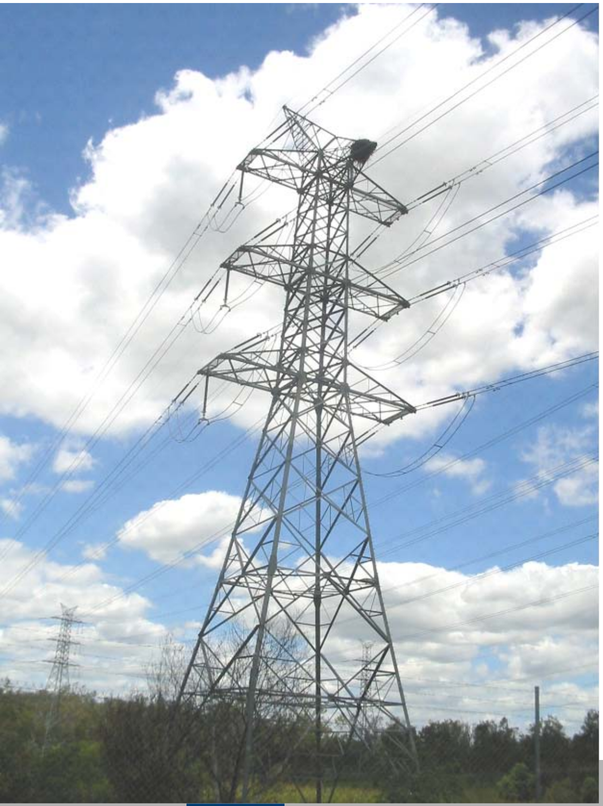
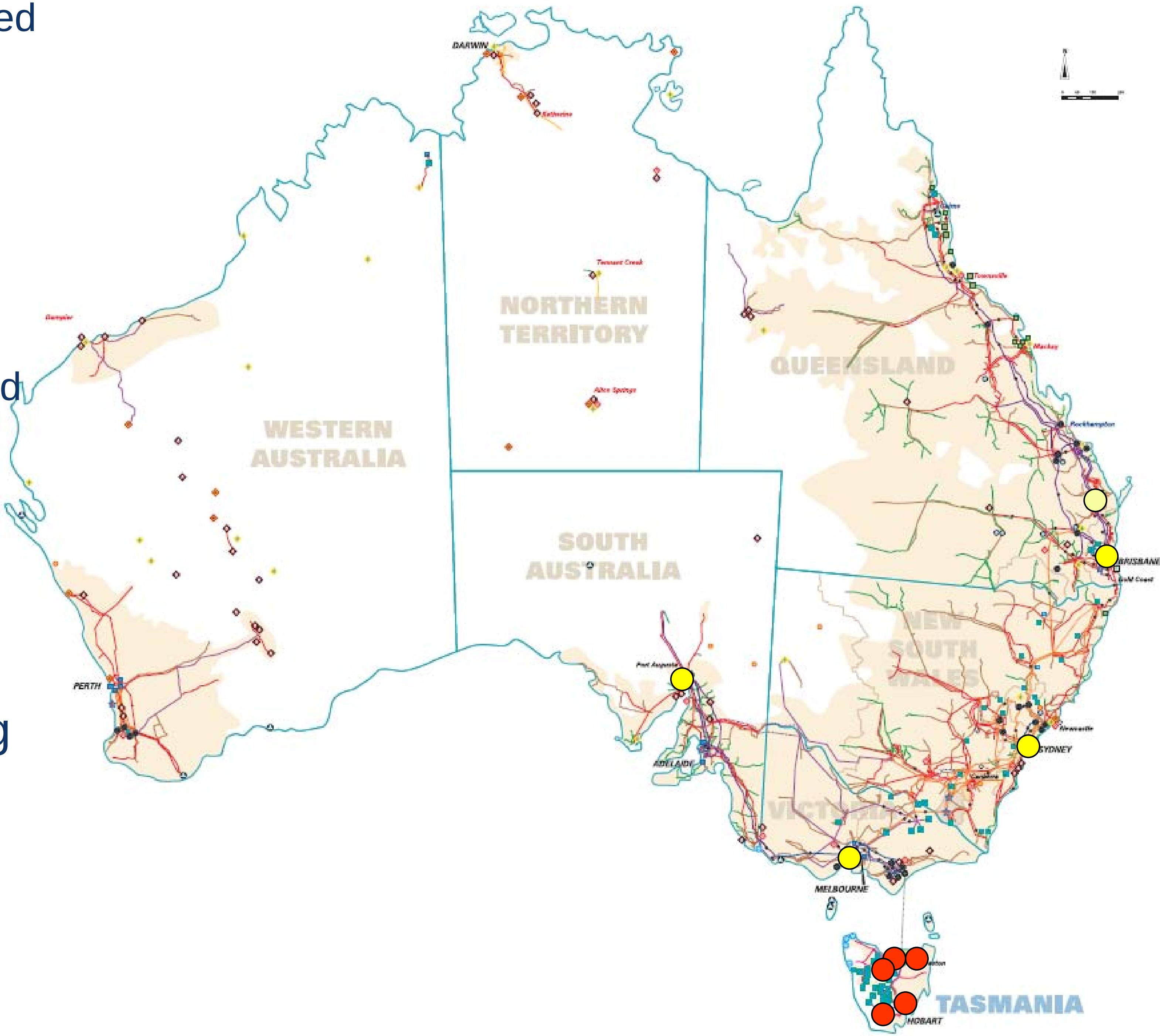
PMU in use in Australia



Gerard Ledwich

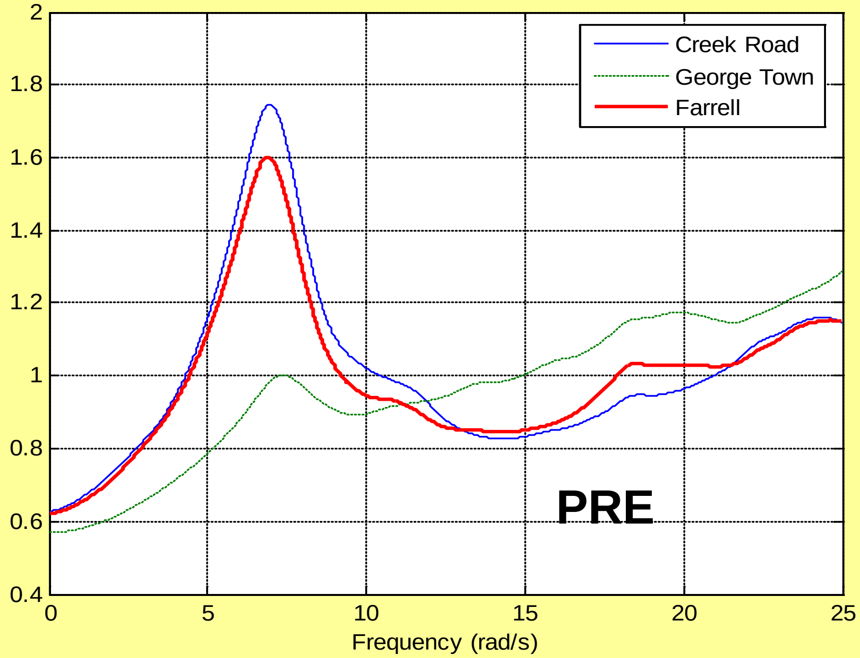
- 44,900MW installed capacity in the interconnected Eastern network
- Managed by Aust Energy Market Operator

- PMU Local Record rate is 50Hz
- Transmit rate is 10Hz to aggregation in Brisbane
- 🟡 System model
- 🔴 Load modelling
- ○ mobile

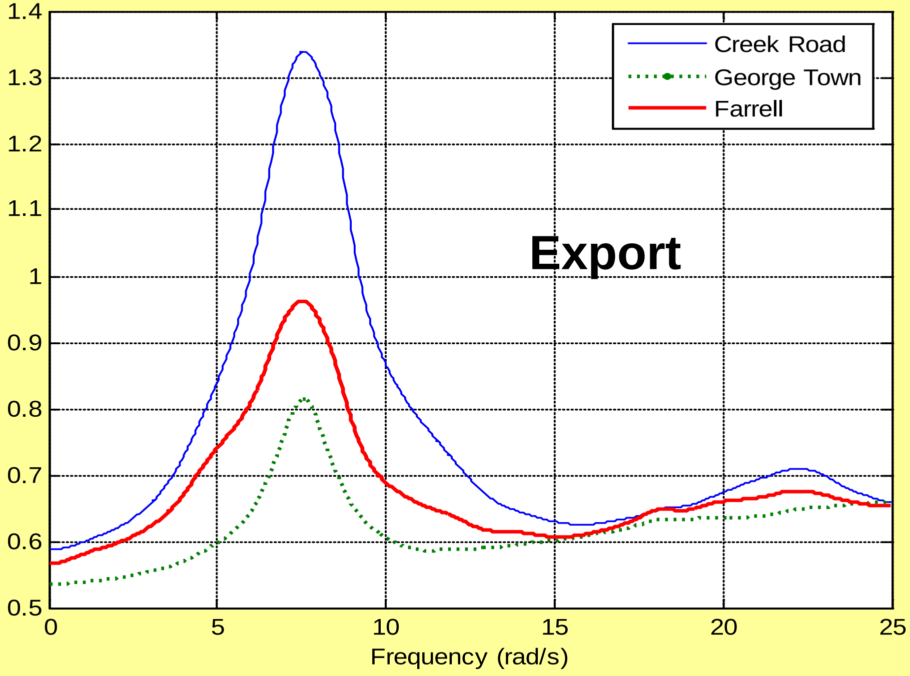


Spectrum of autocorrelation– **post Basslink**

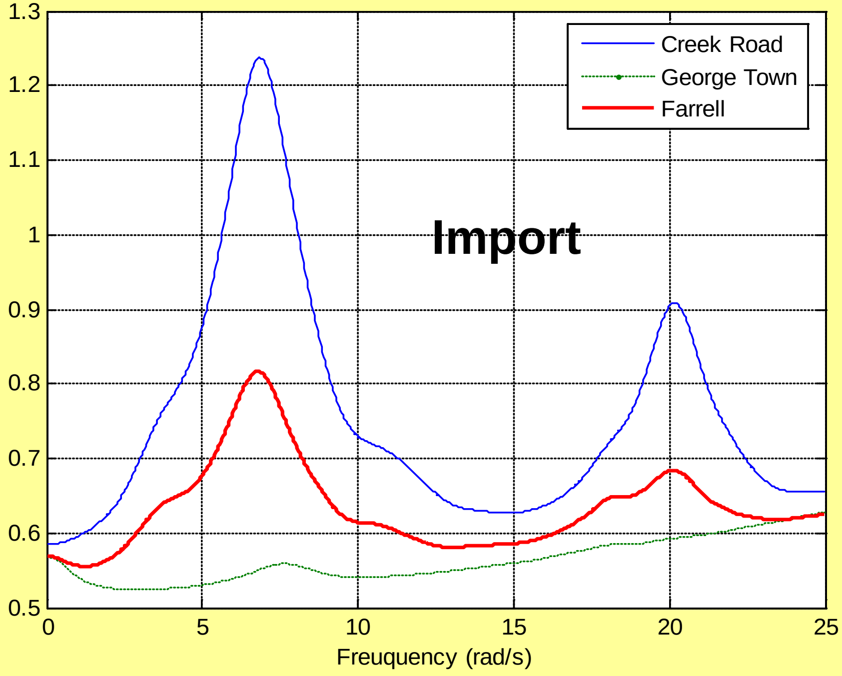
Spectrum of autocorrelation (Pre-Basslink)



Spectrum of autocorrelation (Basslink exports 510MW to VIC)

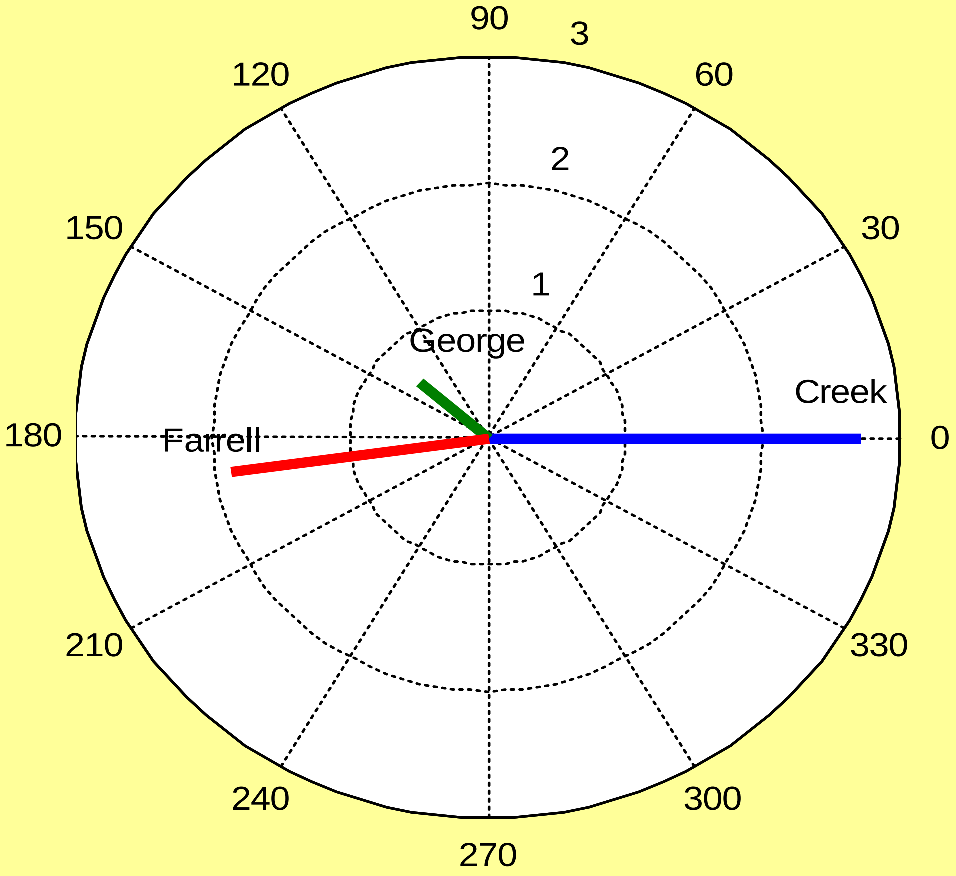


Spectrum of autocorrelation (Basslink imports 450MW from VIC)



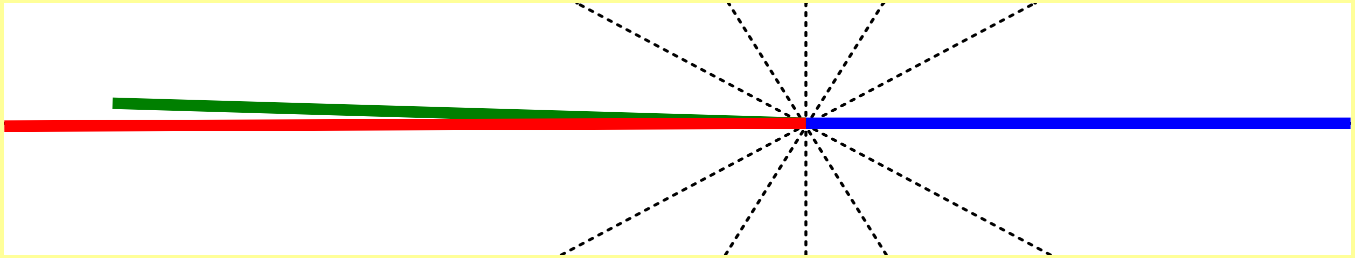
Mode 1 shape from Measurements

Phasor plot at W=7.5961 rad/s (Basslink export 510MW to VIC)



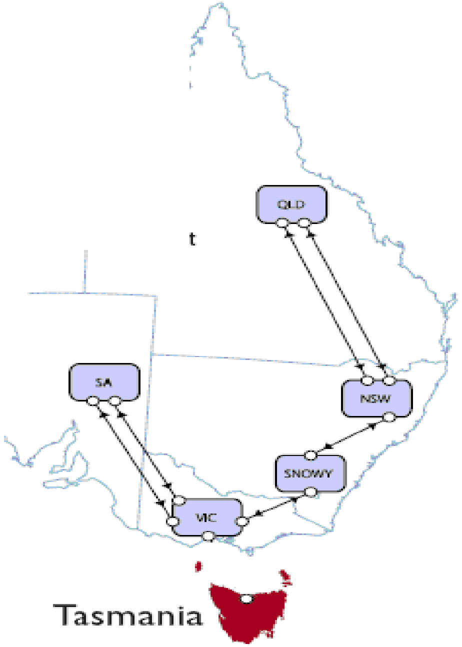
(B) Mode shape of mode 2 (Basslink with power export to Victoria

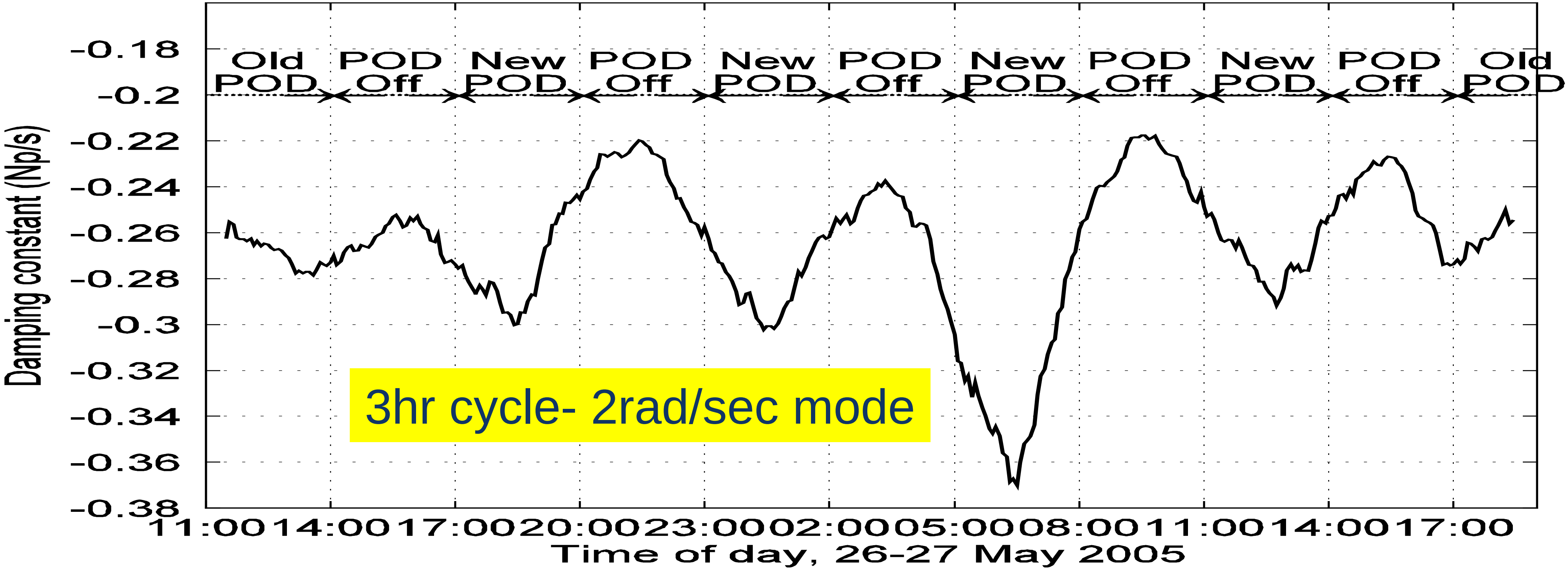
Phasor plot at W=22.6498 rad/s (Basslink exports 510MW to VIC)



Modal Damping Estimation

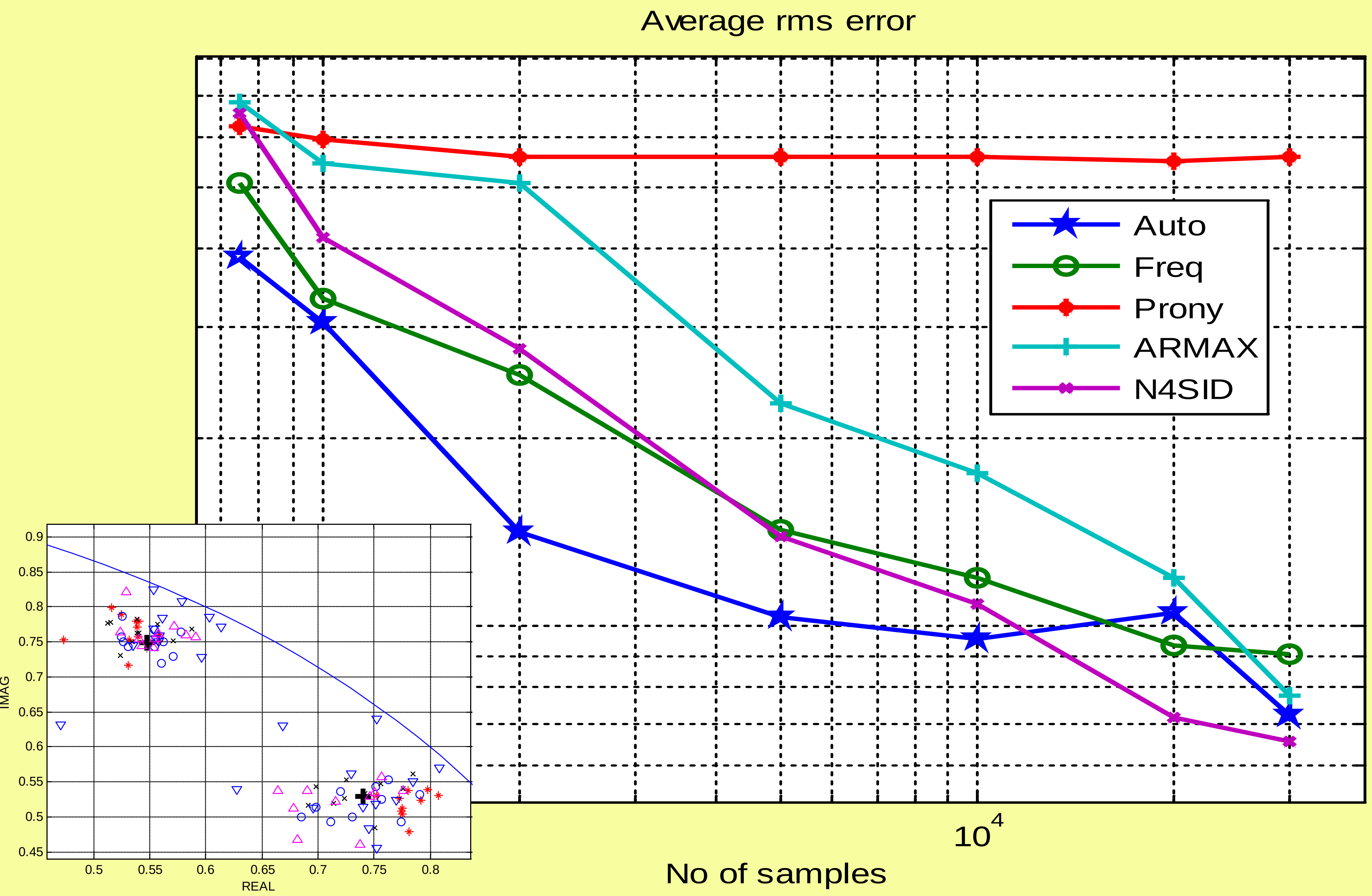
- Multisite angle to COA, auto and cross correlation
- Apply matched filter approach and shape with approx 10 sec exponential decay
- Fit common pole model to frequency domain data
- Mode damping is key parameter 3 main modes:





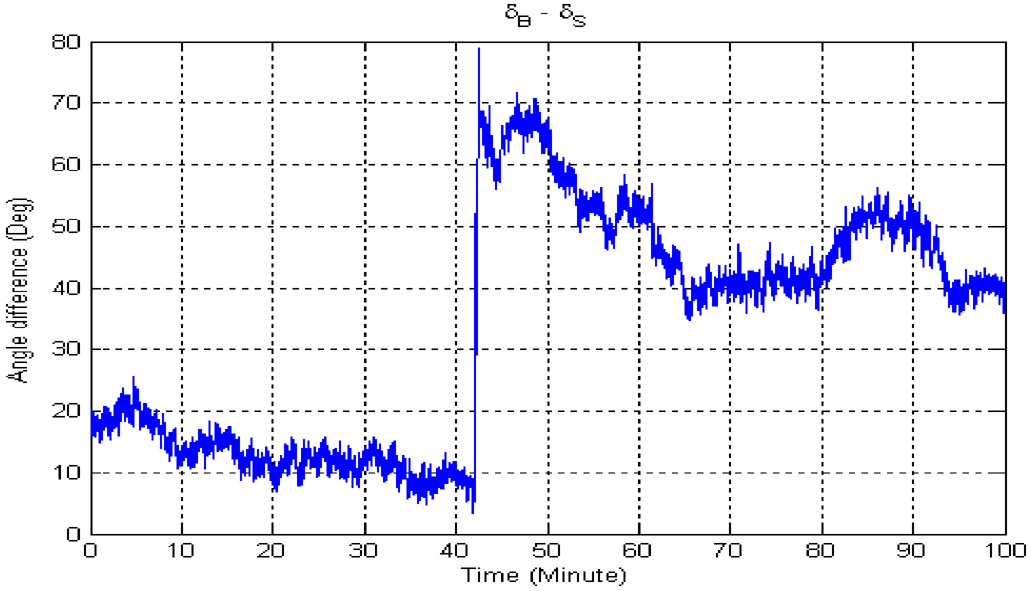
3hr cycle- 2rad/sec mode

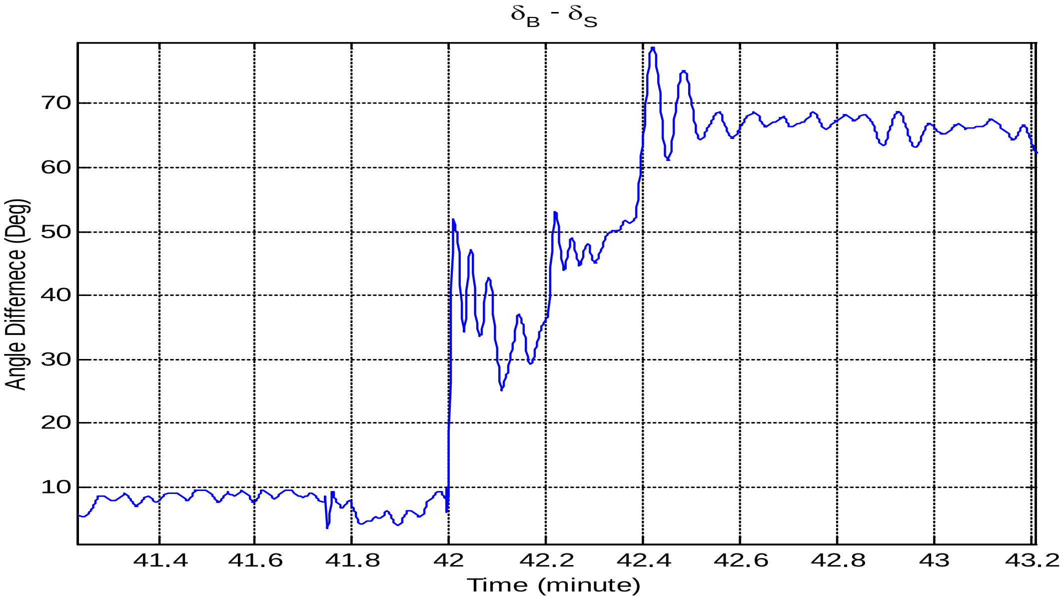
Find 2 modes –synthetic data: best performance for smaller data sets is weighted time domain fitting to autocorrelation



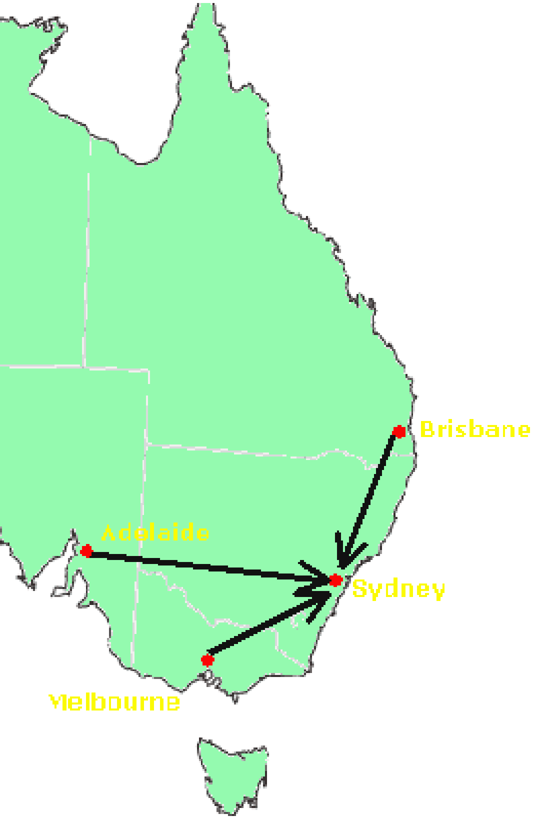
Recent Events in Australia

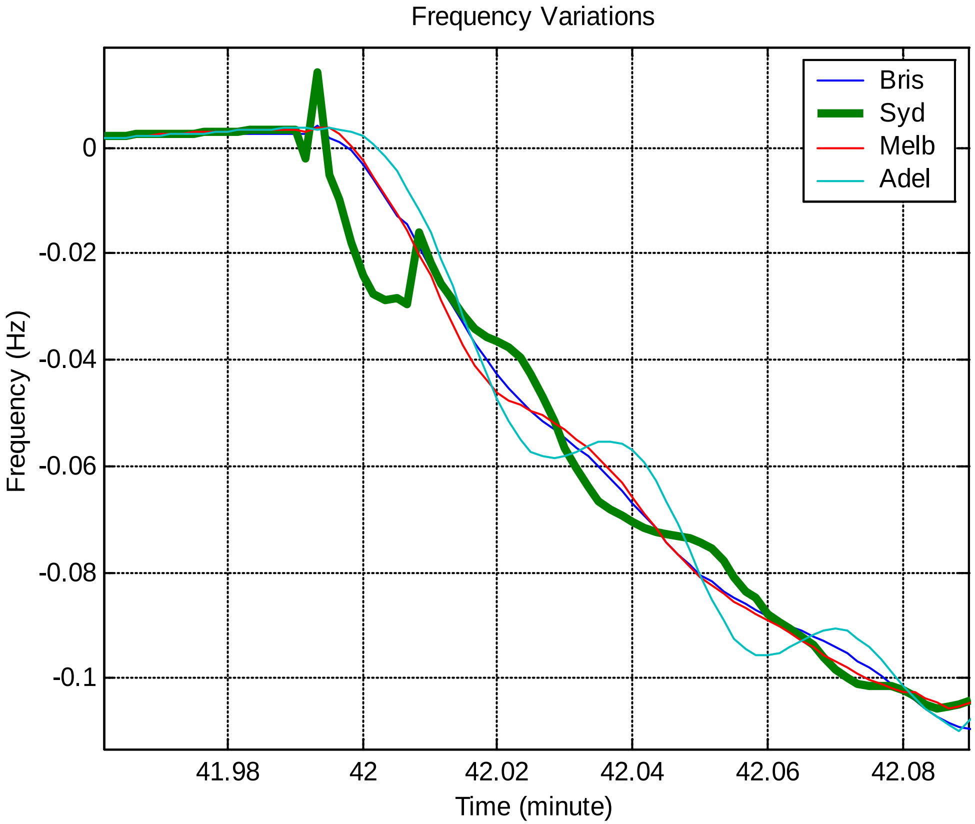
- Loss of 5 generators near Sydney
- Significant load shedding in Qld
- Peak Stress across link between states became high
- Recommend that load shedding scheme respond to initial df/dt as that shows the region of fault





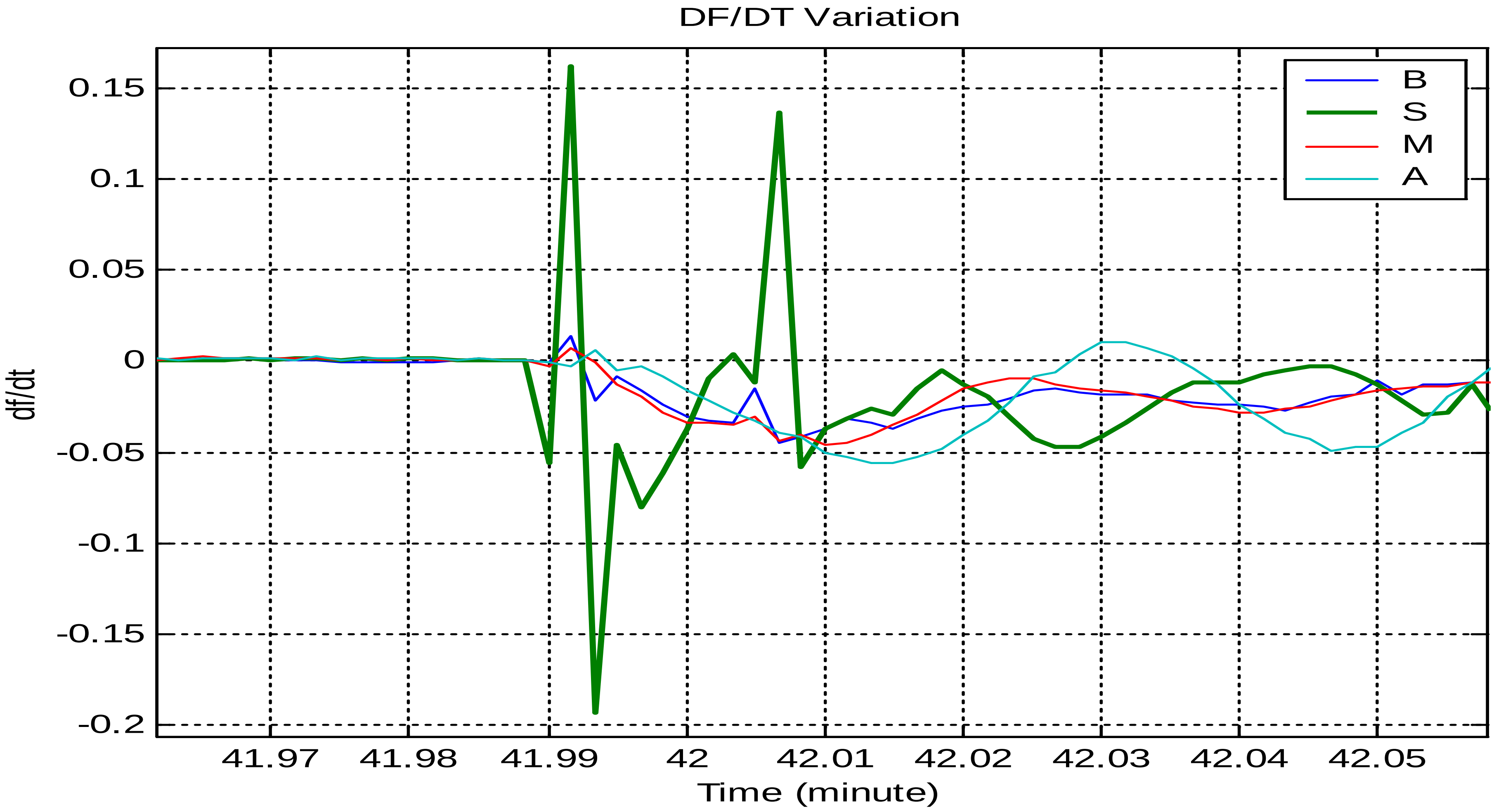
Initial df/dt much worse in NSW





- Can advance local load shedding if that region has major loss of generation

The stress on the interconnector QLD-NSW would have been reduced if load shedding was biased in the area of highest initial df/dt



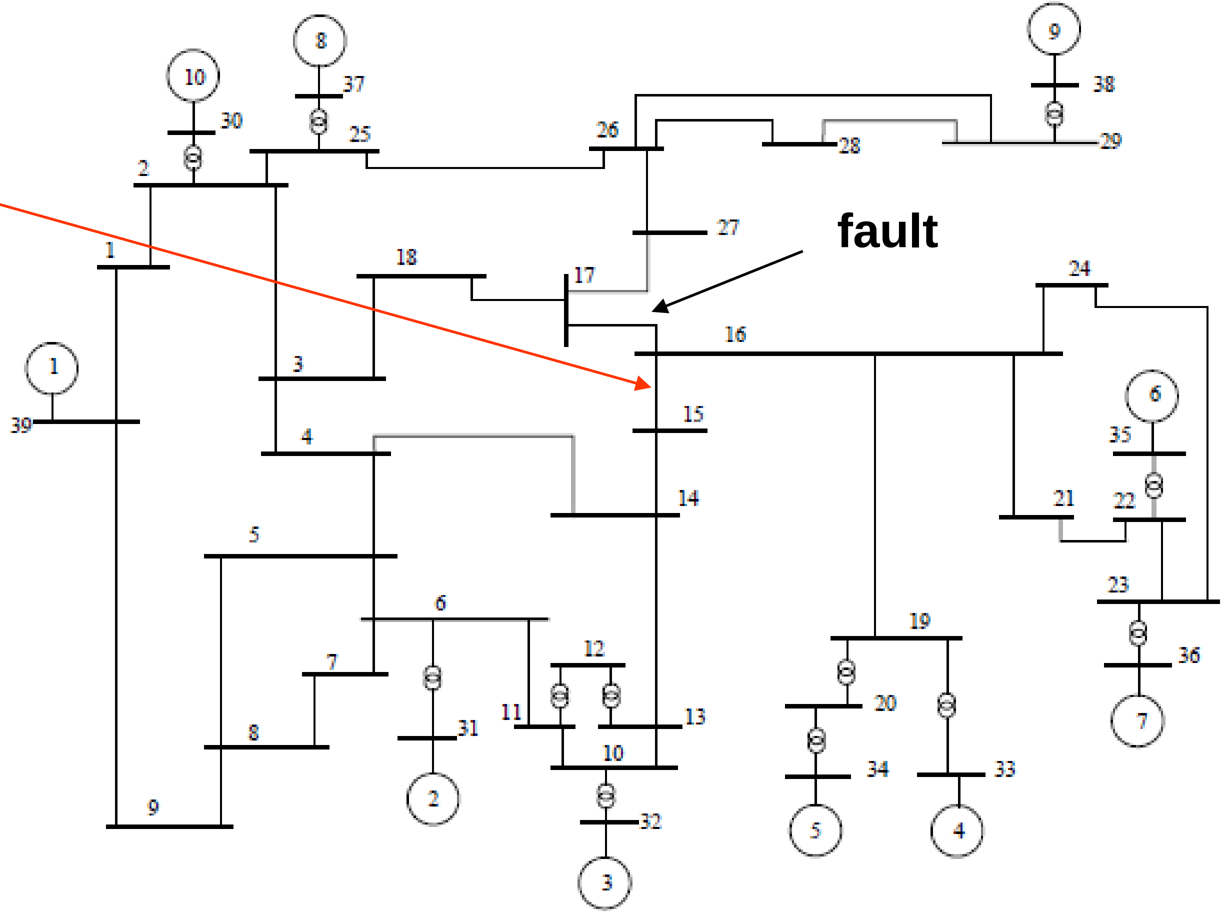
WIDE AREA CONTROL: Model predictive control to determine best nonlinear control

- Model predictive control starts a model of the system from the current state.
- The control values over the next set of time steps U=[u1 u2 u3..u20] is then optimized using search techniques optimizing some performance measure.
- Thus we will have initial U_0 and performance J_0 and then have a step to U_1 and J_1 to find best U

Model predictive control to determine best nonlinear control- part 2

- The first step for the control value is then applied to the real plant and the optimizations re-commences from the state at that time
- Originally for complex but slow chemical plants. Now with reduced models and an energy based performance it becomes applicable to power systems

Model predictive control to determine best nonlinear control

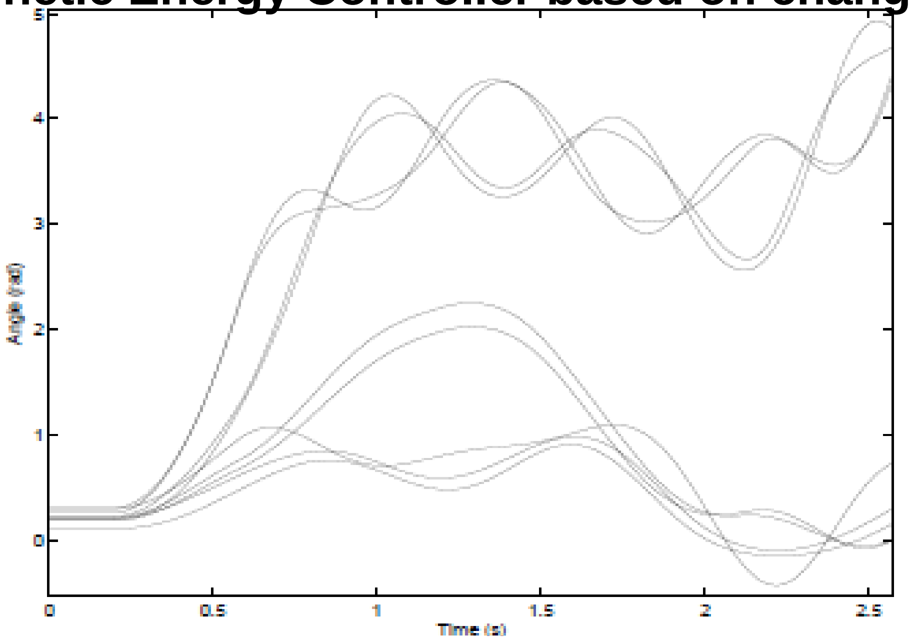


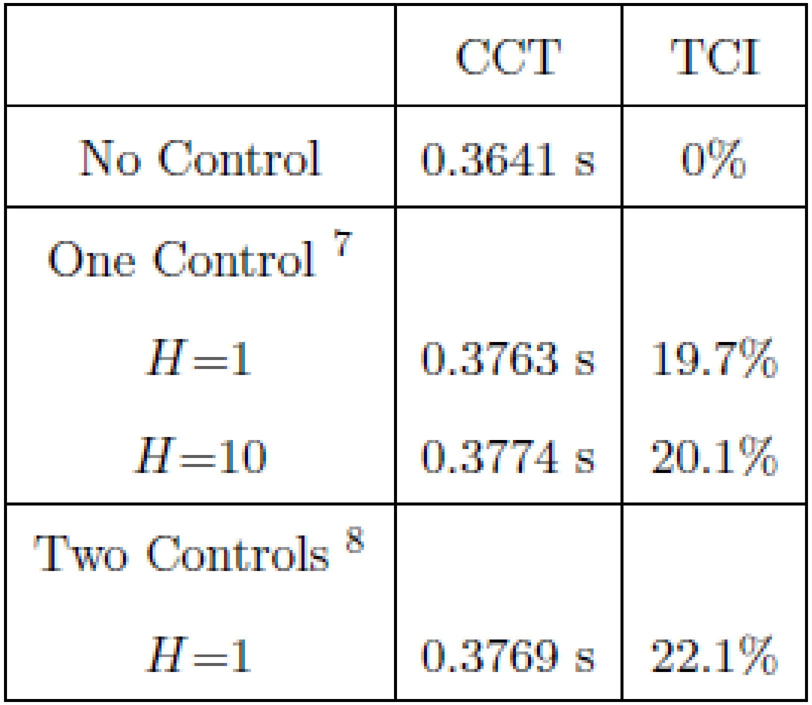
series controller
line 15-16

fault

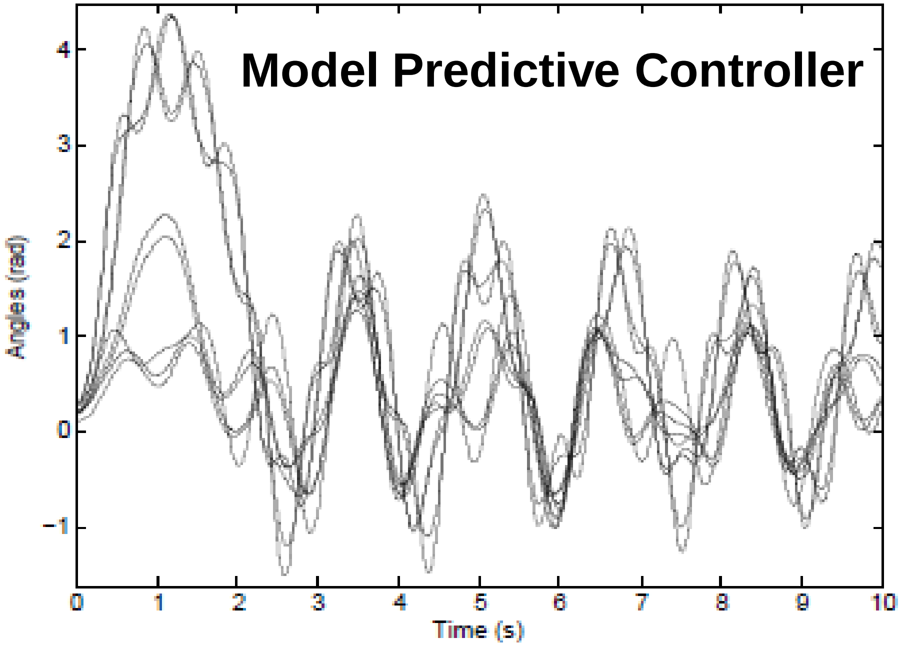
- New England test System

Kinetic Energy Controller based on change of angle across link





	CCT	TCI
No Control	0.3641 s	0%
One Control [7]		
$H=1$	0.3763 s	19.7%
$H=10$	0.3774 s	20.1%
Two Controls [8]		
$H=1$	0.3769 s	22.1%

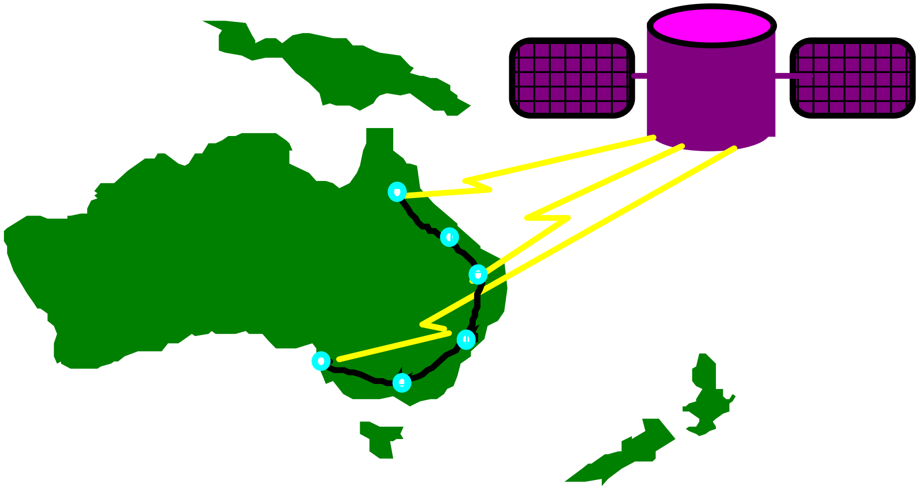


Model Predictive Controller

Improved transfer capacity following 16-17 fault with MPC

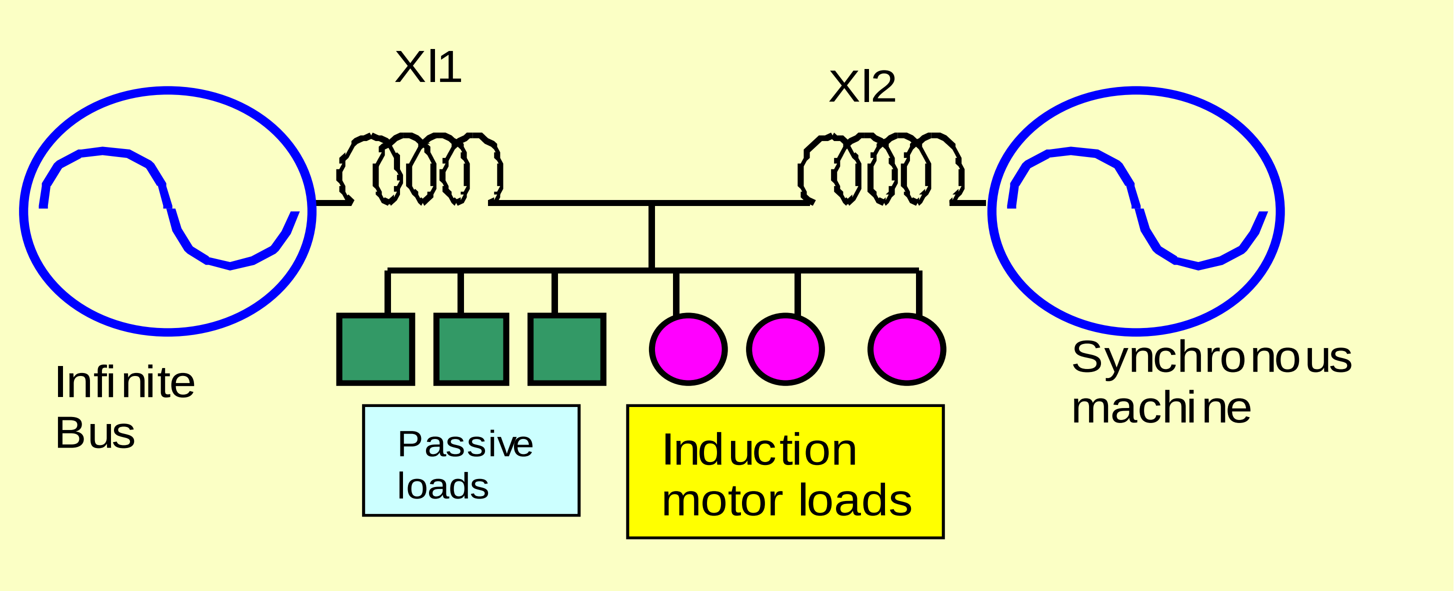
Summary of one “smart” transmission algorithm

- Remote measurements can permit live nonlinear modelling of network dynamics and the development of non-linear controls



- Commenced in 1993 Measurements in Qld
- High accuracy measurement of phasors of Voltage and Current
- PMU to 4 substations for system dynamics and 5 new units now deployed for Tasmania major load modelling
- Identify dynamics of loads from live measurements of V and F affecting P and Q

Load effects



- Time constants of composite loads affect the damping contribution of loads and response to major transients.
- Effect varies as time of day depending on mix of motor loads.
- Not one single time constant but mix of time constants of motor loads

Concepts and Issues

- The basic idea is usually to get the transfer function from frequency changes to P and Q , ‘f’ is the input and P is the ‘Output’

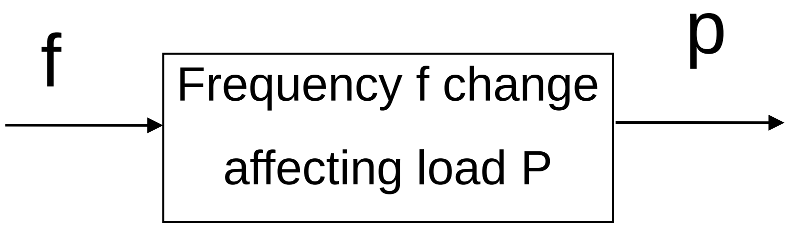
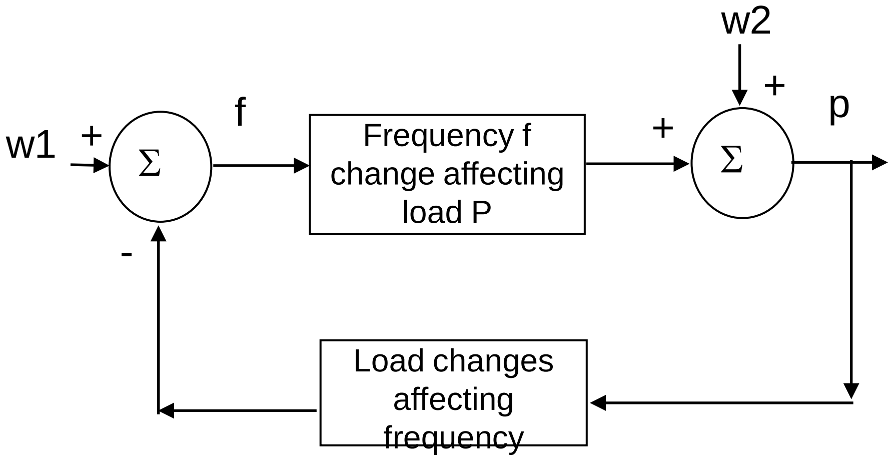


Fig 1 Basic Model

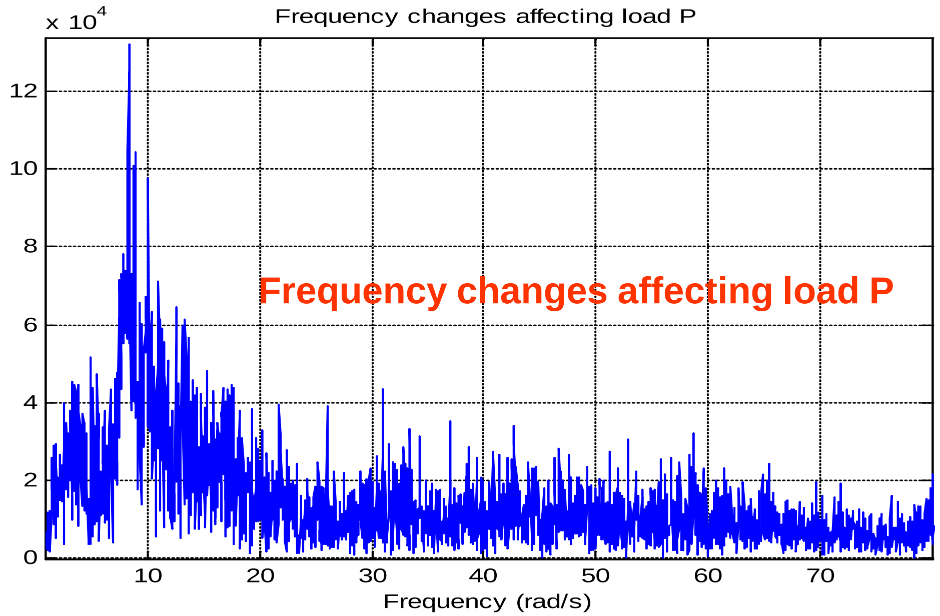
- The reality is that changes within the feeder will affect bus angle and thus the measured frequency. P is input f is output

Fig 2 Feedback Model



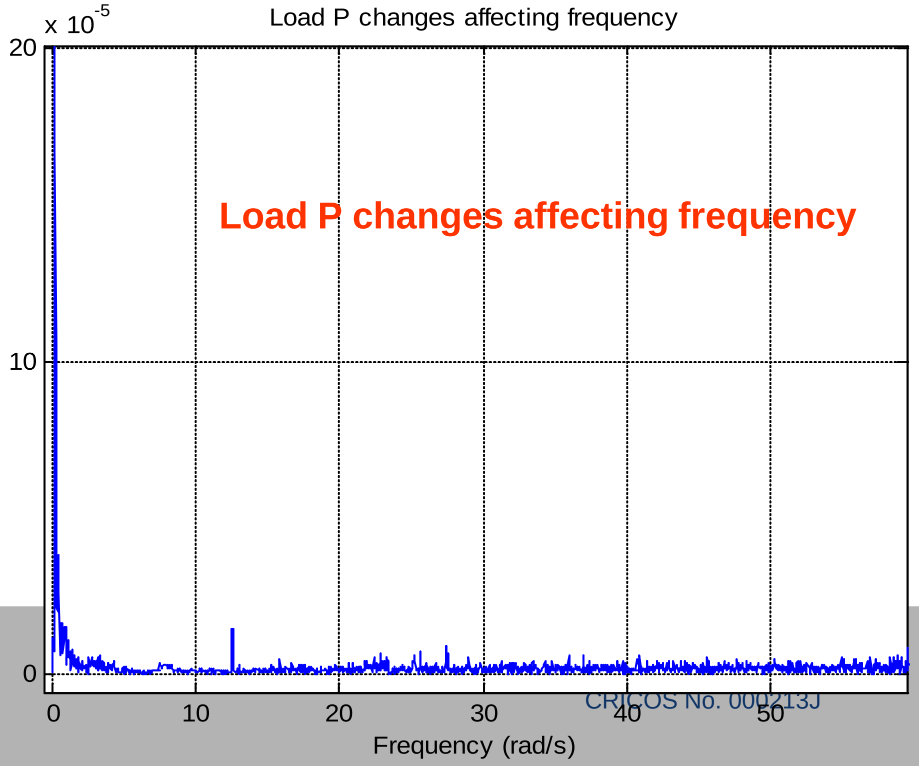
Industrial Load Tasmania

- This industrial load showed a good separation of feedforward and feedback terms (resonance in one not other)
- Located at node of system the load only affected governor mode not electromechanical



Frequency changes affecting load P

Frequency changes affecting load P

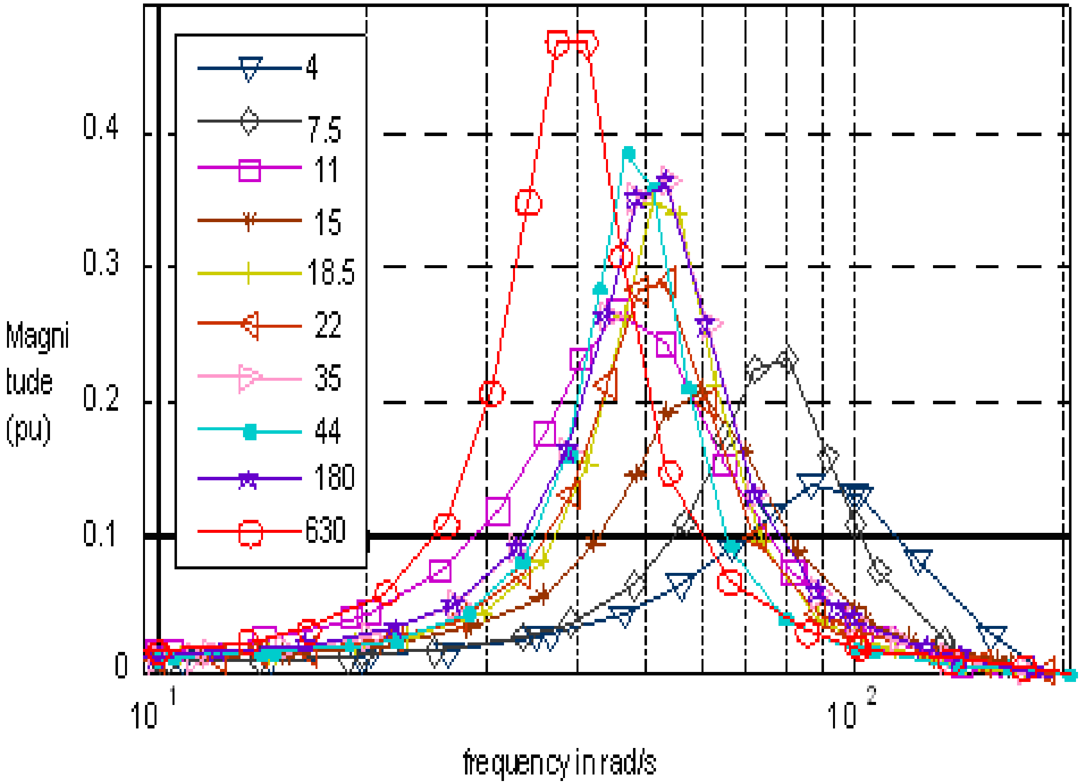


Load P changes affecting frequency

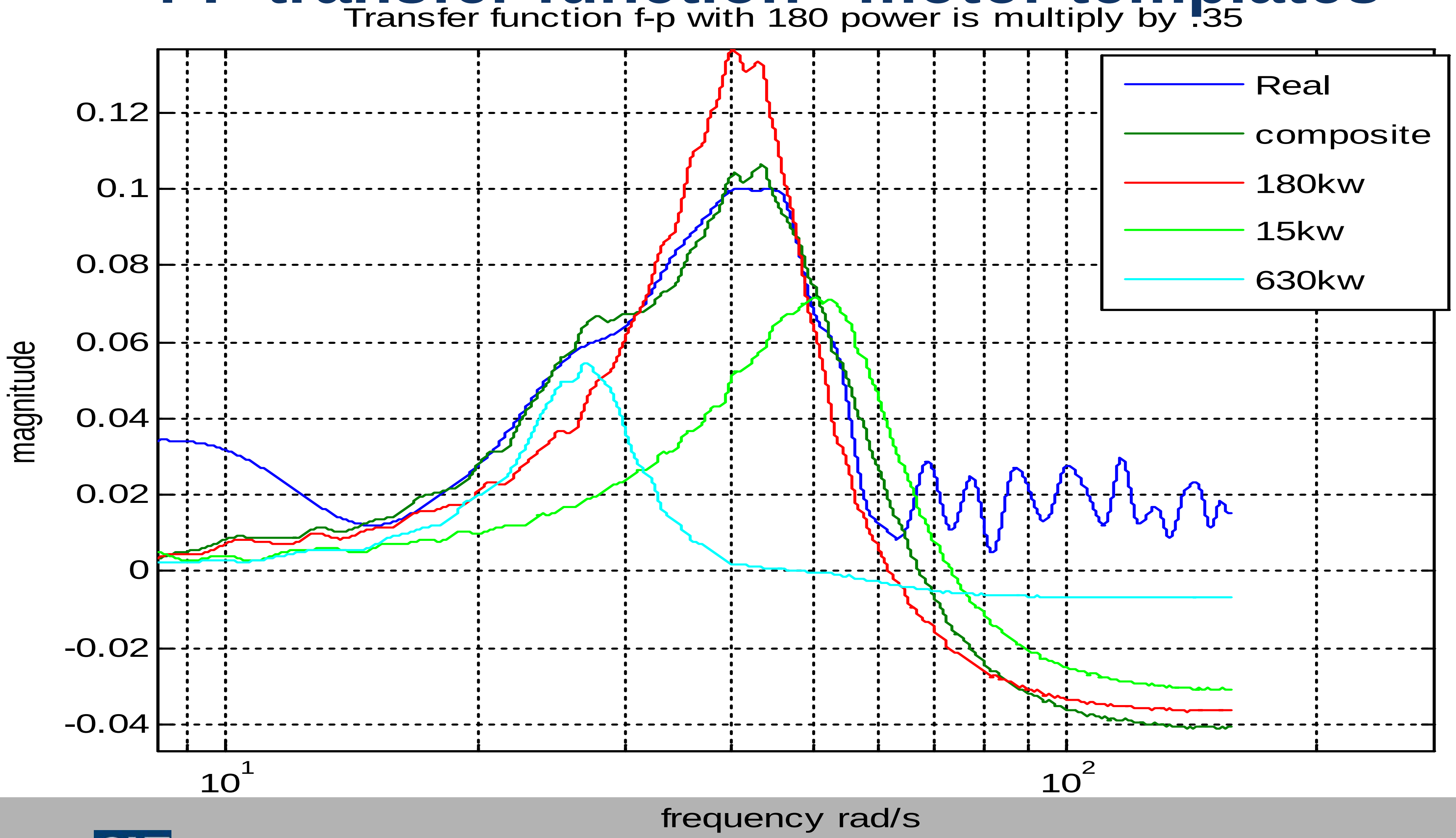
Load P changes affecting frequency

Induction motor frequency to Power transfer function

- Ten machines from 4kW to 630kW
- The area under the curve is roughly the machine power



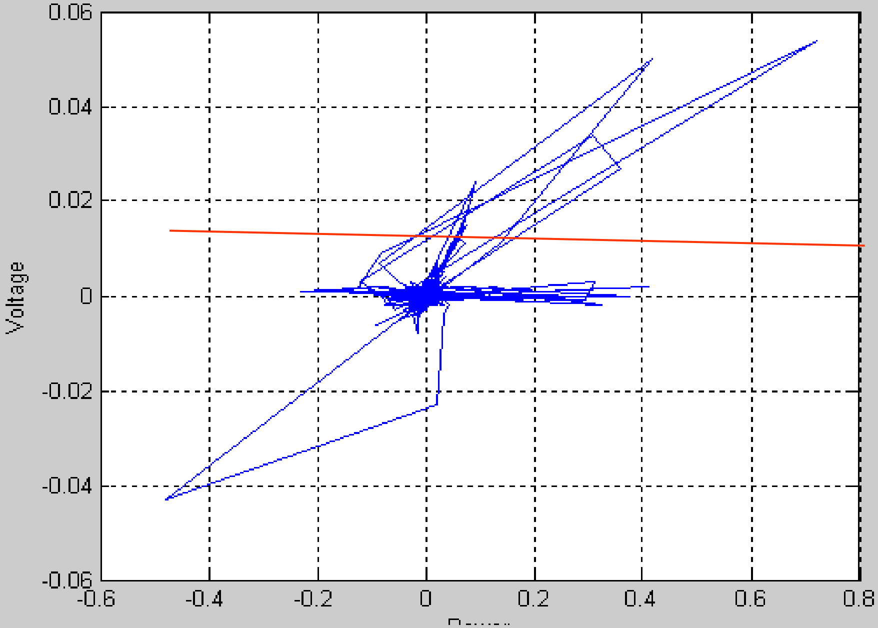
Data from Sydney West Sub: f-P transfer function –motor templates

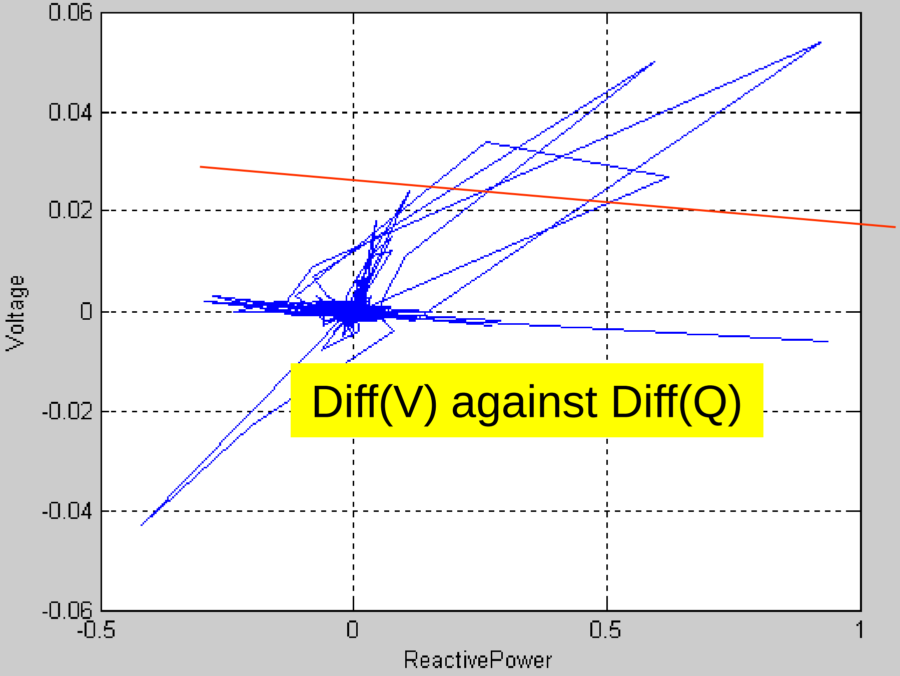


Voltage affecting loads

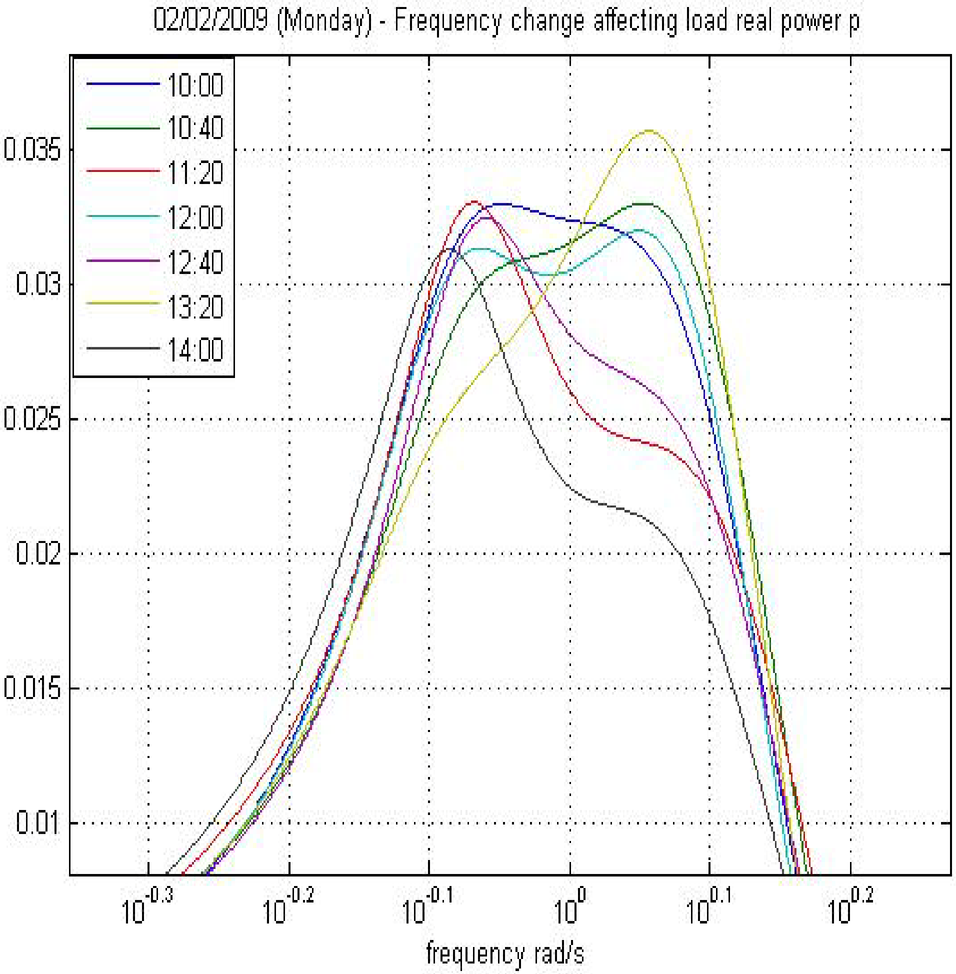
- Data from Sydney west shows voltage and P,Q.
- There are distinct events which are in the feeder and from other lines/loads
- V rise from external causes a +ve P change
- A P change in load causes a small V change but Q change gives a bigger V change- transformer high X/R

Diff(V) against diff(P)

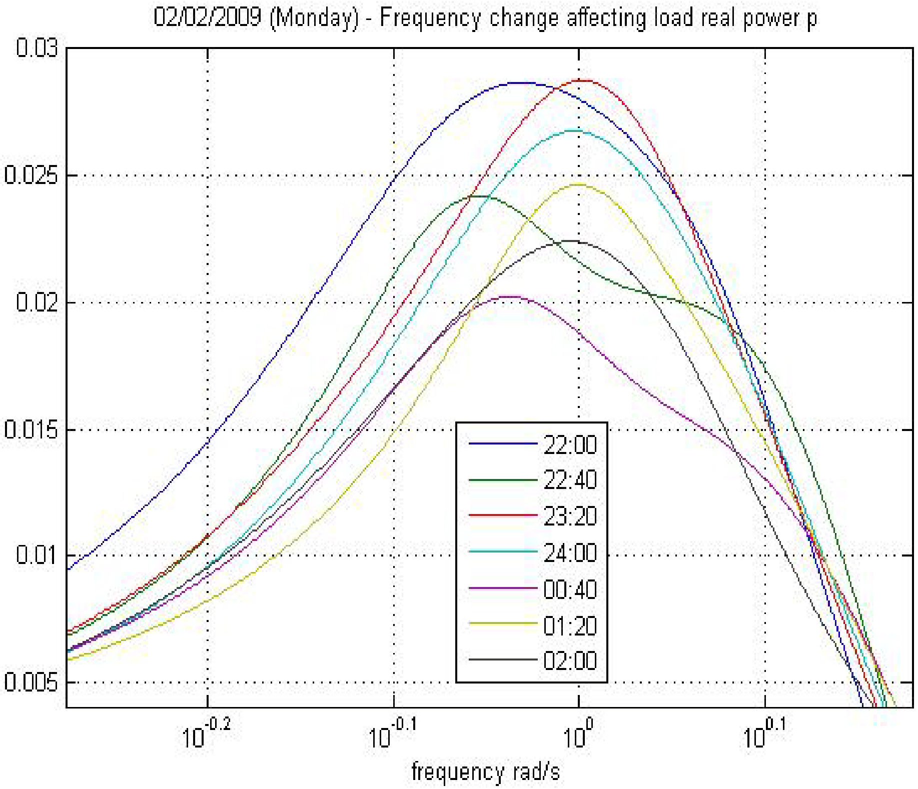



Diff(V) against Diff(Q)

Changes over 2Hrs, using 40 minute windows

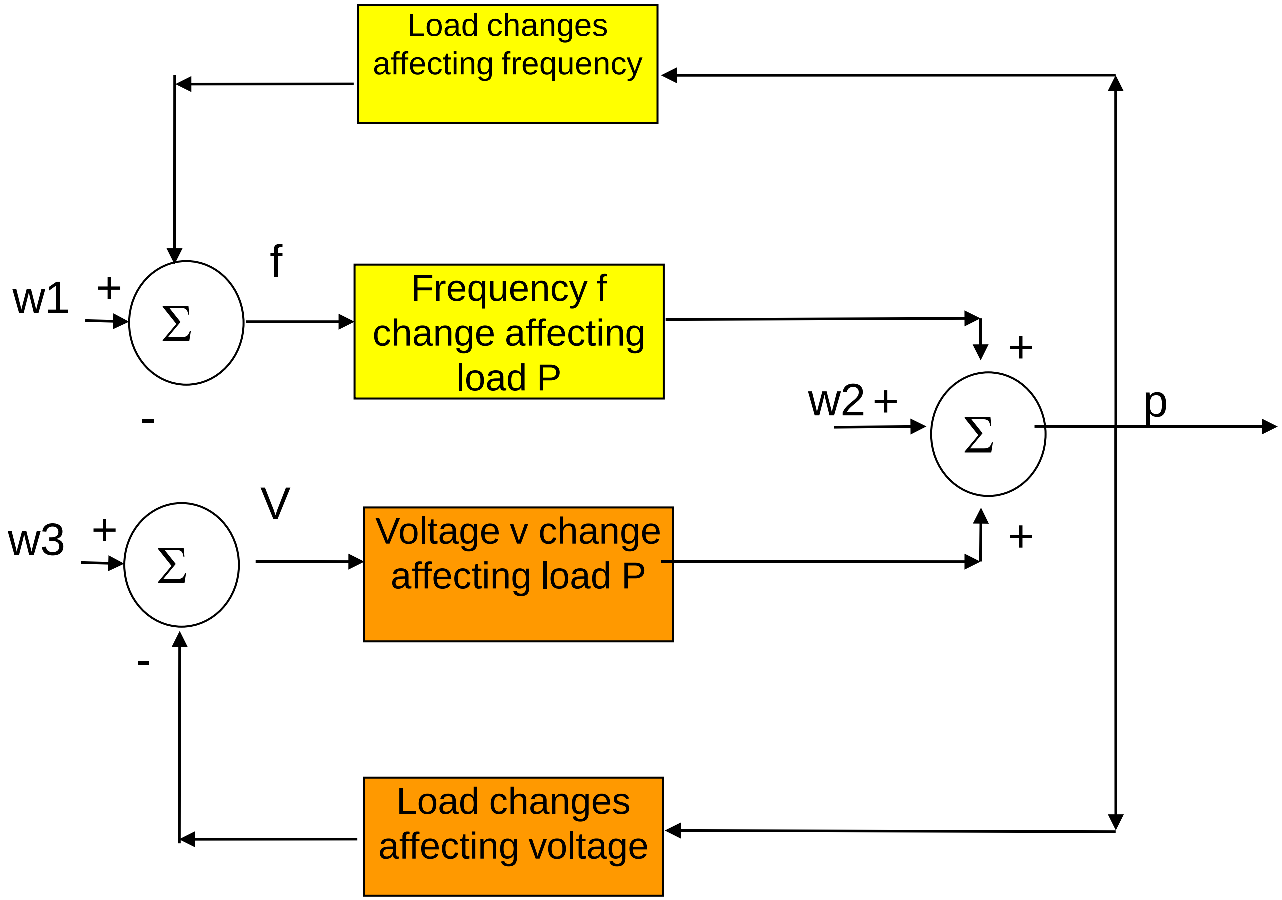


10:00 am to 2pm



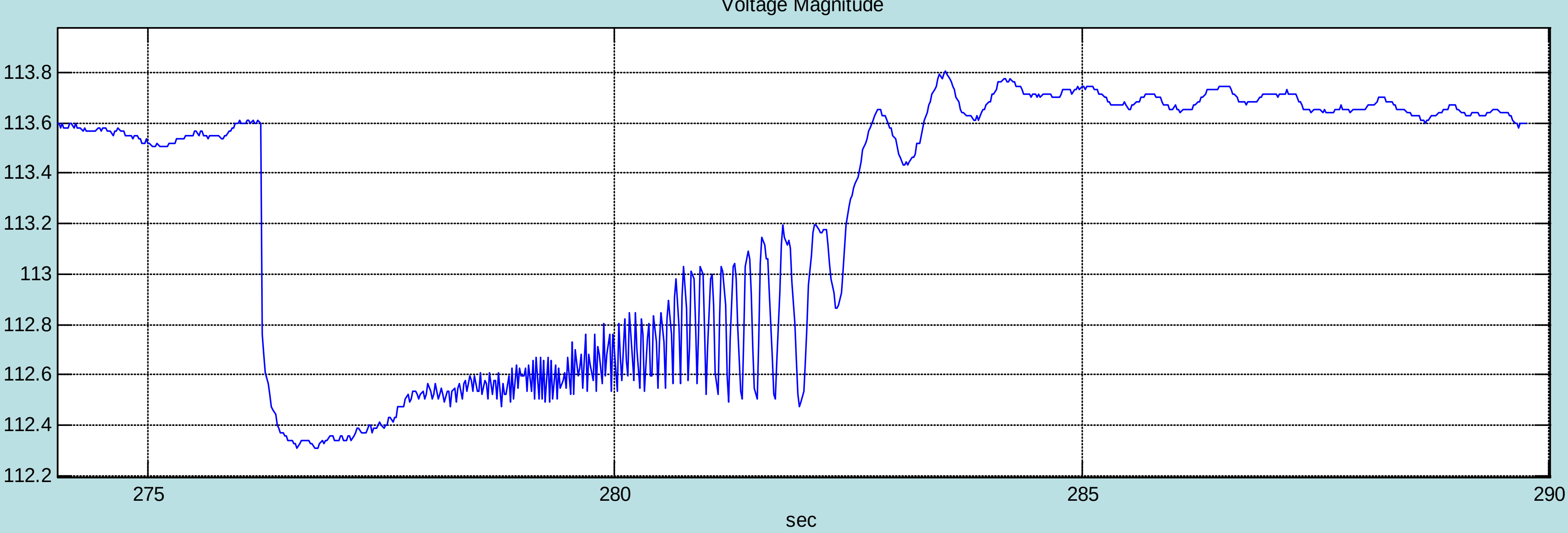
10:00 pm to 2am

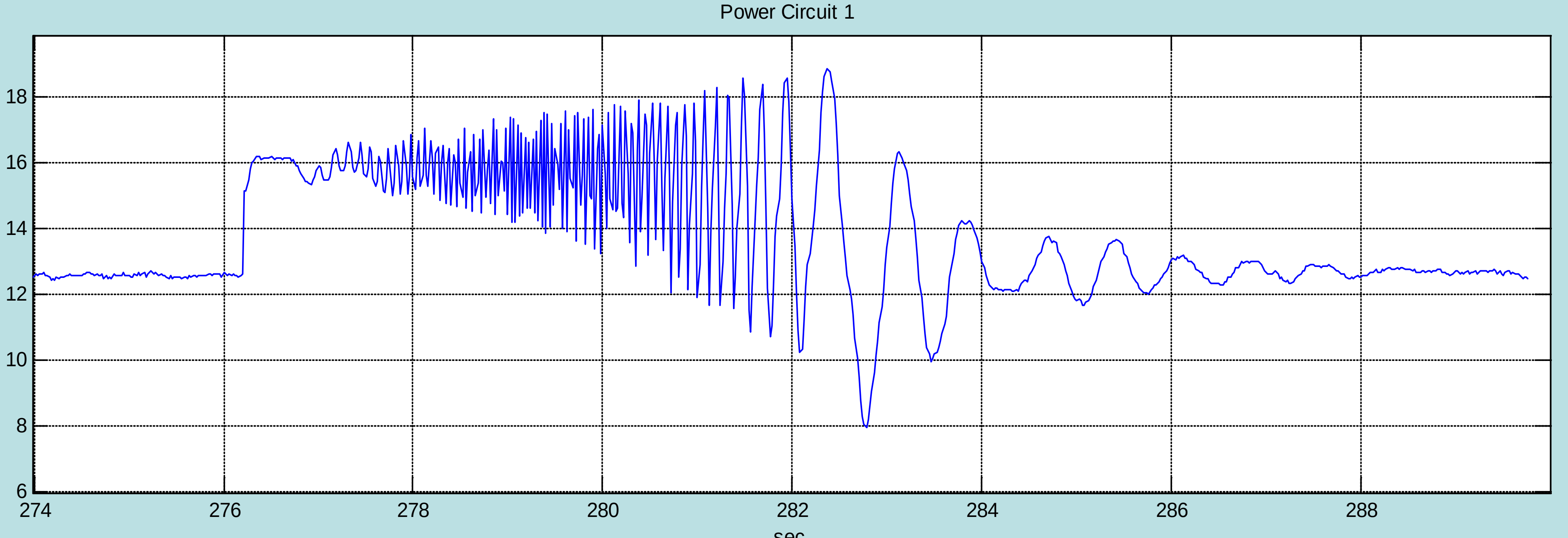
Actual system has at least 2 inputs



Conclusions

- **Load Modelling**: From small changes continuously occuring, the system affect load and load affect system can be separated because of low measurement noise of PMU
- From f-P relationship of "system affect load" the motor power and inertia can be separated as well as total motor power.
- This permits a continuous model of loads which means that response under major disturbances is better predicted and larger transfers can be safely used


Voltage Magnitude


Power Circuit 1