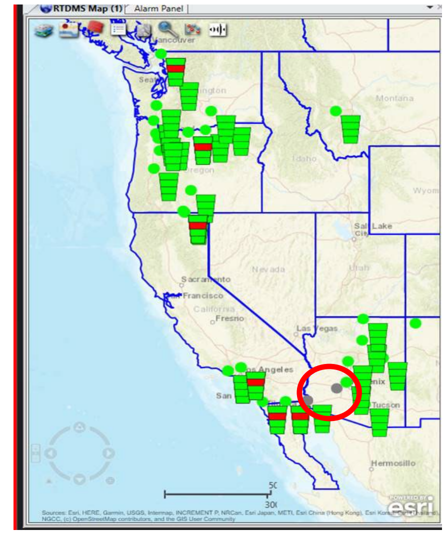
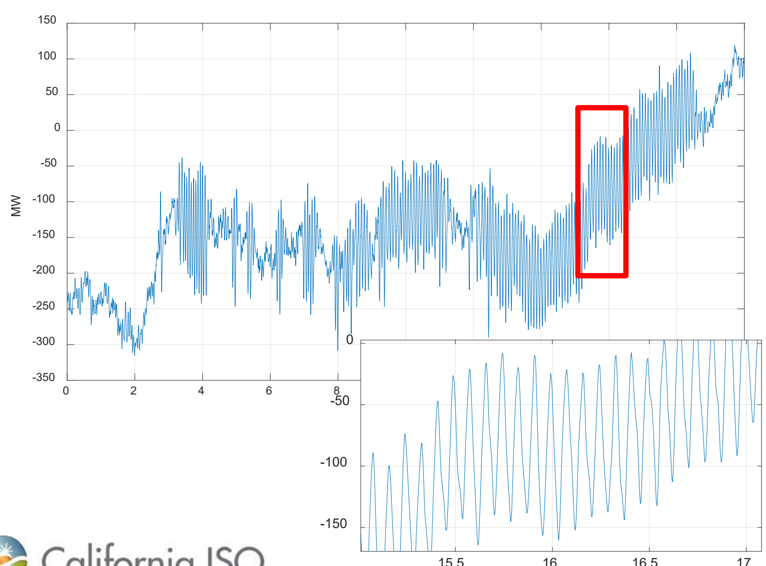


Figure: Example of wide-area forced oscillations in WI that originated in Arizona on 20th September, 2023. Figures show active power output of the source unit (Top) and the Periodogram spectral estimate calculated using PMU measurements at one of the AZ stations (Bottom).

Wide- area Forced Oscillations – Example-2 (2)

- Oscillations observed in several locations in the North and in inter-tie flows such as California – Oregon Intertie (COI).
  - Close to 150 MW power swings observed in COI flow





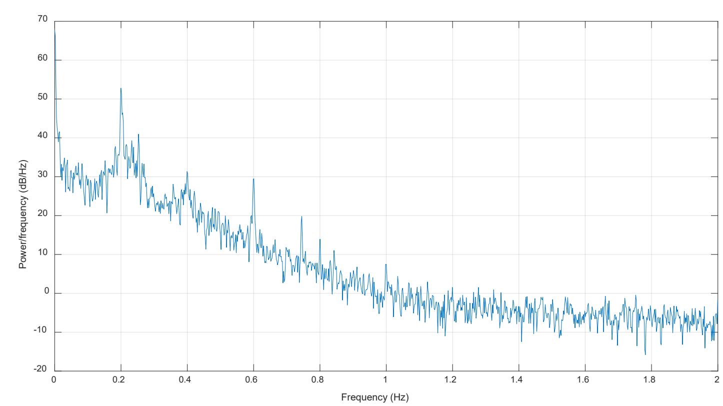


Figure: COI flow (Left) and the corresponding Periodogram spectral estimate (Right) for oscillation event in Western Interconnection that occurred on 20th September, 2023.

Thank you!!!

Questions??