REAL TIME IDENTIFICATION OF GENERATOR EXCITATION SYSTEM MODEL & ROTOR ANGLE

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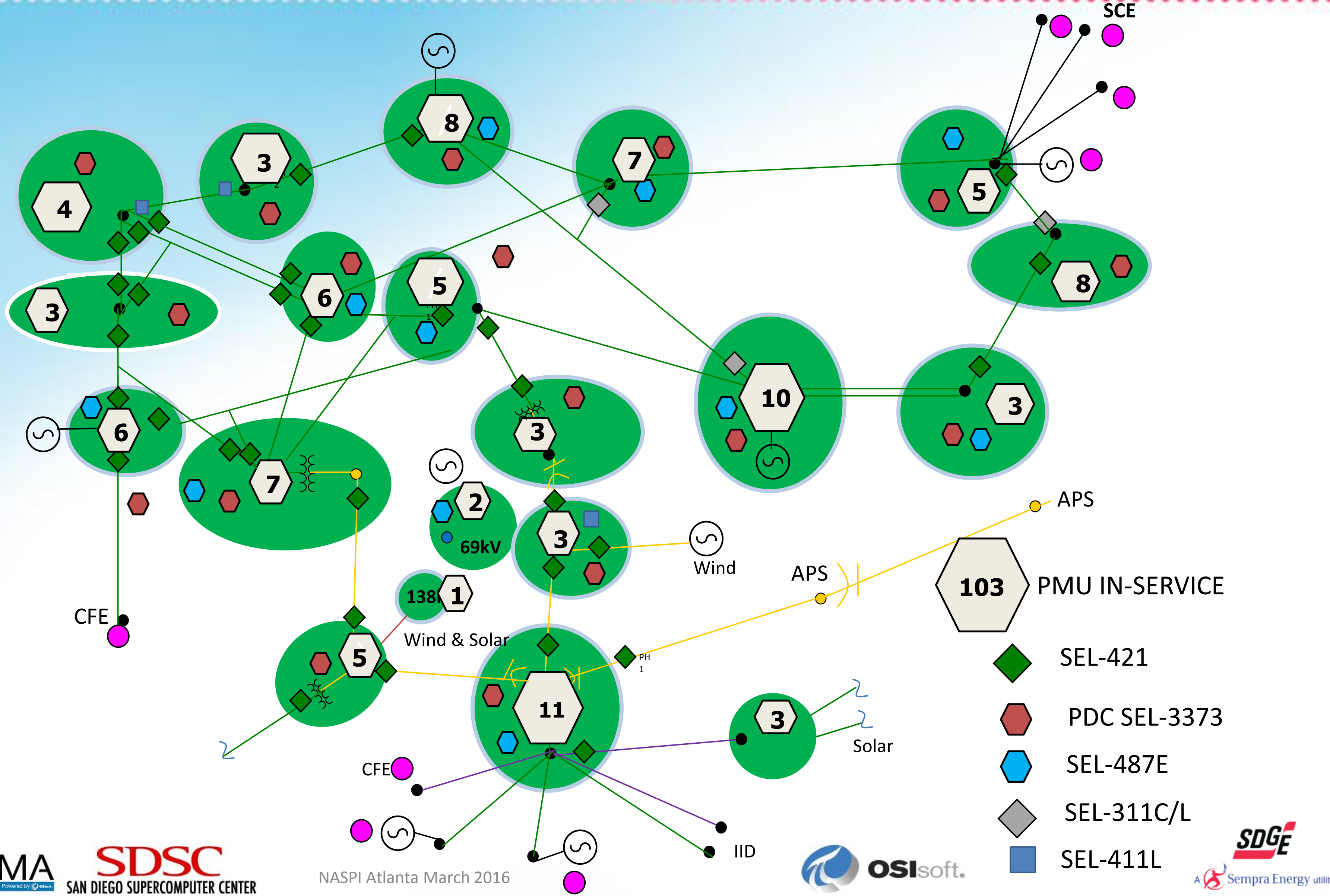
San Diego Gas & Electric (SDG&E)

- Subsidiary of Sempra Energy
- Regulated public utility
- Safe and reliable energy service for 3.4 million consumers
  - 1.4 million electric meters
  - 868,000 natural gas meters
- 4,100 square-mile service territory in San Diego and southern Orange Counties (25 cities)

SDG&E System

- 1,800 miles of electric transmission lines and 21,600 miles of electric distribution lines
- Two compressor stations, 160 miles of natural gas transmission pipelines, 8,100 miles of distribution pipelines and 6,200 miles of service lines
- 4,300 employees

SDG&E PMU Placement

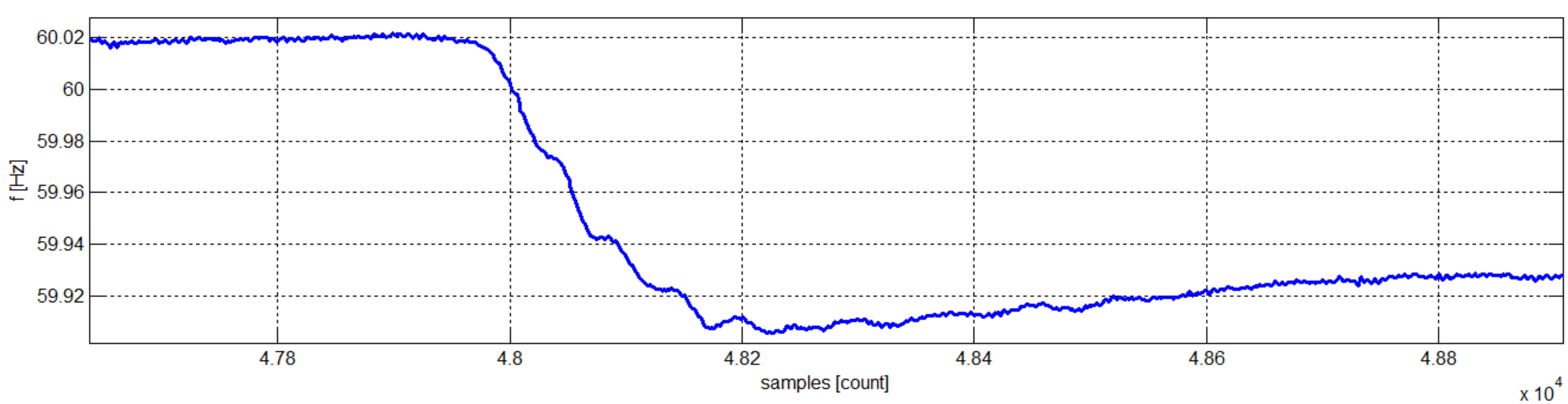


Motivation

Power system stability studies deal primarily with:

- transient in (power) angle and voltage
- transients in frequency

Typical transient effects in AC frequency due to power loss:



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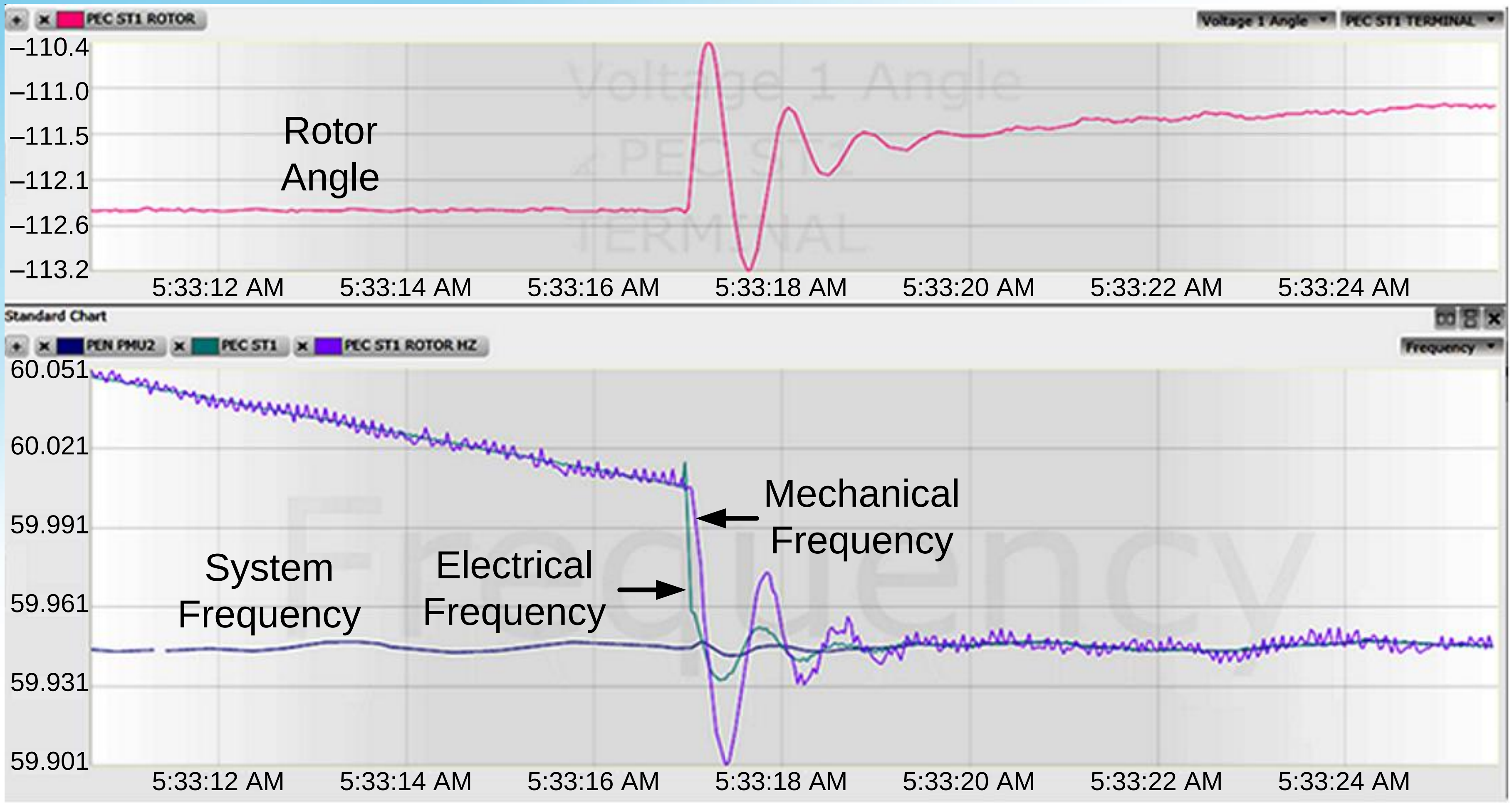
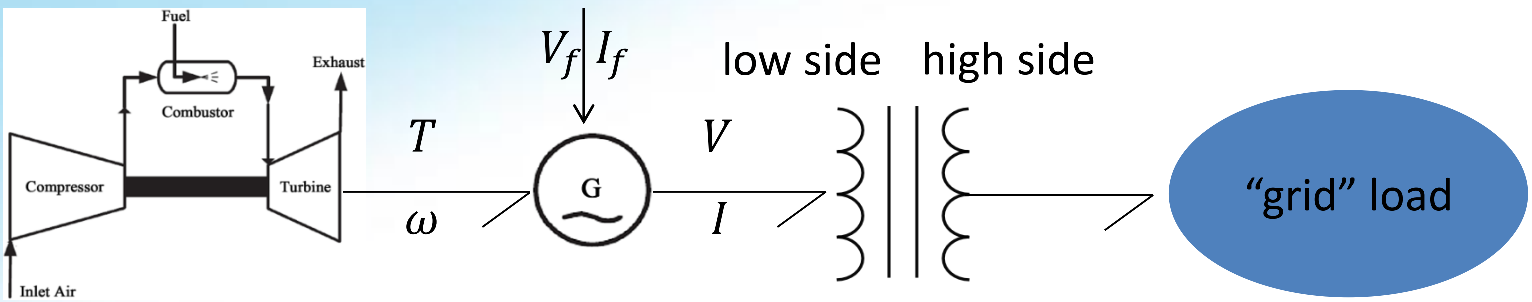
Motivation

Generator Start-up



Contribution

Study transient effects and model dynamics between measurable signal below in grid tied turbine/generator:



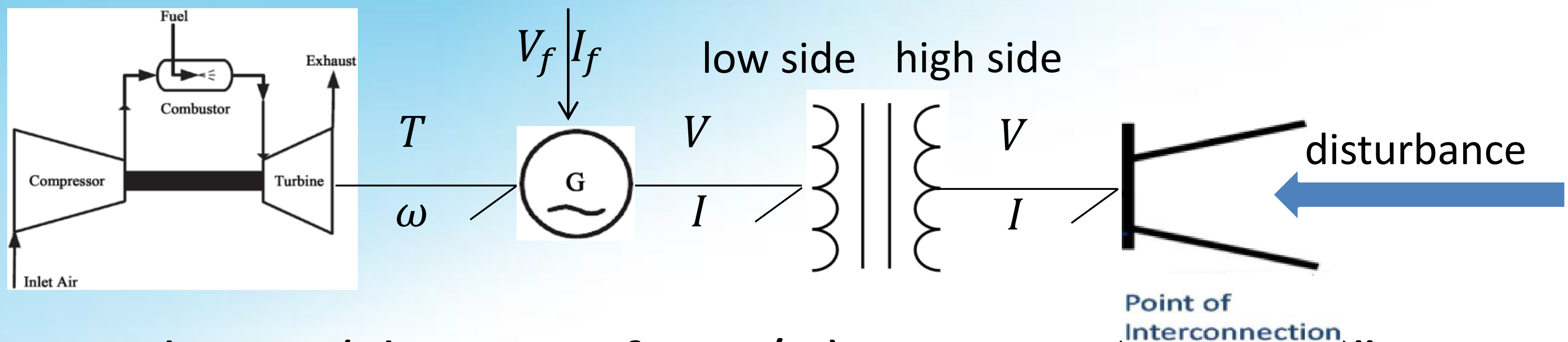
Measurable signals:

- V, I (or real/reactive power P, Q) at high side with frequency
- V, I (or real/reactive power P, Q) at low side with frequency
- Field V_f, I_f of generator
- Rotor angle θ or rotor angular speed ω

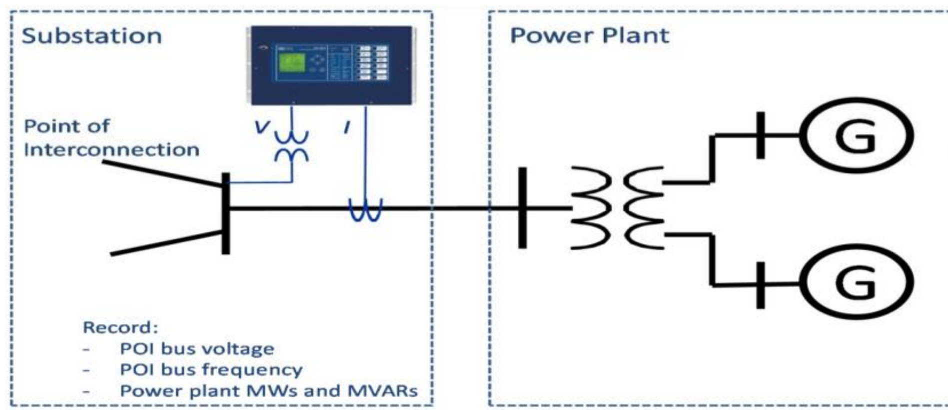
Outline

- Overview of data (from Combined Cycle Plant)
  - Chief Joe Break Test at 9/17/2015 @ 3:24pm
  - British Columbia Hydrotrip: 07/10/15 @ 4:58pm
- Dynamic models of Turbines Generators
  - GAST
  - GGV01 and simplified CIGRE
- Point of Contact Interconnect Modeling
- Results
- Conclusions

Overview of data

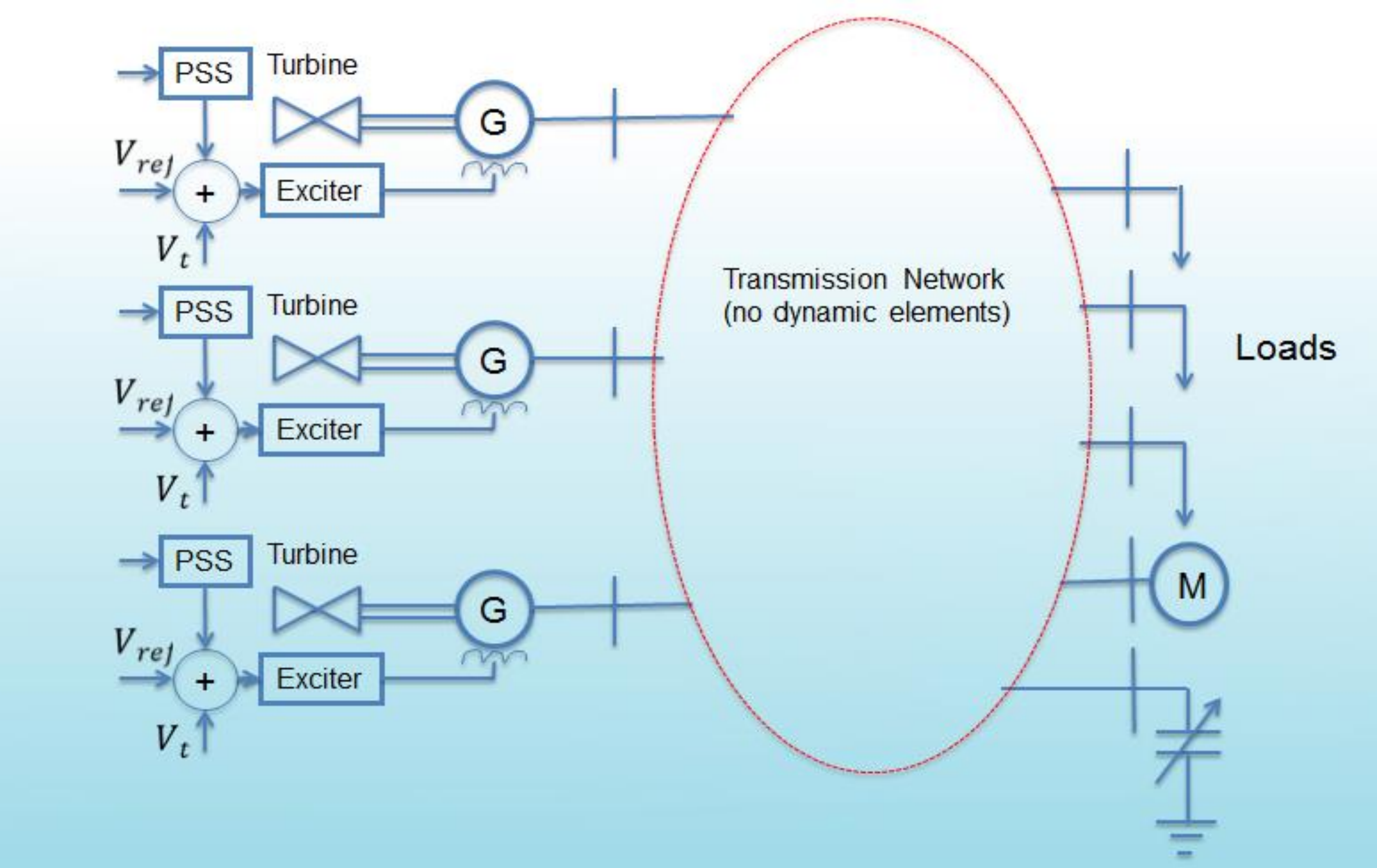


- Disturbance (change in f or P/Q) generated by “grid”
- Measurements of f, V/I and P/Q at high/low side
- In addition to Koserev/Yang approach:
  - Rotor “phasor” angle θ and rotor frequency ω
  - Field $V_f \; I_f$



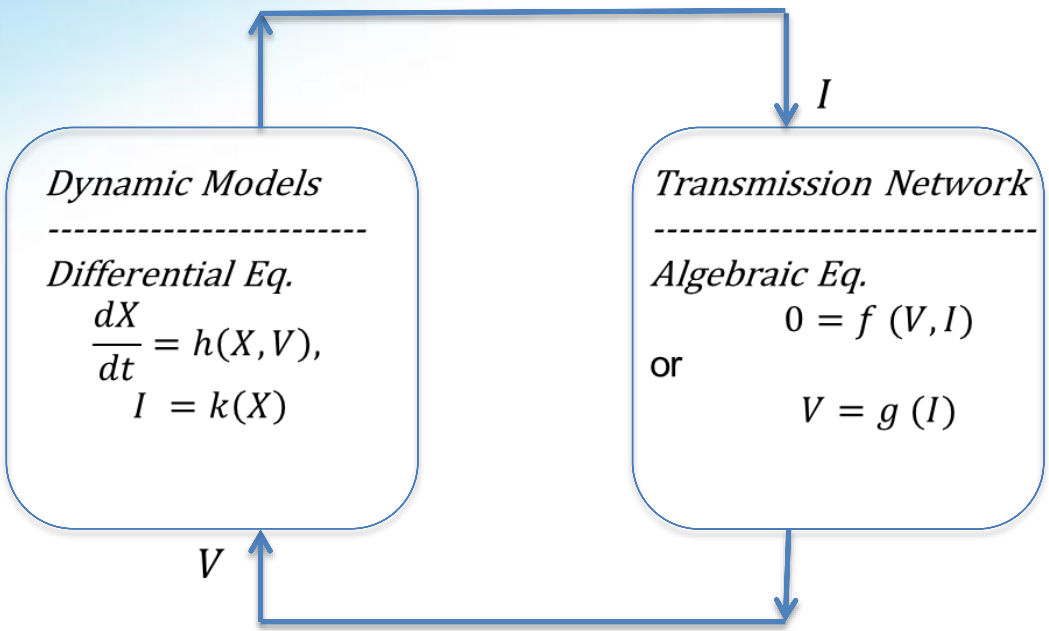
Overview of data

Dynamic (differential equations) and non-dynamic (algebraic equations) elements of the network



Overview of data

Dependence of generator unit dynamics on the network voltage magnitude and angle (or frequency)



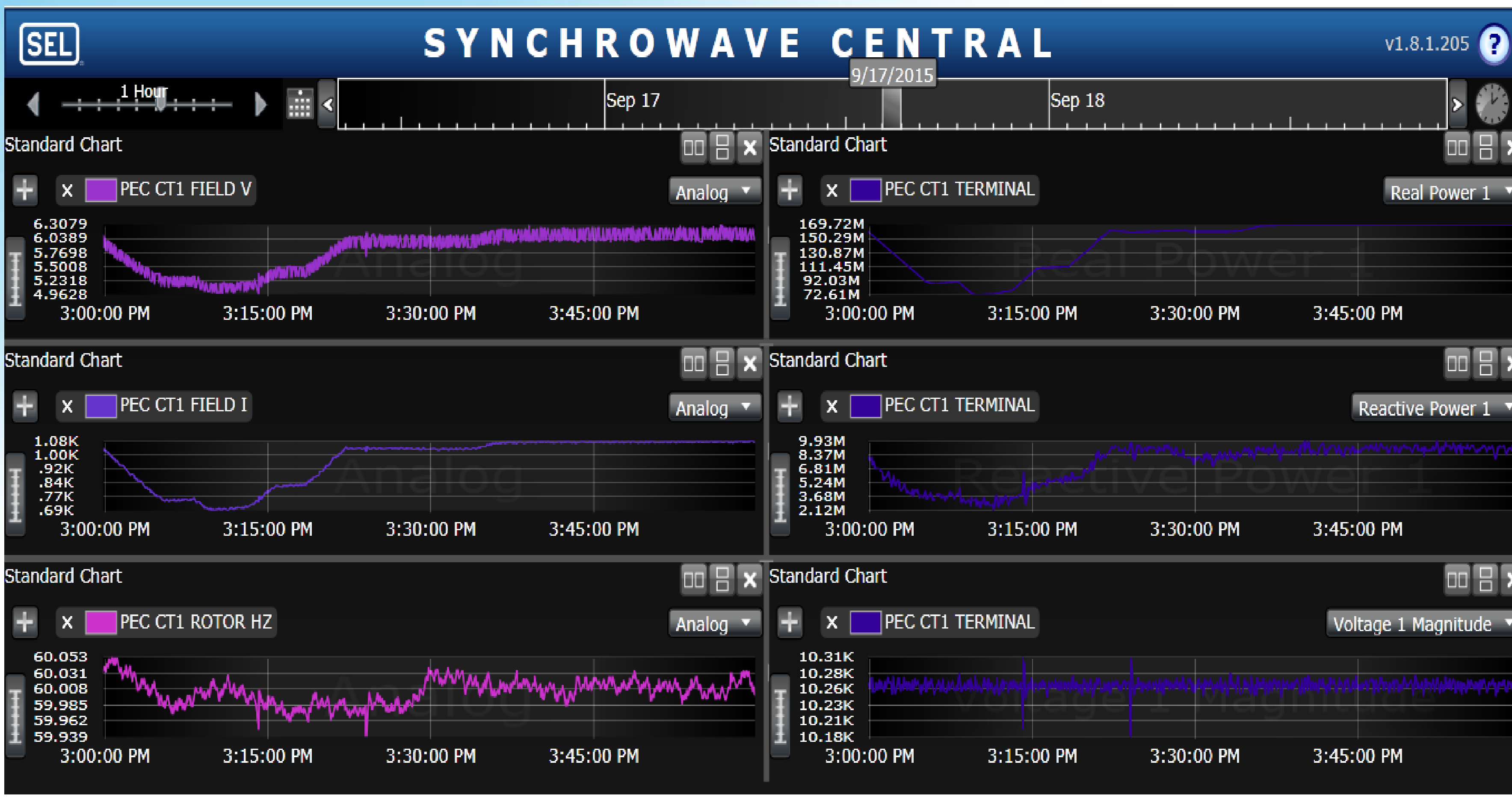
Overview of data

Excitation system model validation

1. Select a disturbance of significant magnitude
2. Extract the measured data from PI database Voltage magnitude, frequency, V_field and I_field, and Rotor angle
3. Create a reduced Power flow and dynamic model for the machine as seen at Point of Interconnection. Make sure that PSS is modeled
4. Playback measured PMU data for voltages and frequencies to the dynamic model
5. Compare the measured values of V_field, I_field, and Rotor angles with those from transient stability simulation
6. Tune parameters of the dynamic models to get a better match with the measured quantities.

Contribution

Sample PMU measurements of a Generating unit



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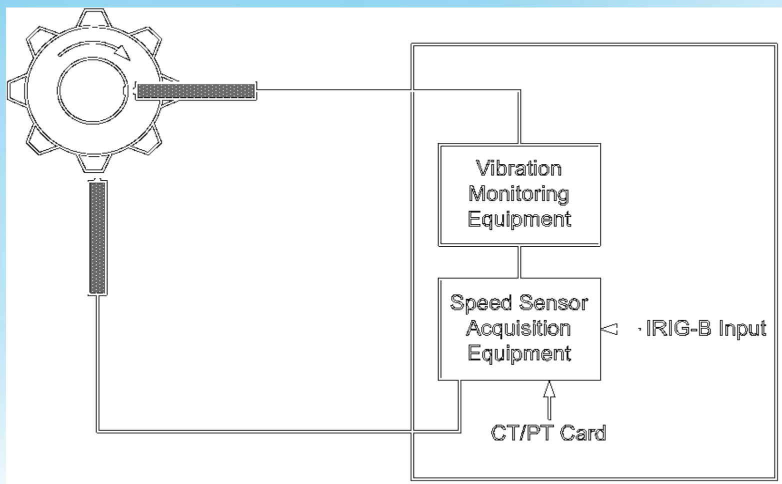
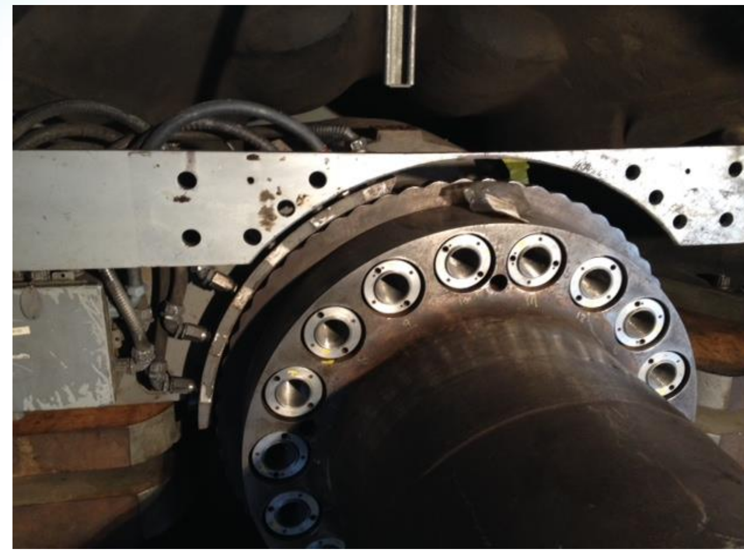
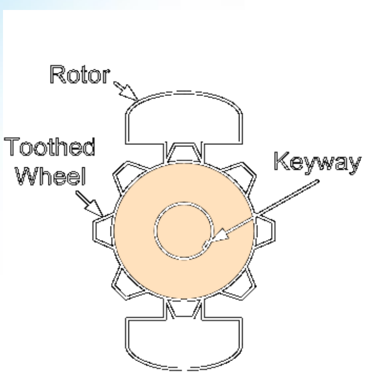
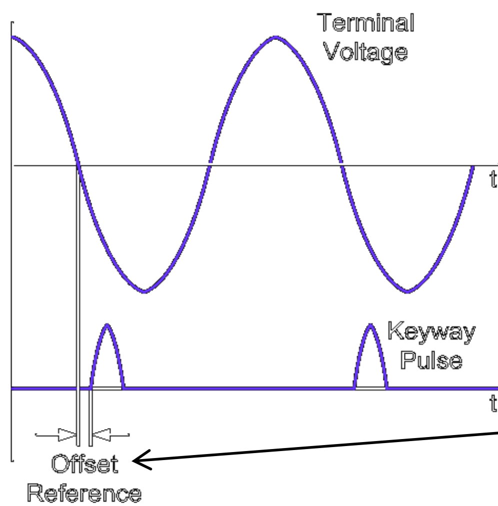
Overview of data

- Instrumentation for rotor angle measurements







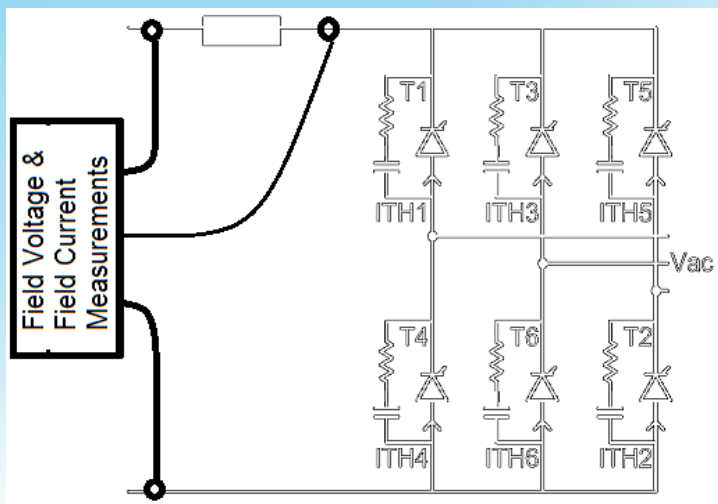


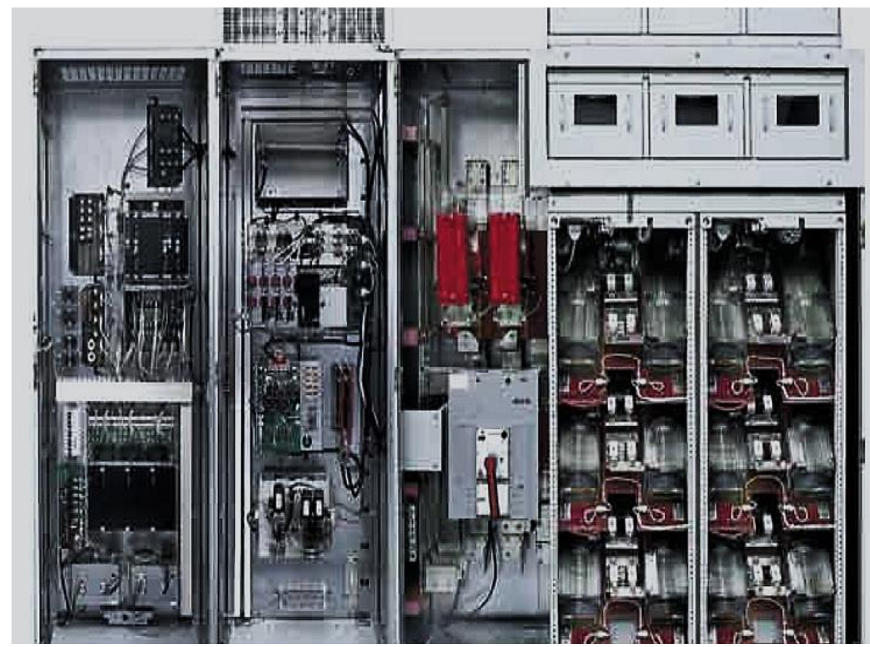
Rotor phasor angle via zero-crossing detection

Rotor frequency via timing measurement

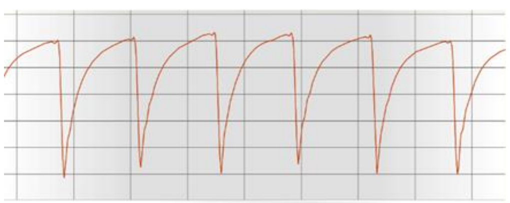
Overview of data

- Instrumentation for Field (V/I) measurements

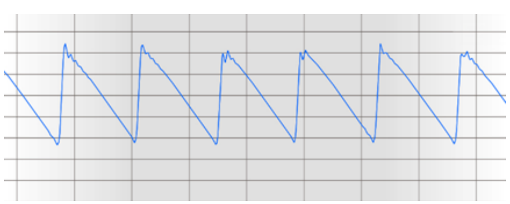




field current

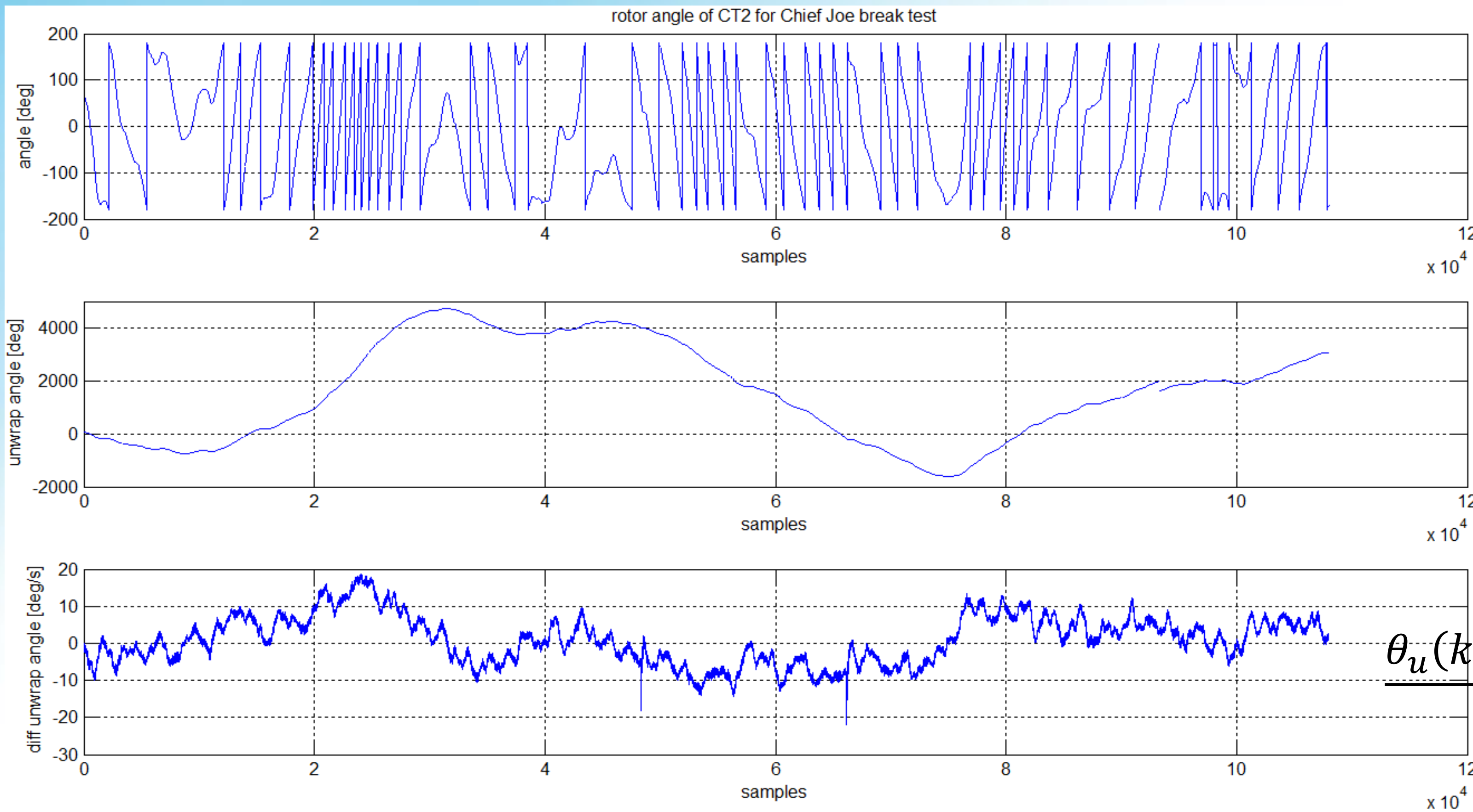


field voltage



Typical Rotor Angle Data

Chief Joe Break Test: 09/17/2015 - 3:00pm - 4:00pm (3:14pm and 3:24pm)



$\theta(k)$

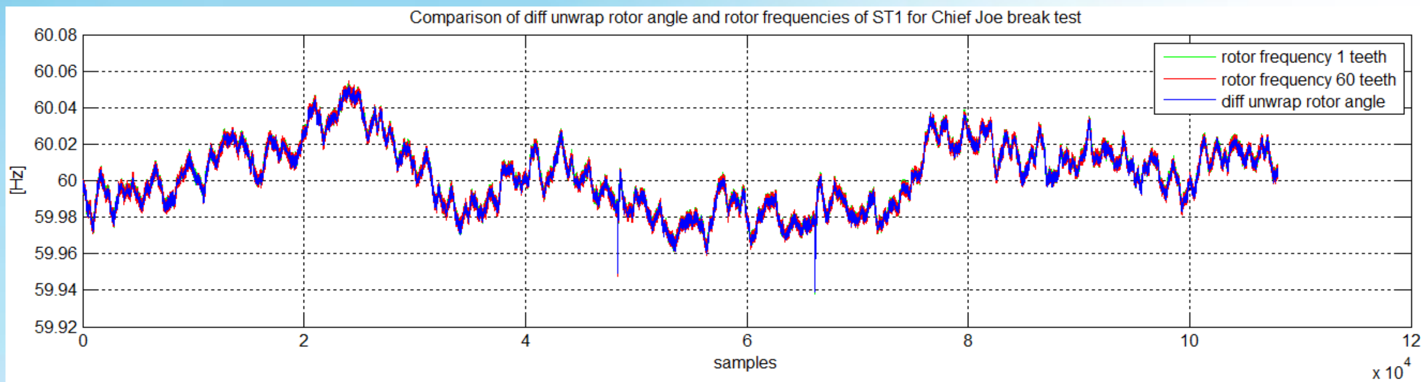
$$\theta_u(k) = uw(\theta(k))$$

$$\omega(k) = \frac{\theta_u(k) - \theta_u(k-1)}{0.03333}$$

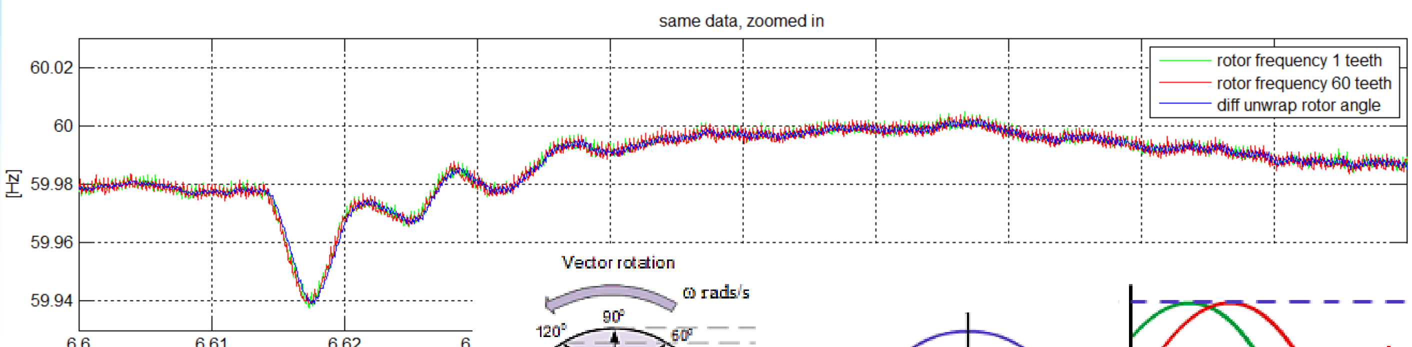
Note: $\theta(k)$ constant if rotor frequency = 60Hz (not absolute rotation)

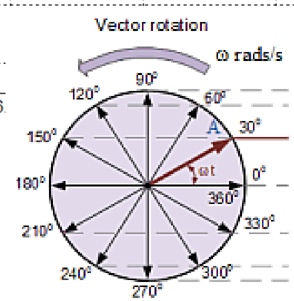
Comparison of rotor angle and frequency

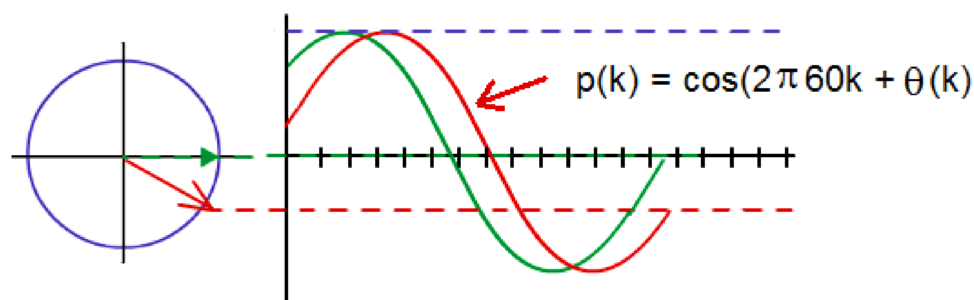
Chief Joe Break Test: 09/17/2015 (zoom in at 3:24pm)



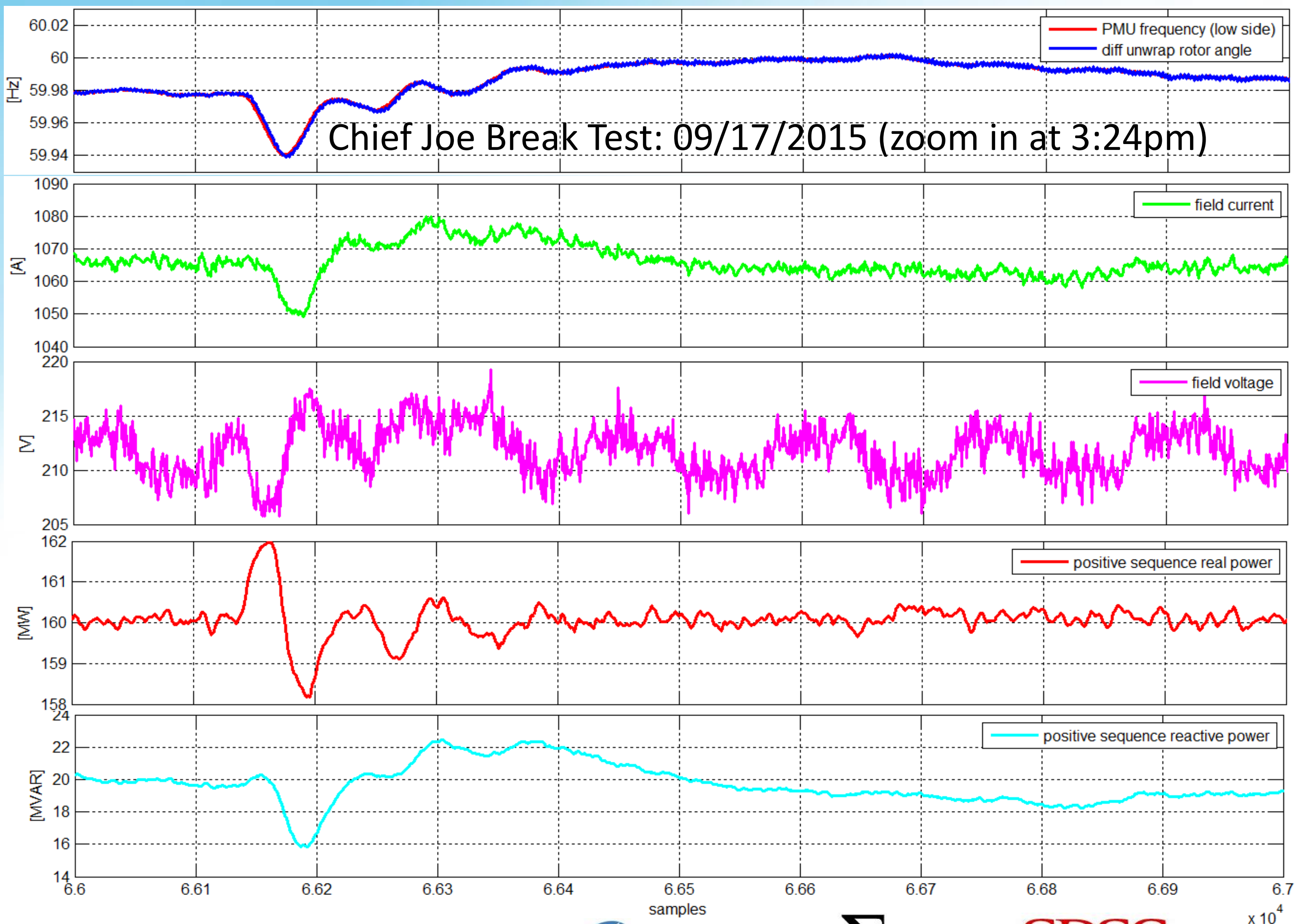
$$f(k) = 60 + \frac{\theta_u(k) - \theta_u(k-1)}{0.03333 \cdot 2 \cdot 180}$$



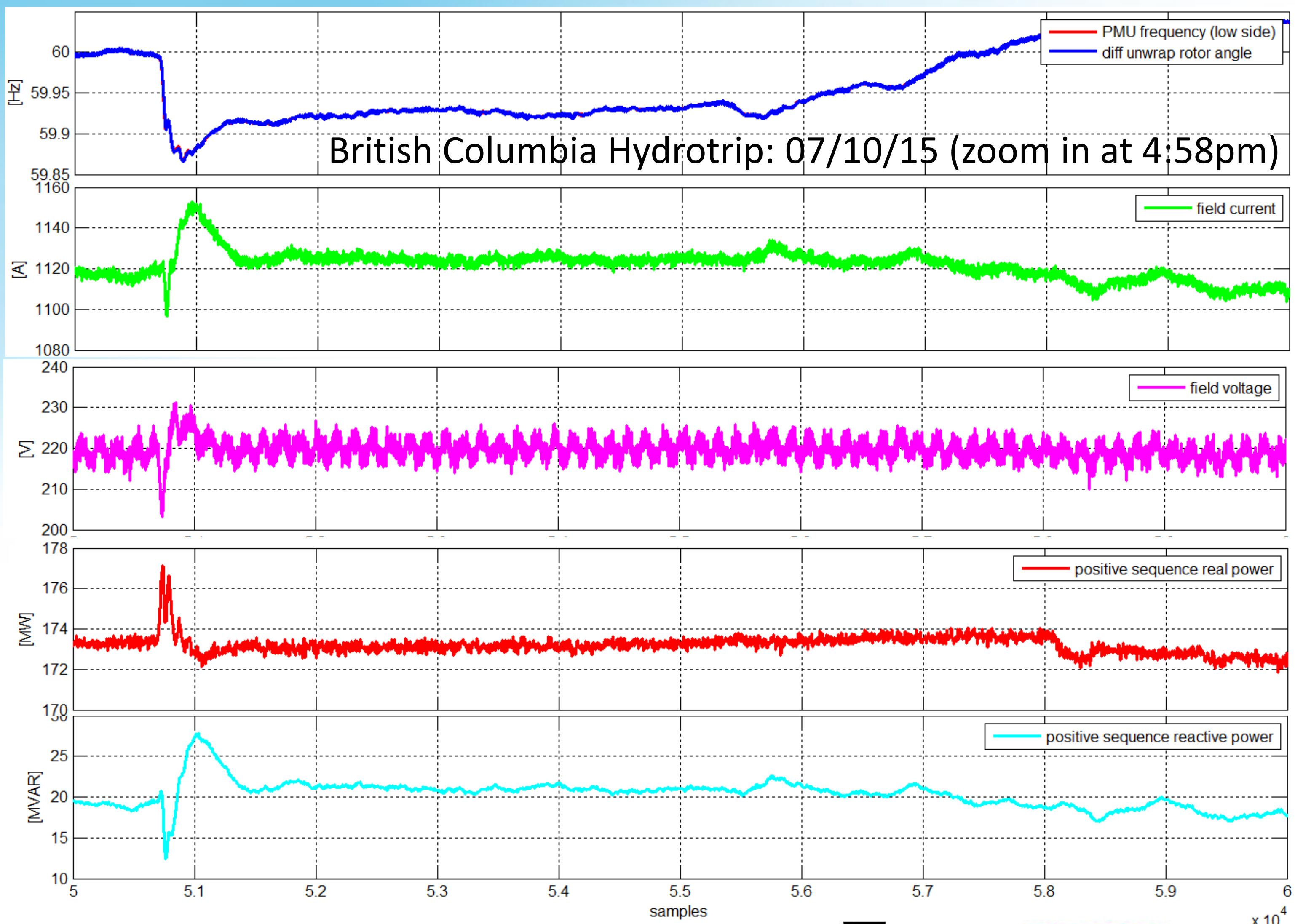




Final Transient Data: Field V,I and P,Q



Final Transient Data: Field V,I and P,Q



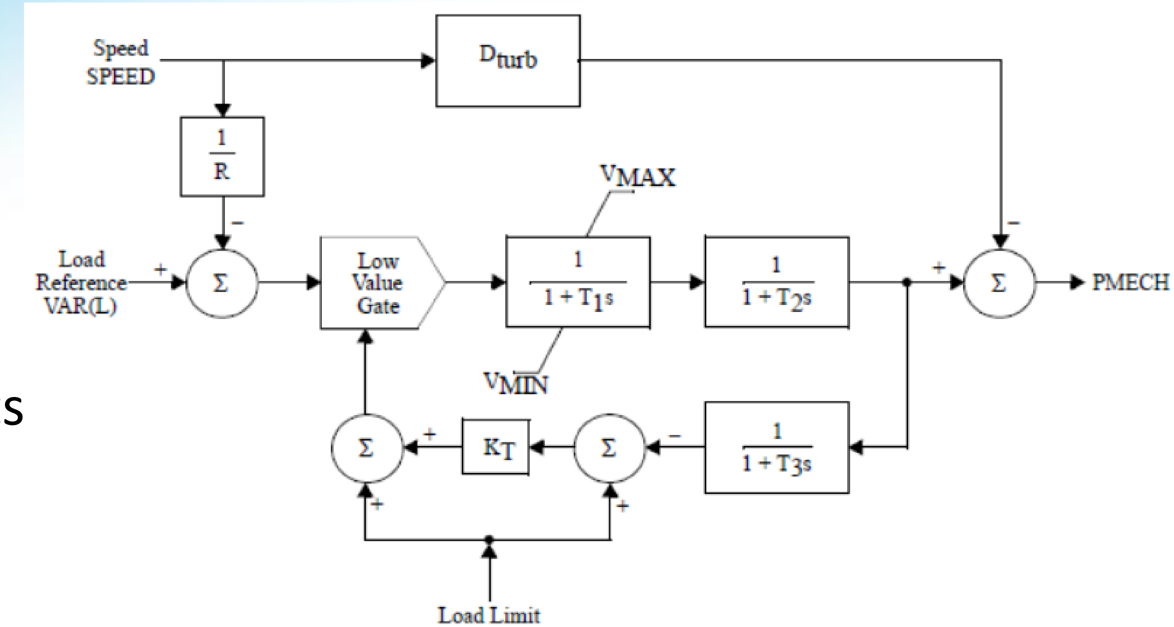
Generator Models

Most simplistic model: GAST (Siemens PTI)

- Still used in WECC and Eastern Interconnection

Features:

- Simple droop control
- Constant Load Limit
- Only three time constants
  - T_1: fuel valve dynamics
  - T_2: turbine dynamics
  - T_3: load response



NAME	Type	Description
R	PU	Permanent droop
T1	Seconds	Governor mechanism time constant
T2	Seconds	Turbine power time constant
T3	Seconds	Turbine exhaust temperature time constant
AT	PU	Ambient temperature load limit
KT	PU	Temperature limiter gain
VMAX	PU	Maximum turbine power
VMIN	PU	Minimum turbine power
DTRUB	PU	Turbine damping factor

Significant simplification of turbine dynamics, ignoring temperature control, speed control, etc.

Generator Models

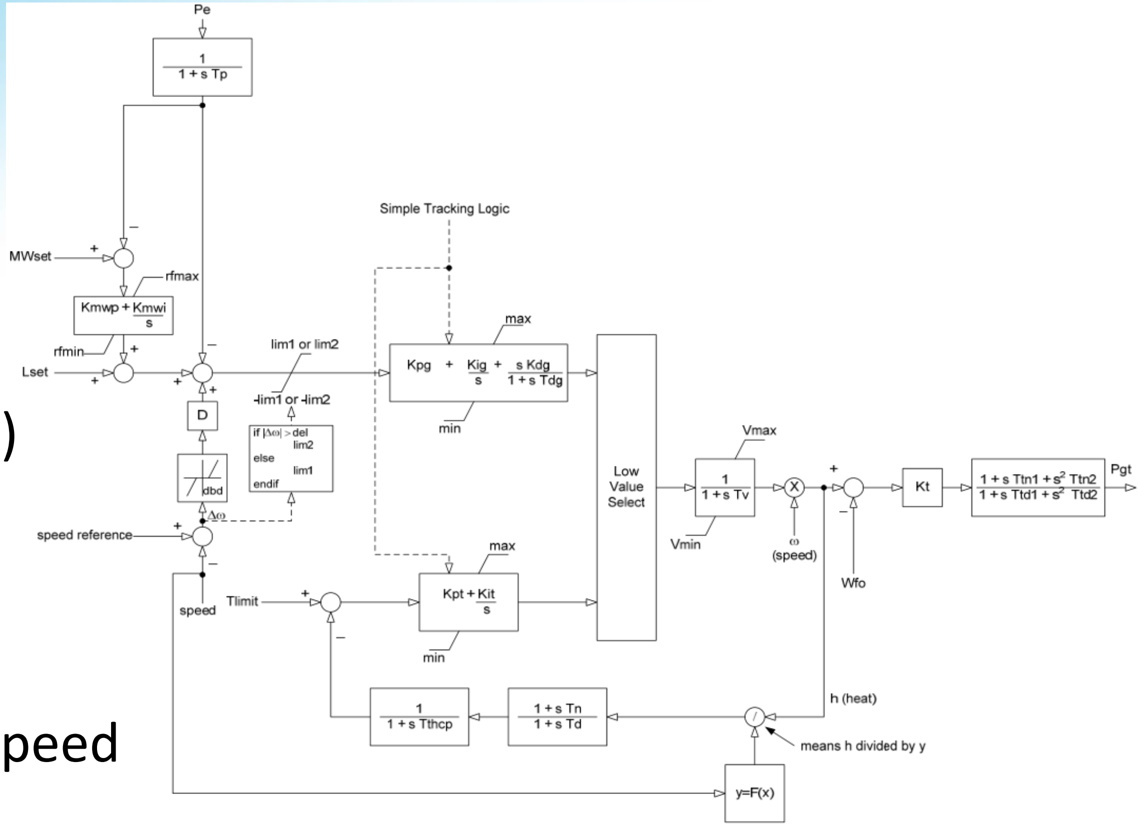
More advanced models

(simplified CIGRE or GT1)

- Still "simplified" model
  Ham et al. "Development and Experience in Digital Turbine Control" IEEE Trans. on Energy Conversion, (1988)

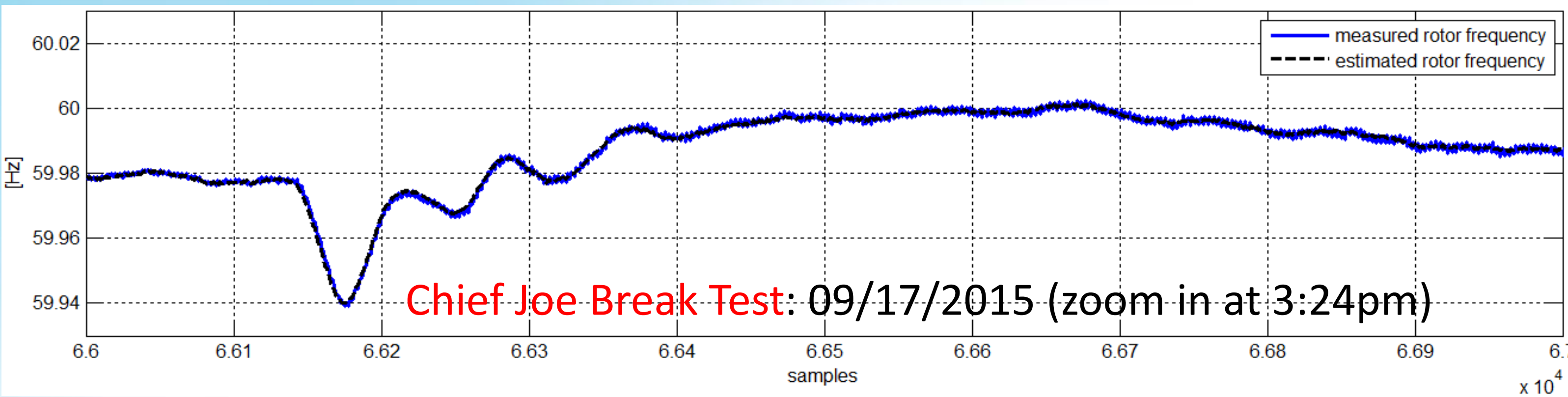
Features:

- Logic for feedback (P/PI/PID)
- 2nd order model for gas turbine dynamics
- Possibility to model power output as function of heat/speed
- Similar to GGVO1
  CIGRE Technical Brochure 238, Modeling of Gas Turbines and Steam Turbines in Combined-Cycle Power Plants (2003)



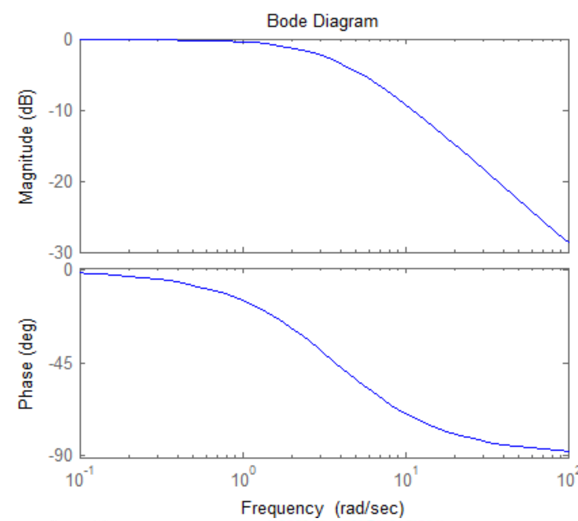
Results

Results of "fitting" measured rotor frequency



Chief Joe Break Test: 09/17/2015 (zoom in at 3:24pm)

Due to simple dynamics between POI PMU frequency and rotor frequency and excellent fit is obtained



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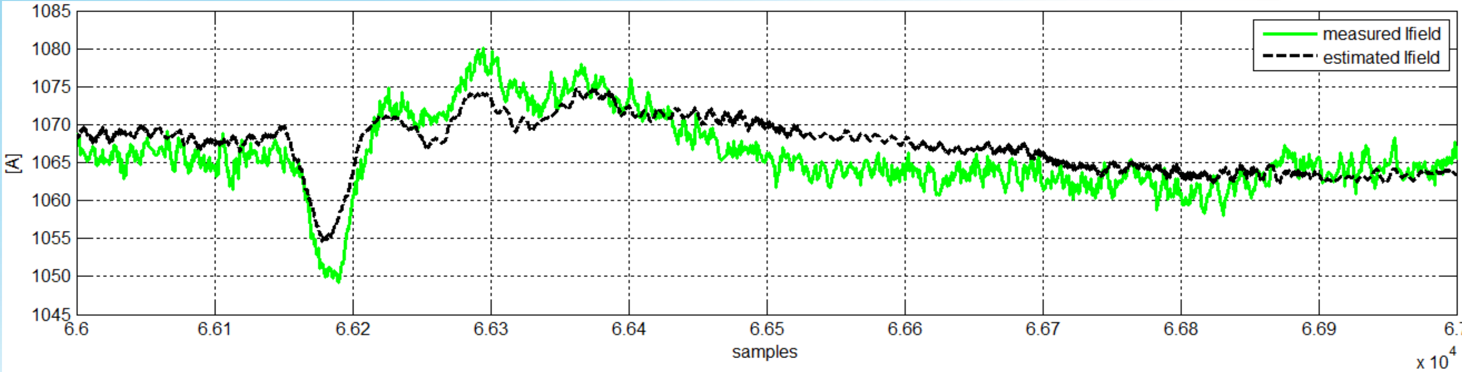
Results

Results of "fitting" Ifield and Vfield



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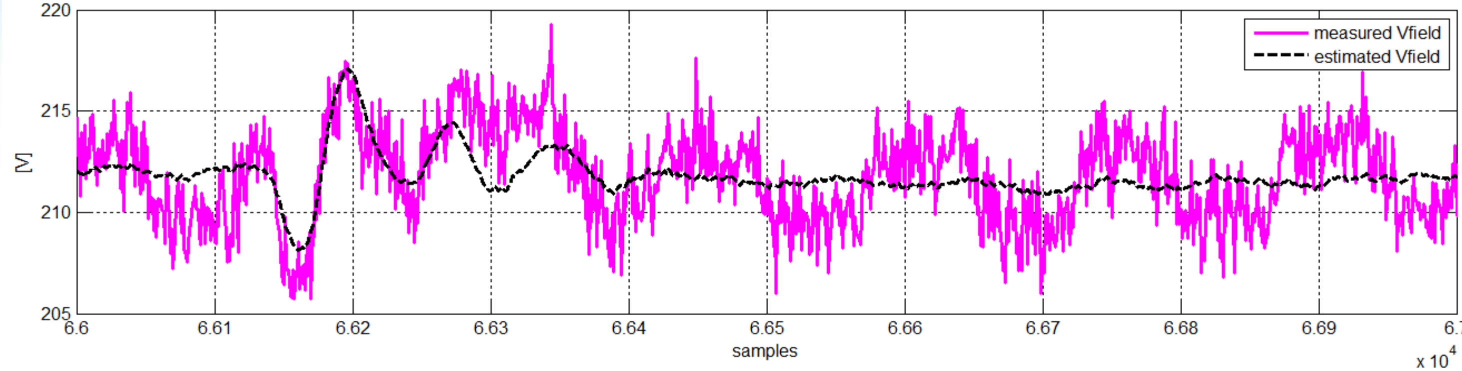

Dynamic effects are captured reasonably well

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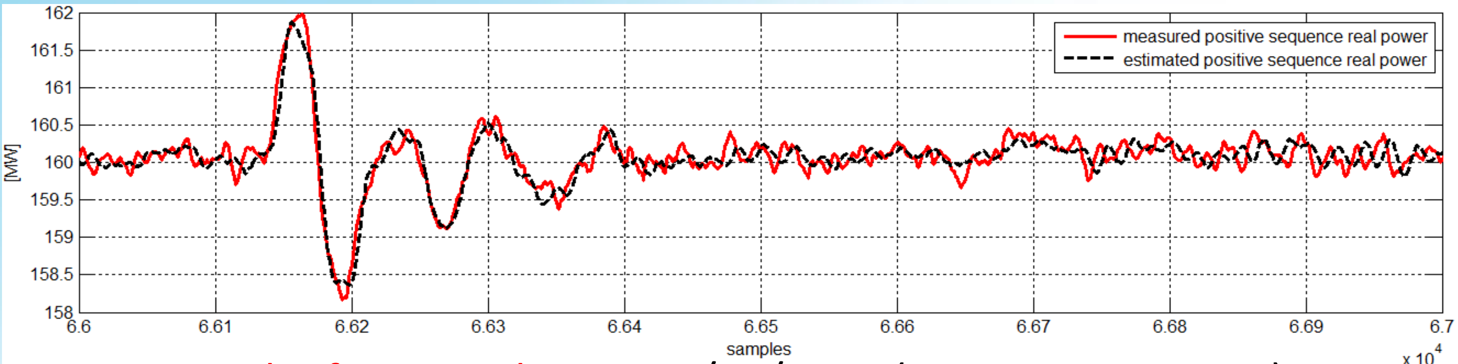
Results

Results of “fitting” positive sequence real P and reactive Q



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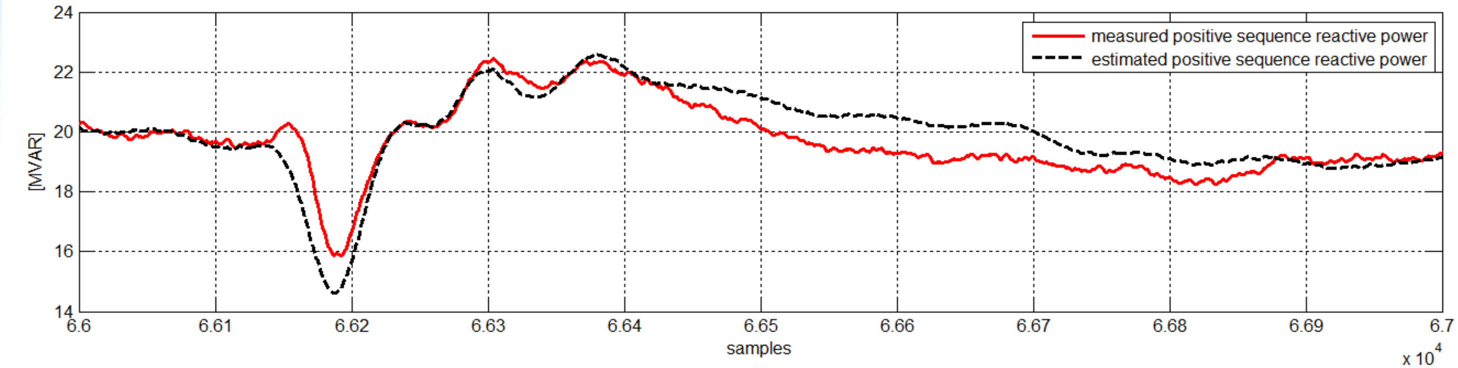
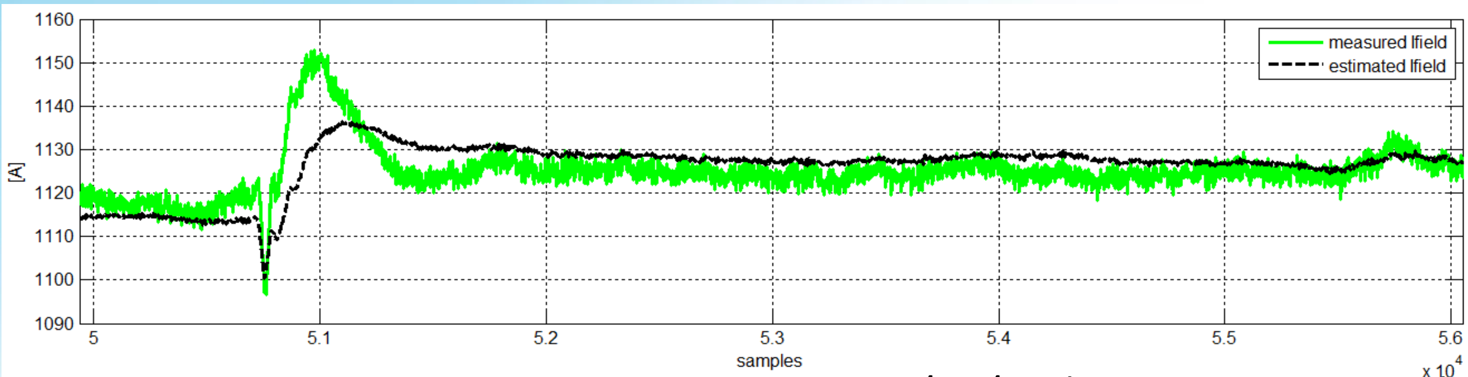


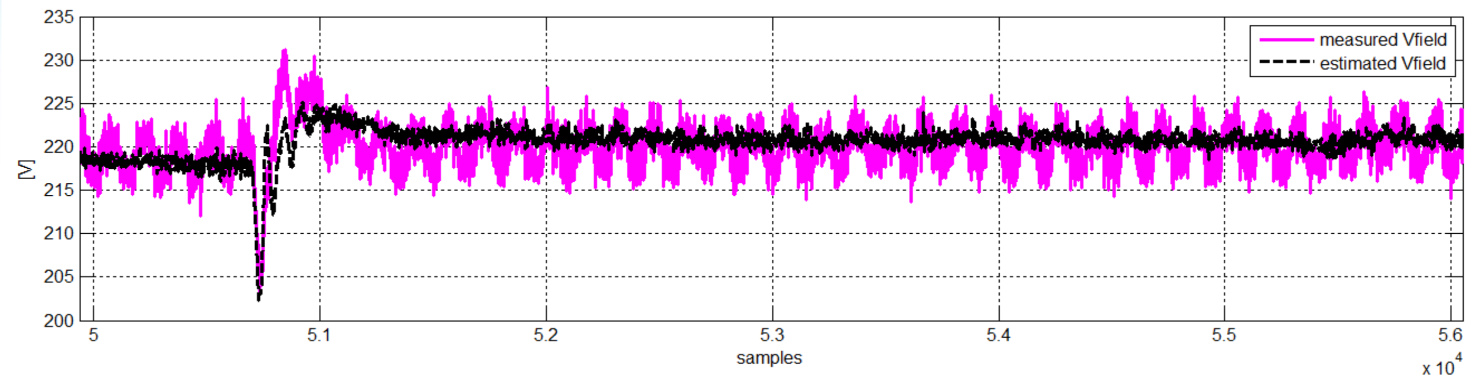
Dynamic effects are captured, but model needs more features

Results

Results of “fitting” Ifield and Vfield



British Columbia Hydrotrip: 07/10/15 (zoom in at 4:58pm)



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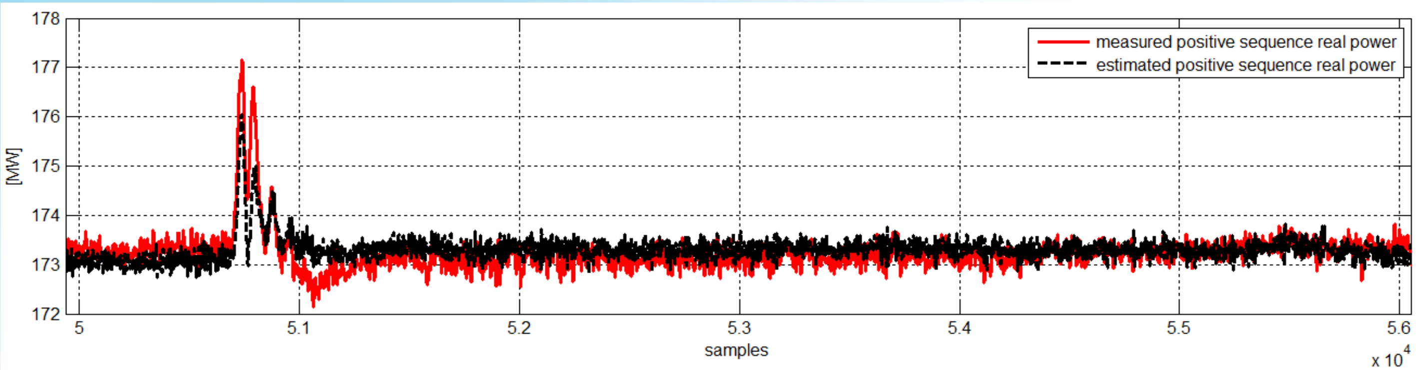

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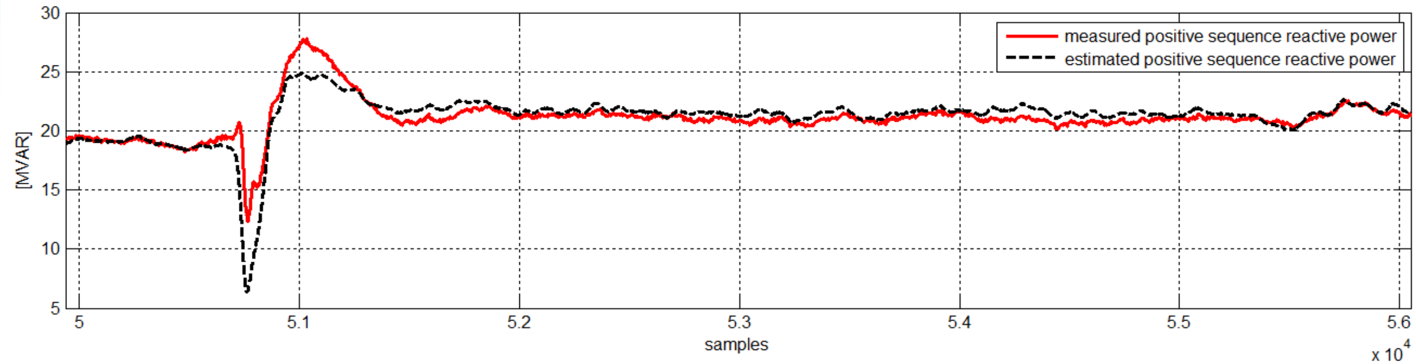

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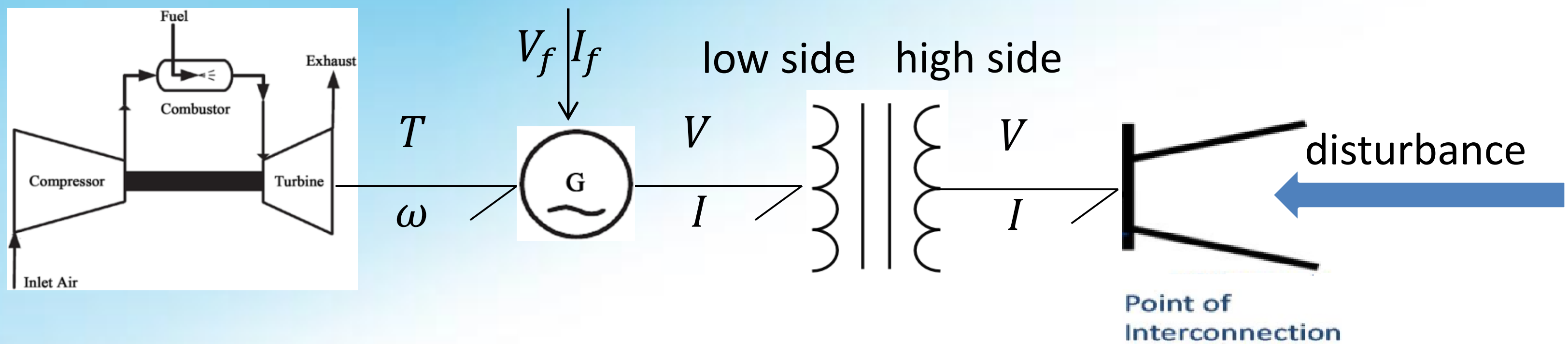
Conclusions



- Additional rotor angle/angular speed ω allows characterization of PMU/transformer dynamics
- In single axis system PMU frequency and rotor frequency strongly correlated
- Additional rotor angle can be exploited for better “fitting” of generator dynamics

Questions?