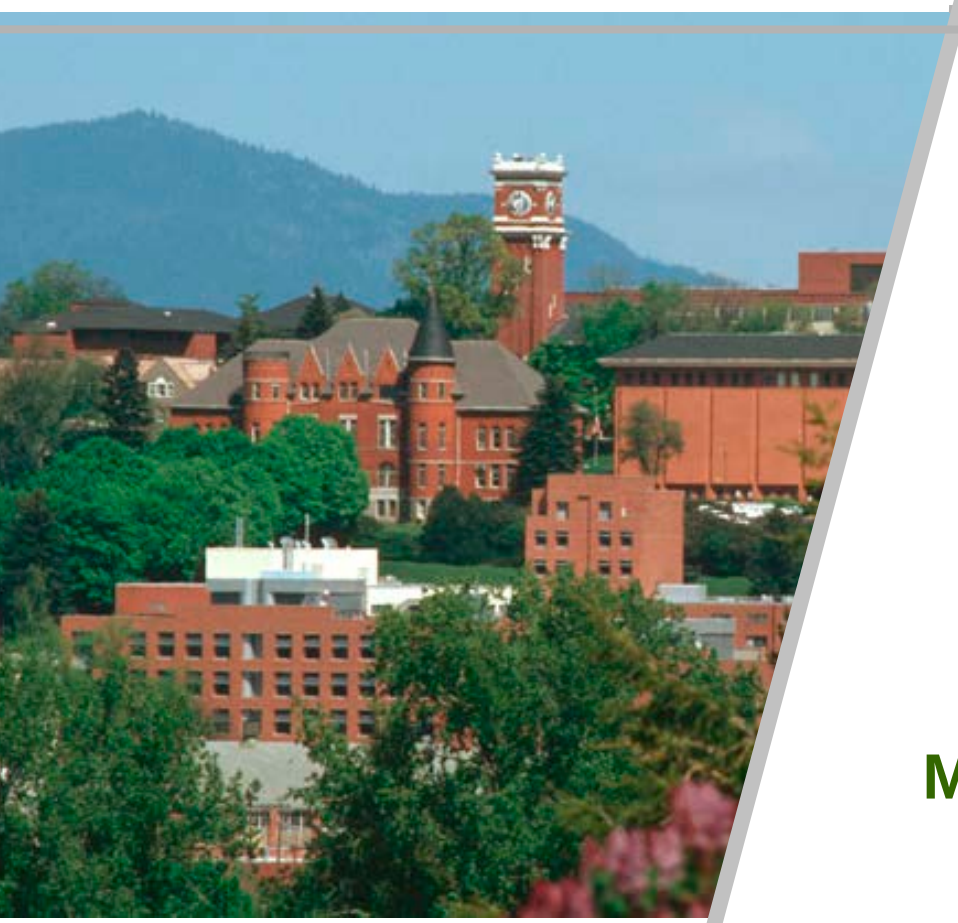
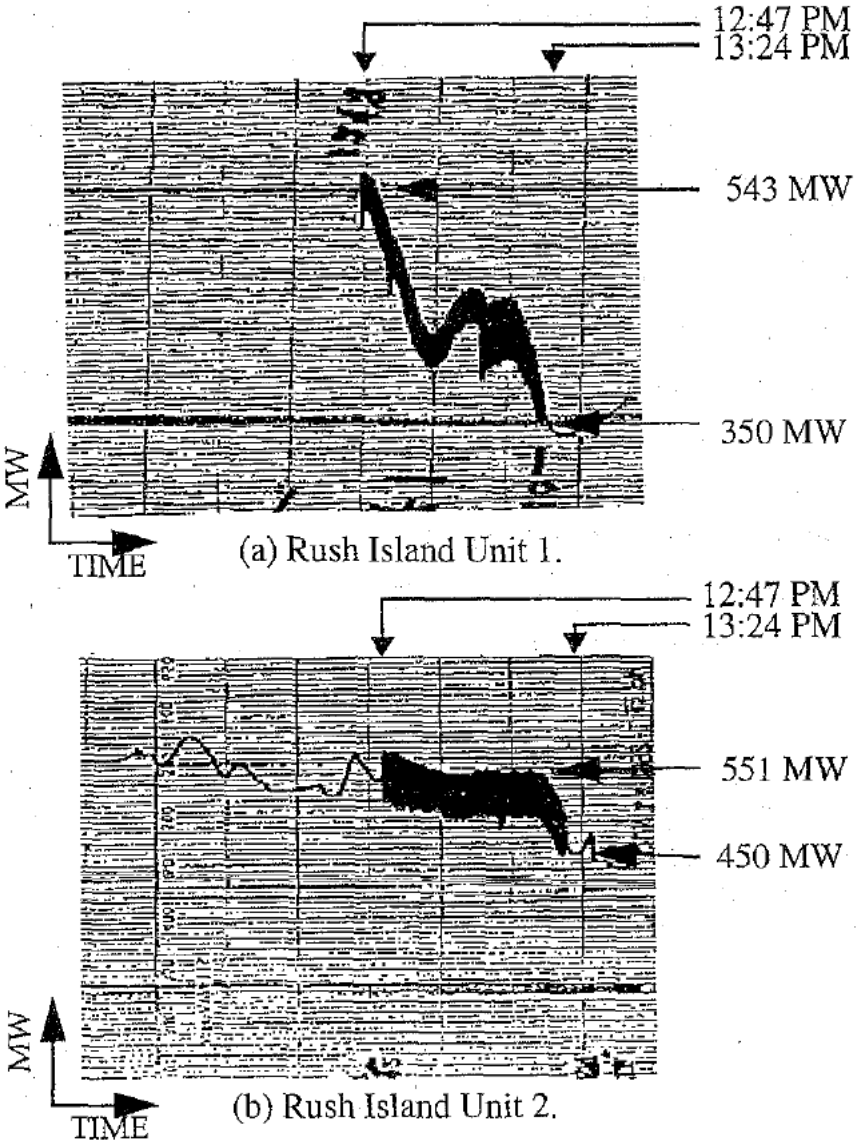


Forced Oscillations and Resonance

Arash Sarmadi
Mani V. Venkatasubramanian
Washington State University

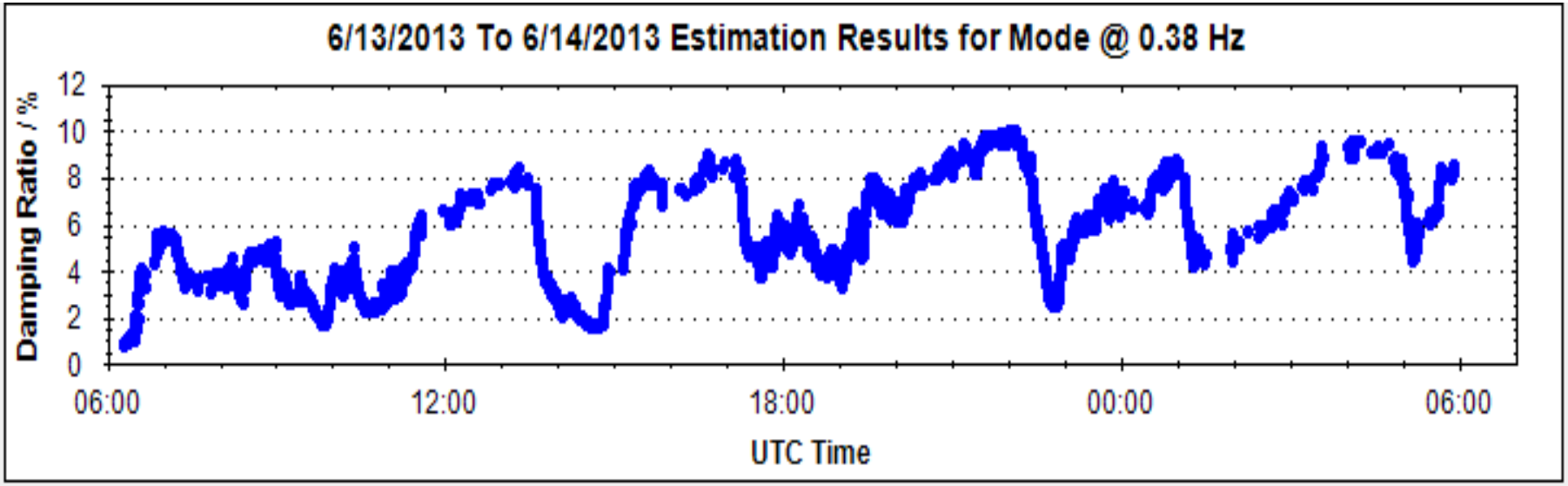
1992 Midwest Oscillations

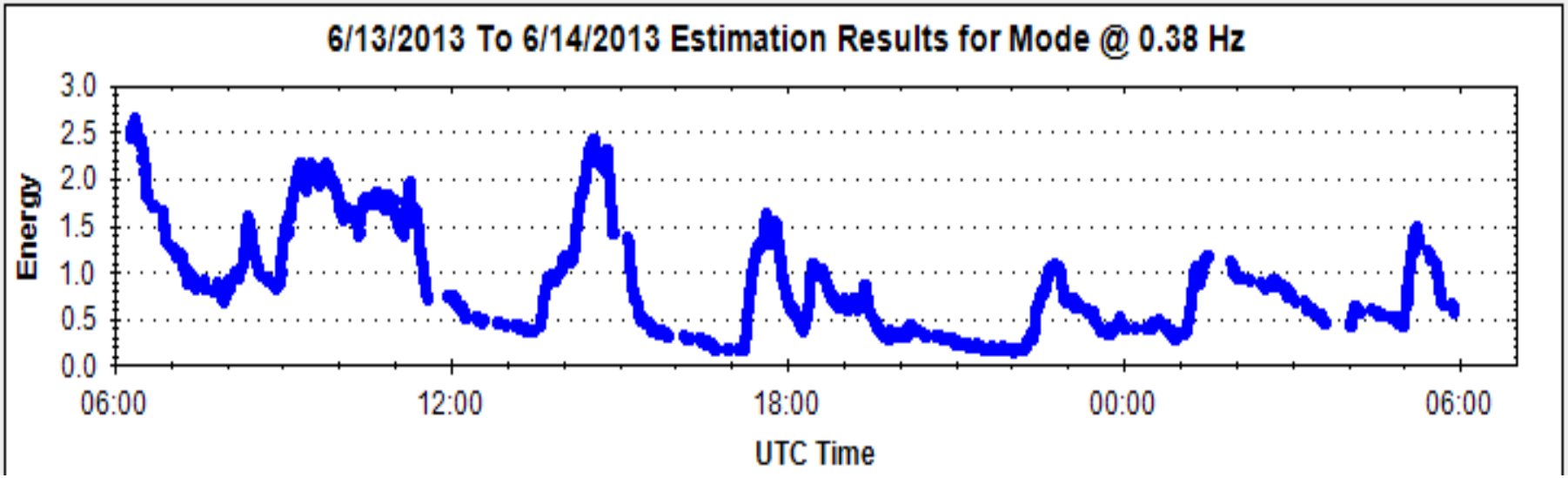


1997 IEEE Trans. Power Systems paper by

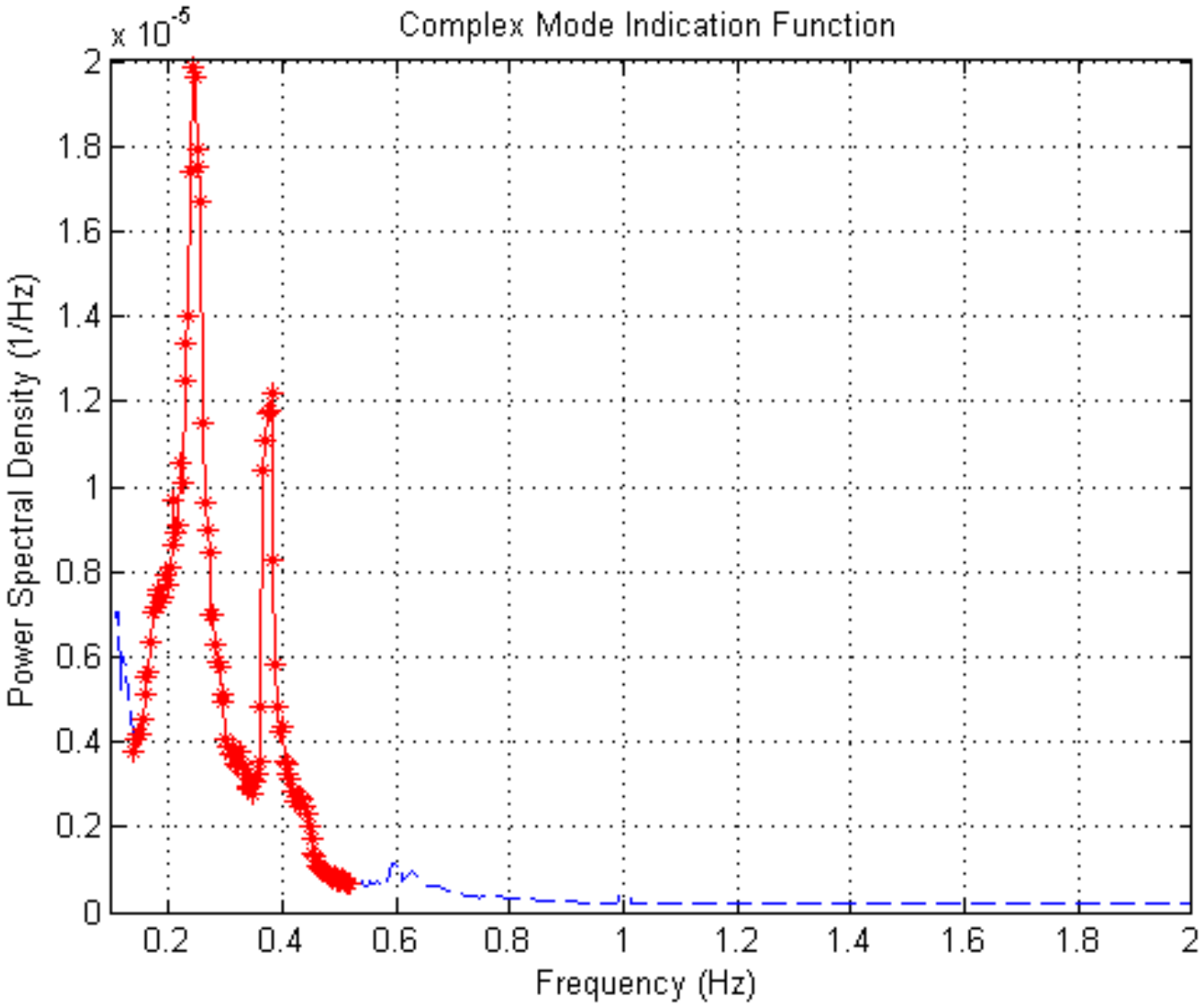
K. Kim
H. Schattler
V.Venkatasubramanian
J. Zaborszky
P. Hirsch

June 13 2013 Results

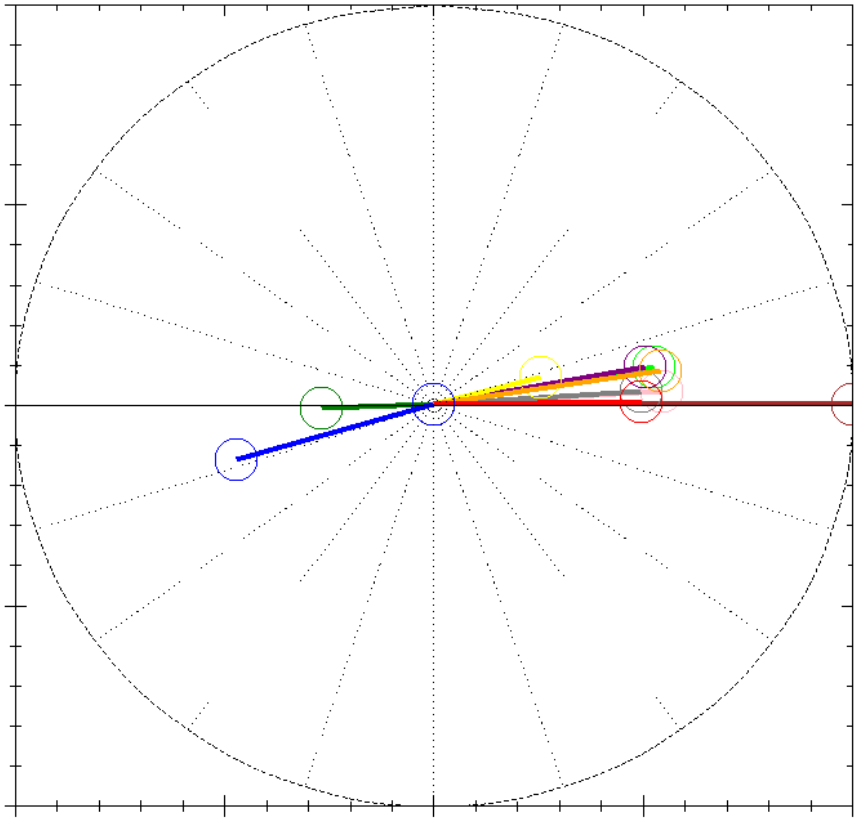




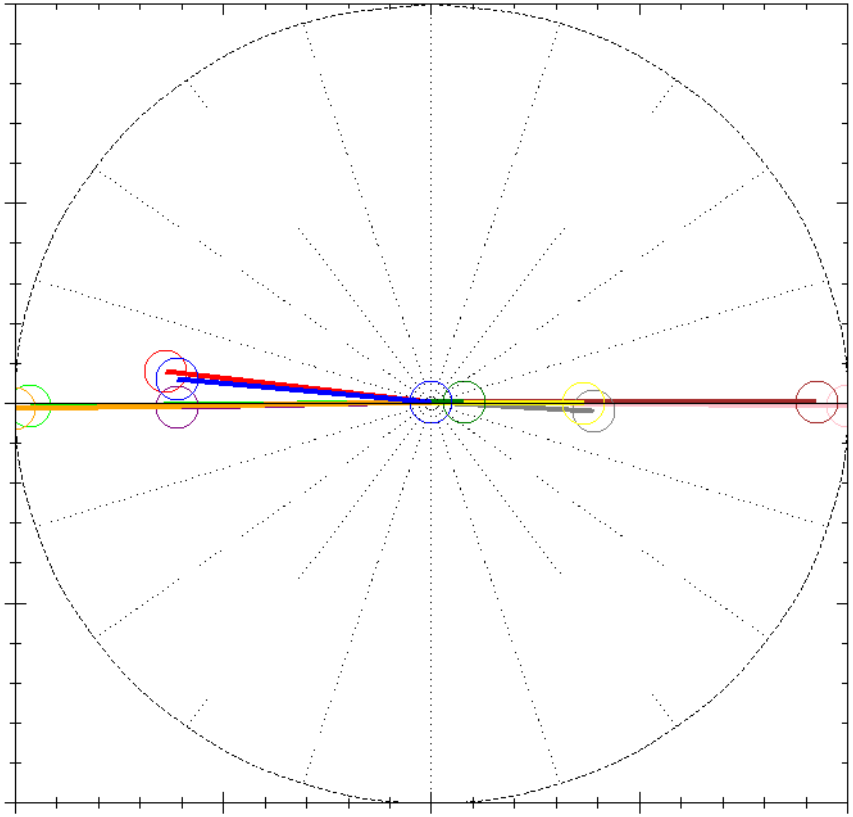
June 13th PSD Singular Values from WECC data



Mode Shapes on June 13, 2013

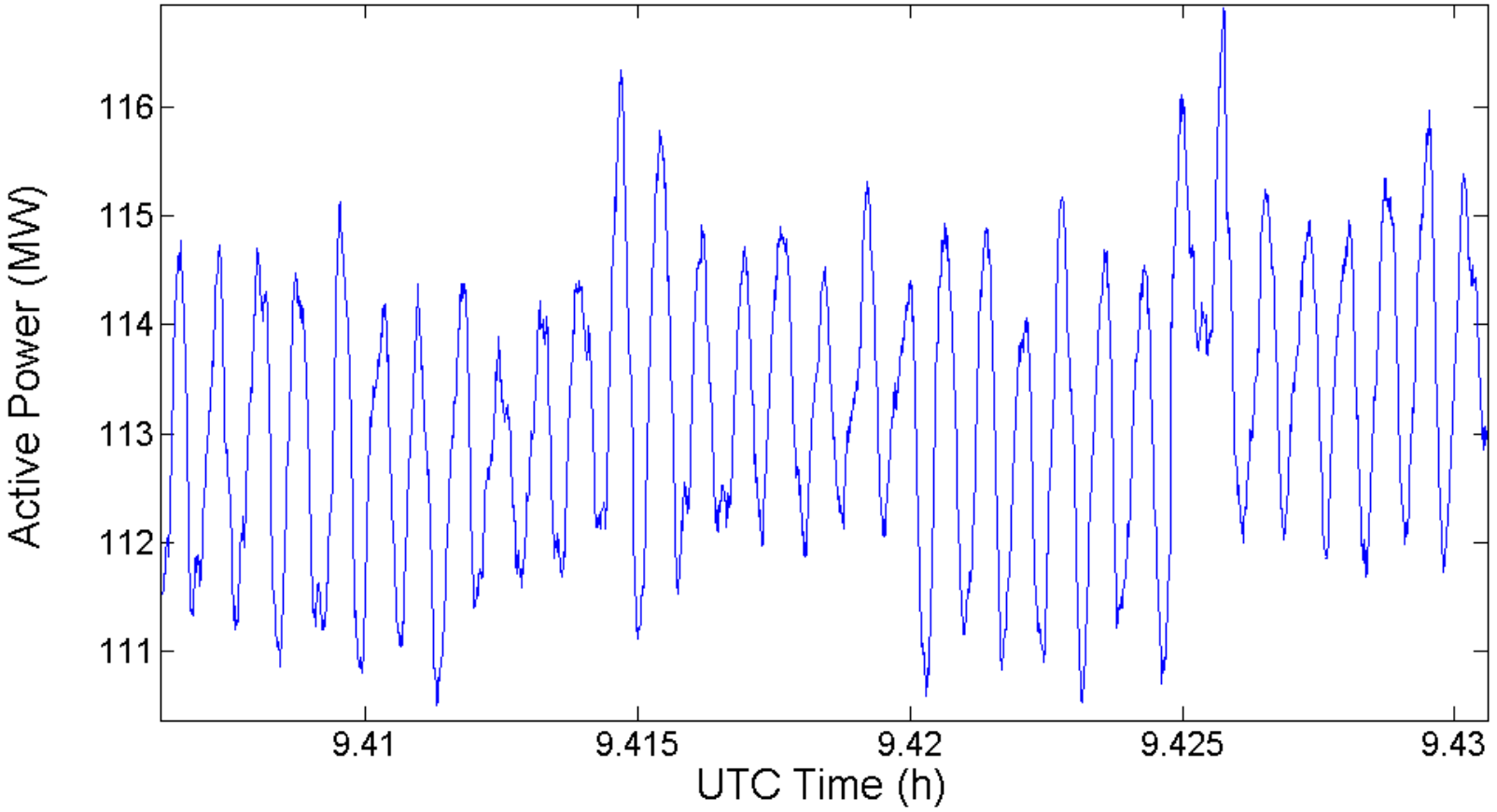


0.37 Hz at
Near Zero Damping Ratio
(7.30 am to 8.00 am)



0.4 Hz at
Near 8% Damping Ratio
(10 am to 11 am)

June 13th 0.37 Hz oscillations at Generator



Generator MW Oscillations

- Hydro unit operated in rough zone when wind power output high
- Vortex effect in Francis turbine when water flow level is low
- Air compressor to keep oscillations low to nil
- **5 to 25 MW oscillations observed at 0.37 Hz**
- Forced oscillations: mechanical oscillations on turbine shaft onto power grid
- False alarm from ambient mode engines
- Mode shape analysis critical
- Multi-dimensional analysis crucial

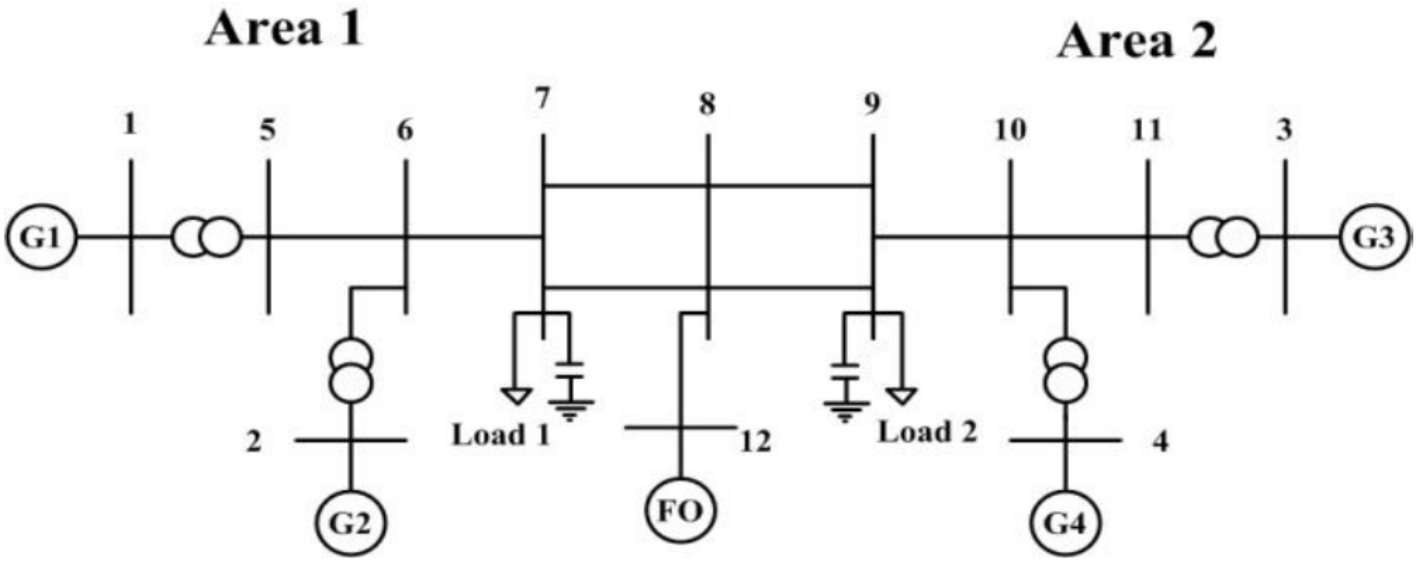
Forced Oscillations from Hydro

- Summer 2013 24 hour data: 0.37 Hz oscillations observed for several hours. Confirmed to be forced oscillations.
- Another 0.5 Hz oscillation also observed. Source points to hydro unit as well.
- Routine phenomenon in hydro units (Francis) when units come in and go out of system
- Detection? Impact on nearby system modes?
- Resonance possible when system mode poorly damped and close. Resonance observed in model simulations. Research and Algorithms at WSU.

Resonance Issues

- Forced oscillation at a frequency near system mode frequency
- Resonance can occur when system mode is poorly damped and **forced oscillation at a location where the system mode is active**
- Especially problematic for inter-area modes

Kundur system simulation



- Inter-area mode damping ratio = 2%
- 10 MW forced oscillation at any generator results in 400 MW oscillation on tie-lines

Forced oscillations and Resonance

- Low frequency forced MW oscillations from Francis turbine vortex phenomena when Francis hydro units come in and out of service – 5 to 10 minutes spent in the rough zone
- Generator control failures
- **Vulnerability for the system if the forced oscillation frequency near system mode frequency and if the oscillation originates at a sensitive location**
- Vulnerable locations should be identified and monitored