Model of Parameterized PMU Estimation Error

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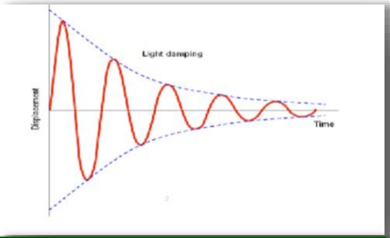
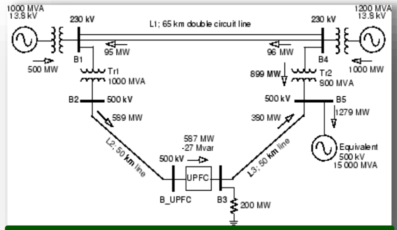
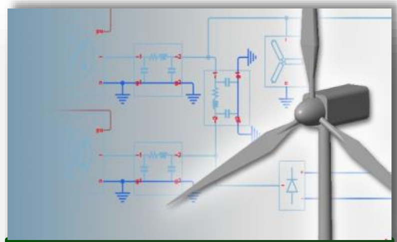
PMU Applications



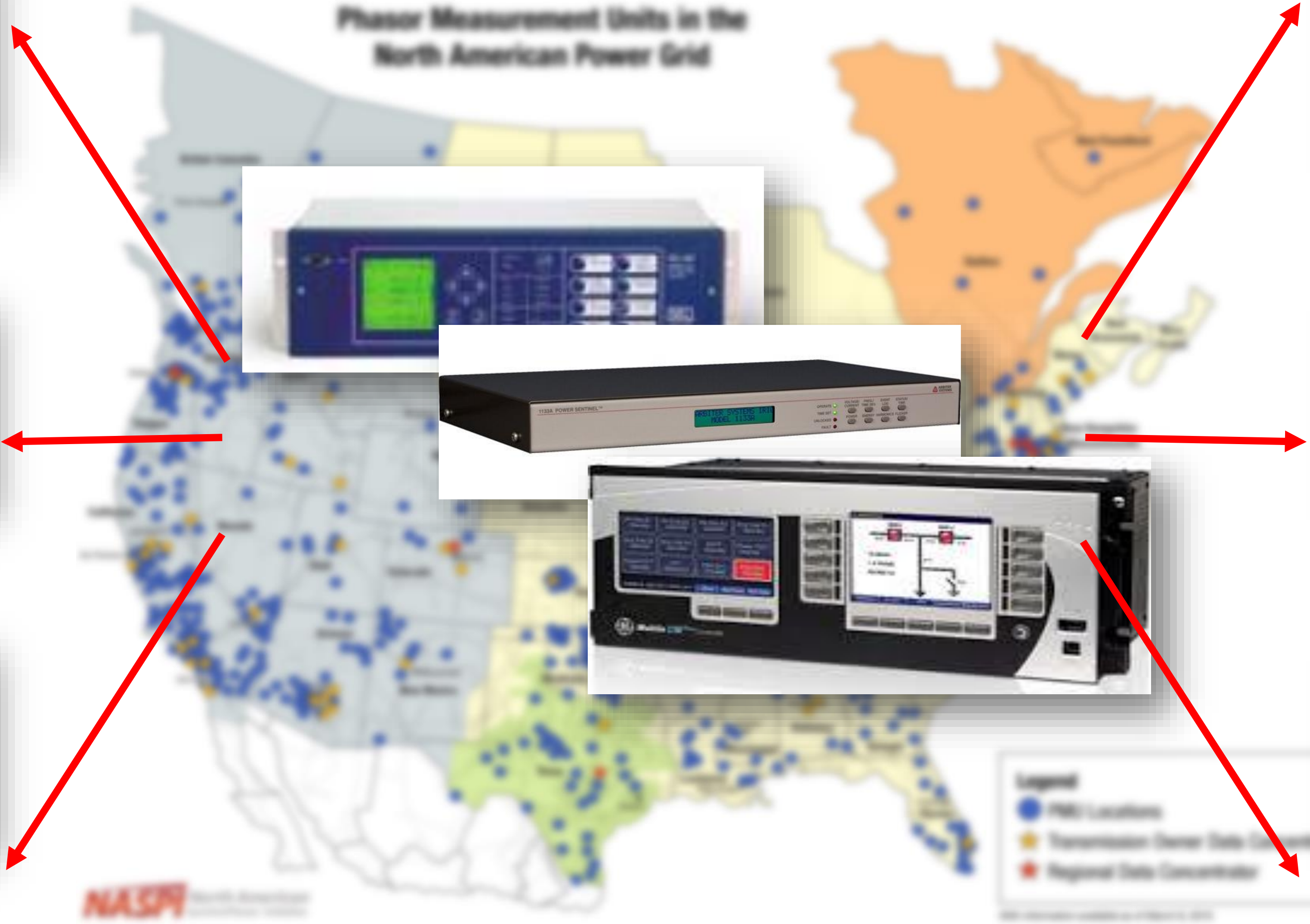
Mode Meter

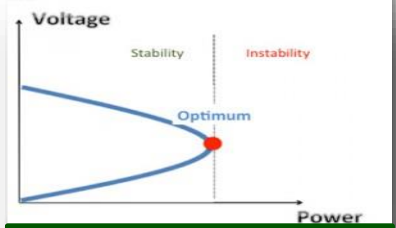


State Estimation

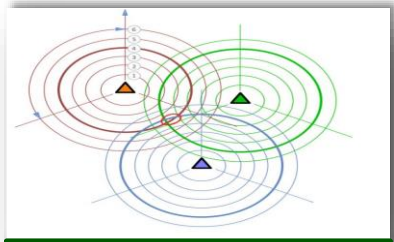


Model Validation





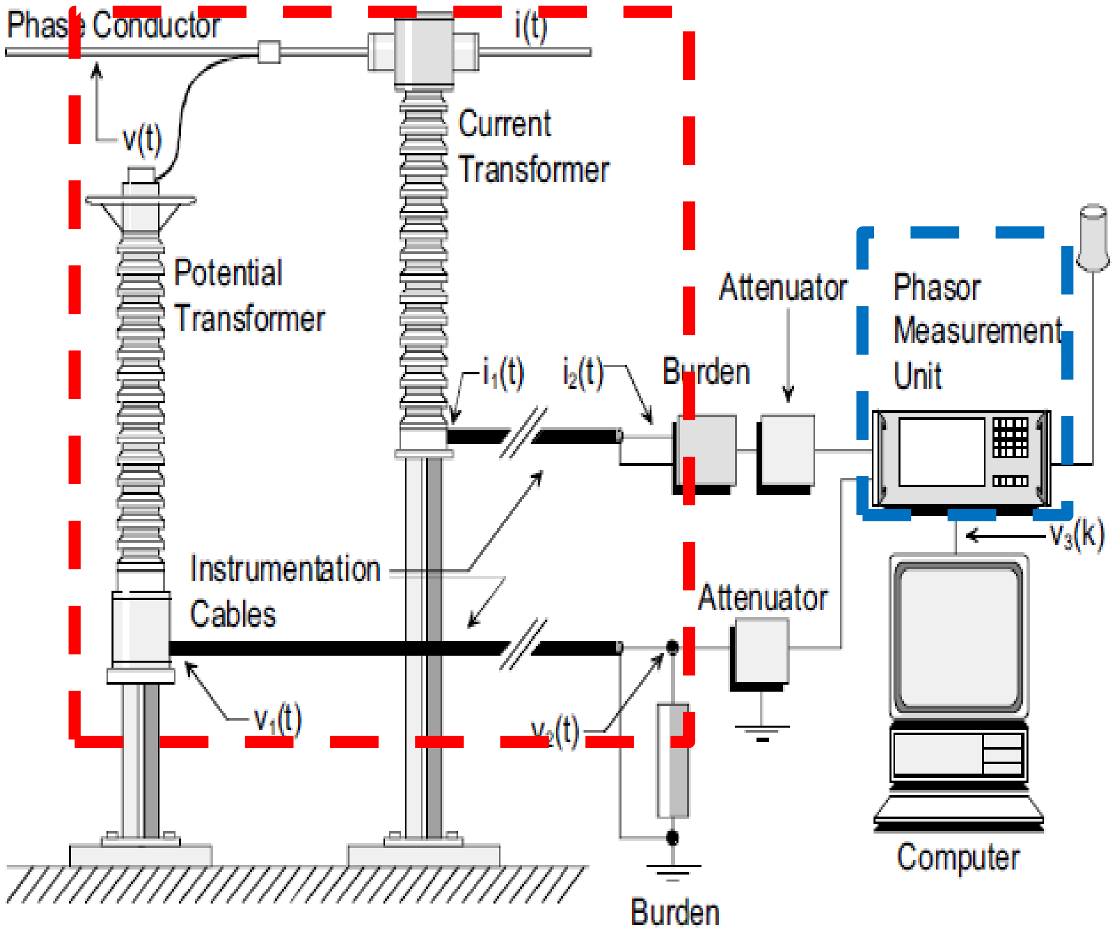
Voltage Stability



Event & Fault Location

Islanding Detection

PMU Measurement Error



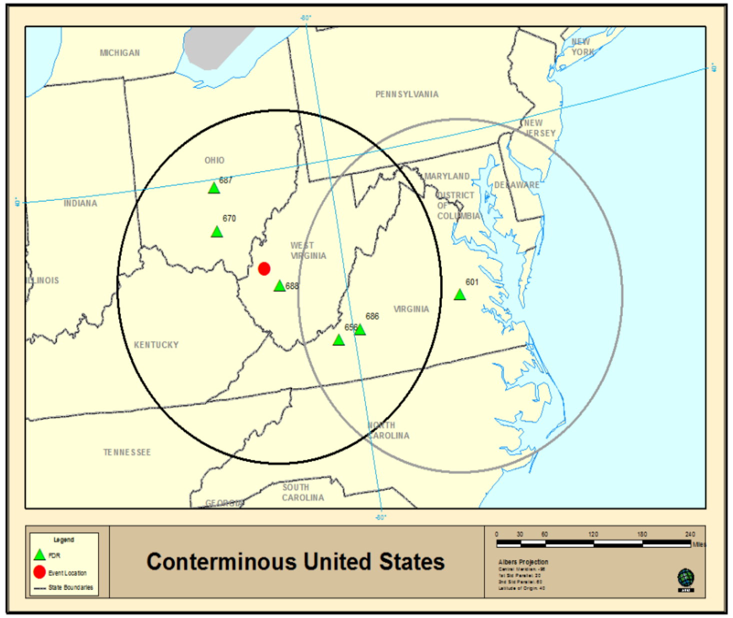
Transducer & Cable:

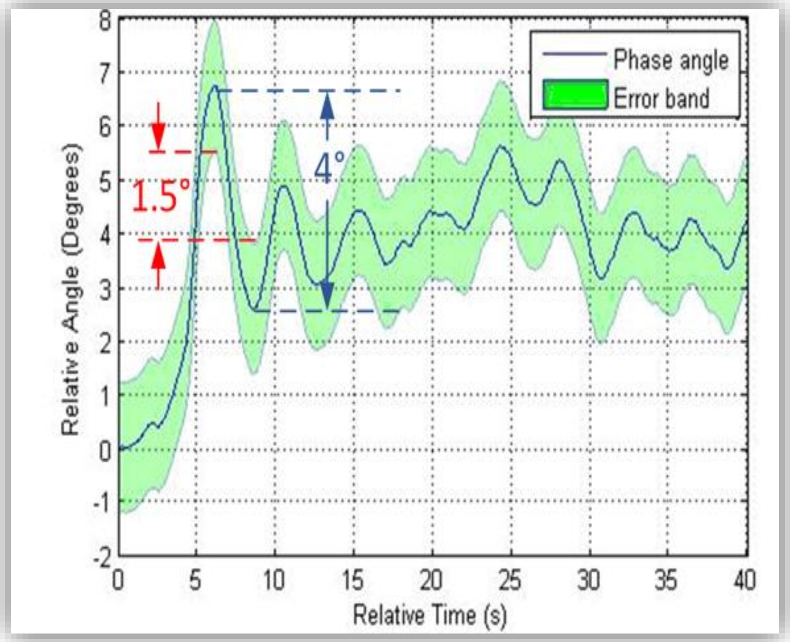
- PT, CT, Cable combined error
- -0.2° to -1.0° for most cases

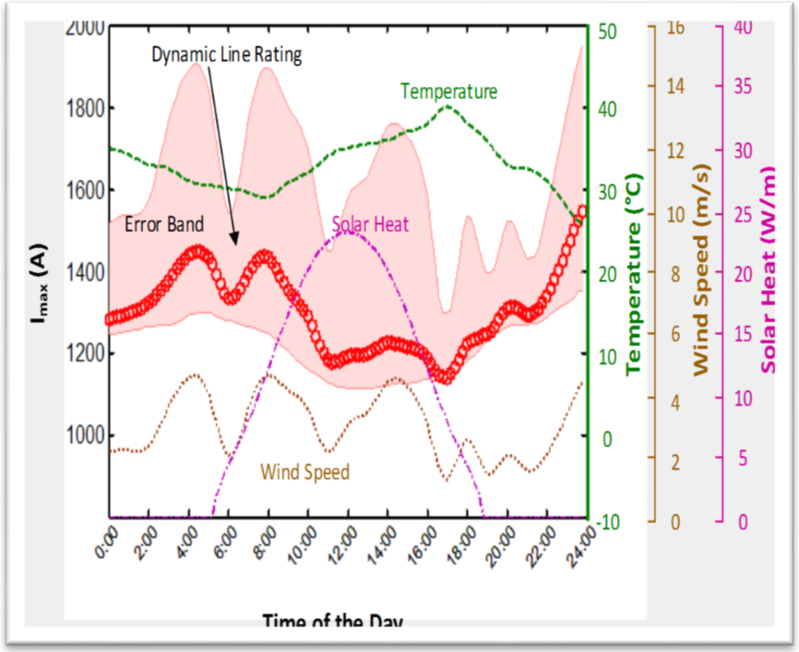
PMU (C37.118 Compliant):

- 0.57 ° for steady state
- 1.71 ° for dynamic
- 0.005 Hz for frequency

PMU Error Impacts







Event Location

- Deviation, fault, or failure
- ~**45%** vulnerable

Oscillation Detection

- Failure to detect
- False alarm

Dynamic Line Rating

- Up to **46%** error in summer with high wind

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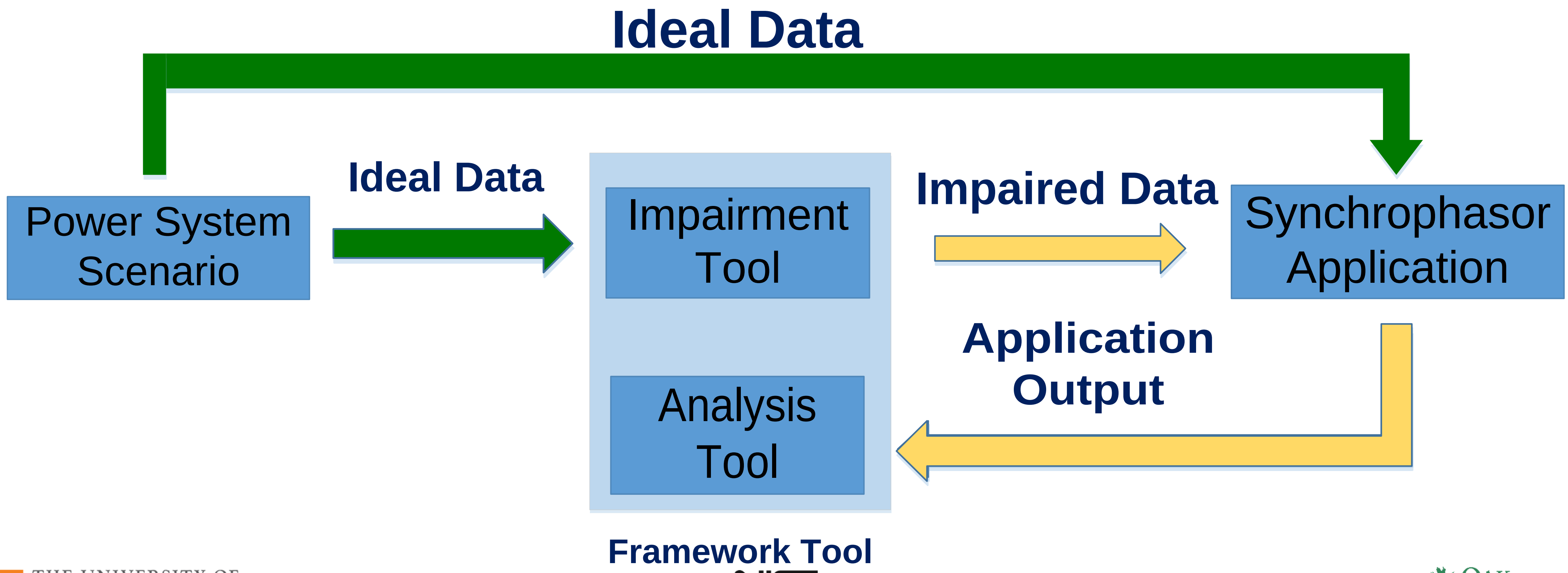
Methodology

- Step 1: Model the PMU estimation error
- Step 2: Analyze the impact on applications



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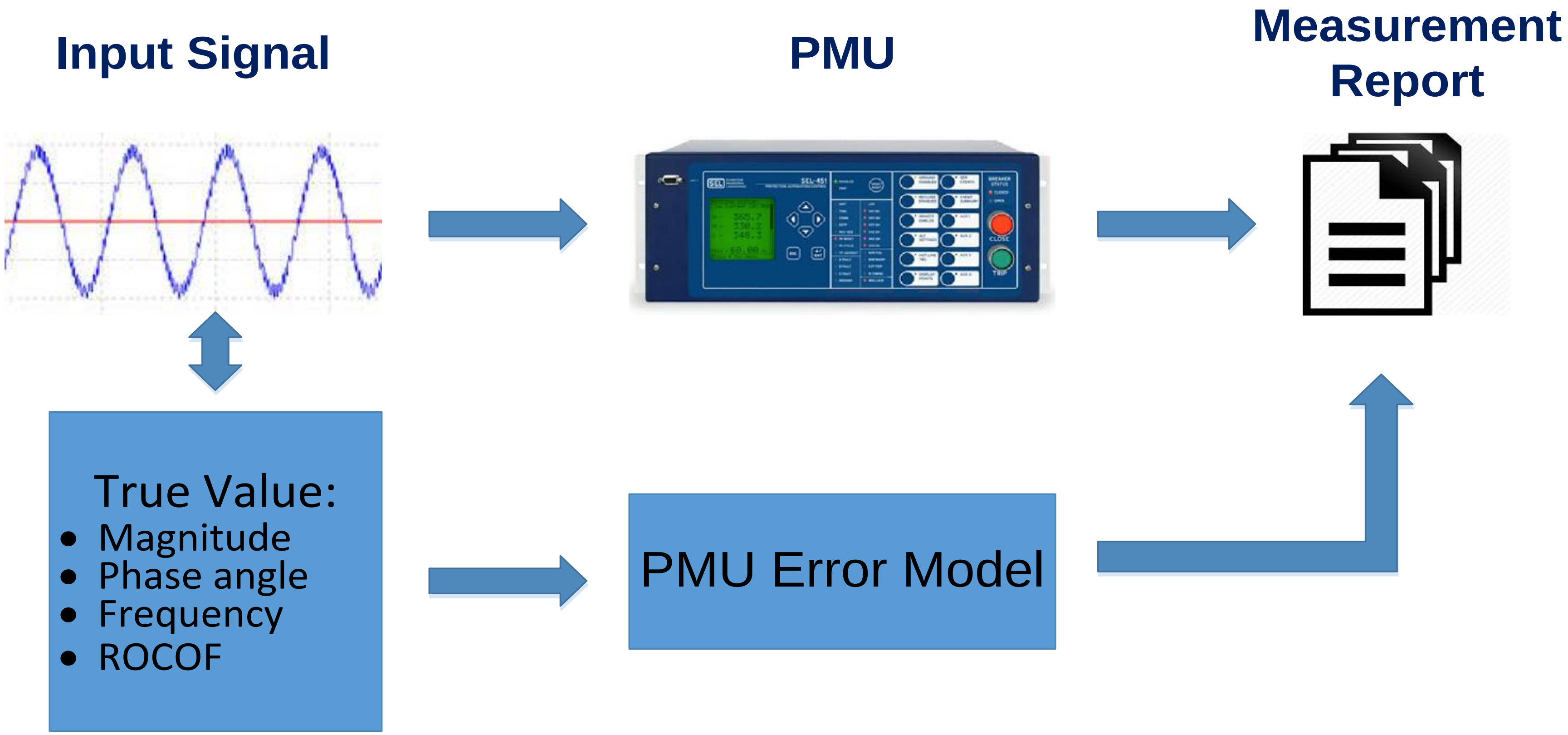
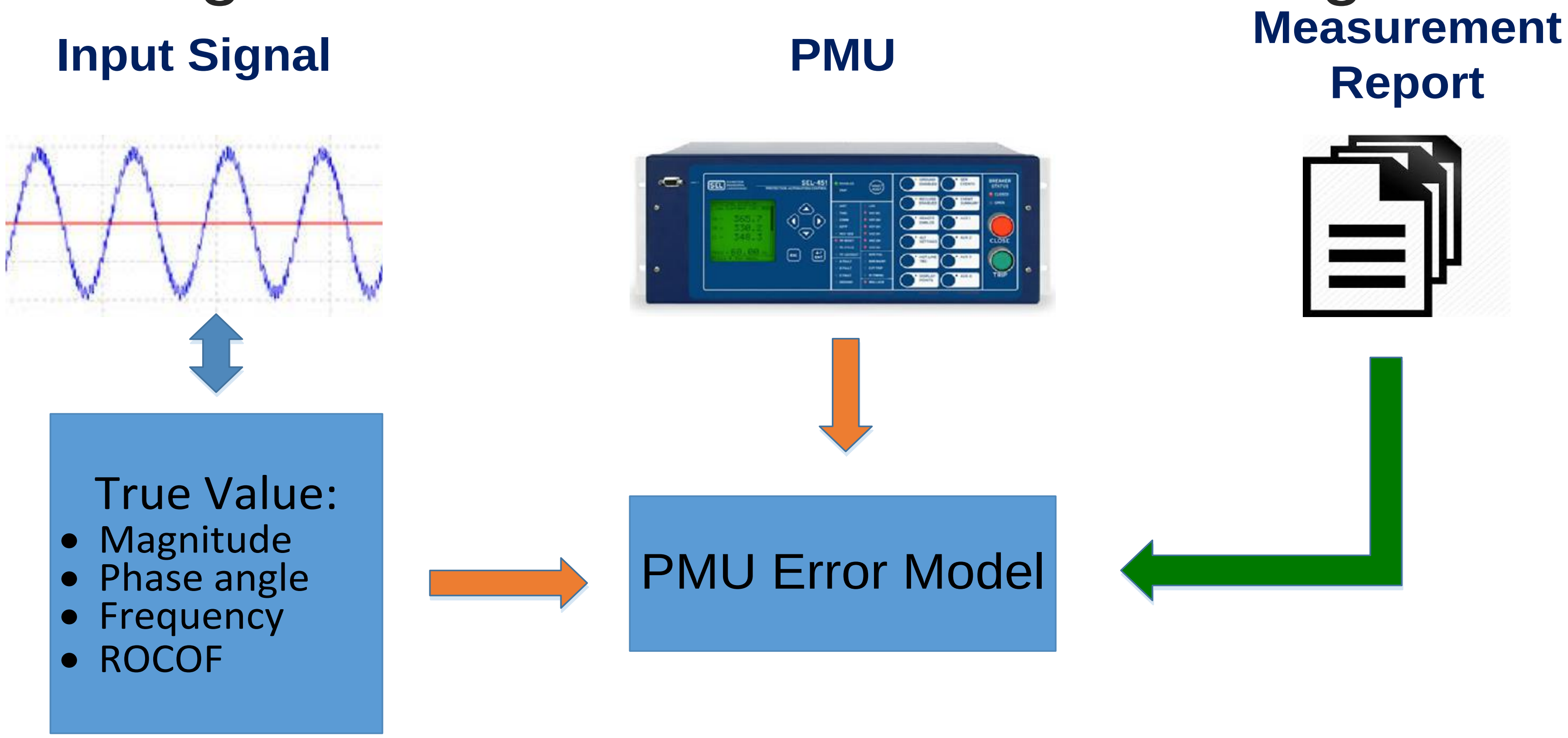
Methodology

- Modeling the PMU measurement error



Methodology

- Modeling the PMU measurement error
- Extracting error behavior from PMU testing



Parameterized Model

PMU Estimation Error Model

Product Model
- Prototype
- Product

Class
- P Class
- M Class

Nominal Frequency
- 50 Hz
- 60 Hz

Reporting Rate
- 10 Hz
- 12 Hz
- 15 Hz
- …
- 60 Hz

Standard Test
- Frequency range
- Magnitude range
- Harmonics
- Modulation
- Step change
- Ramp change

Estimation Error
- Magnitude
- Phase Angle
- Frequency
- ROCOF

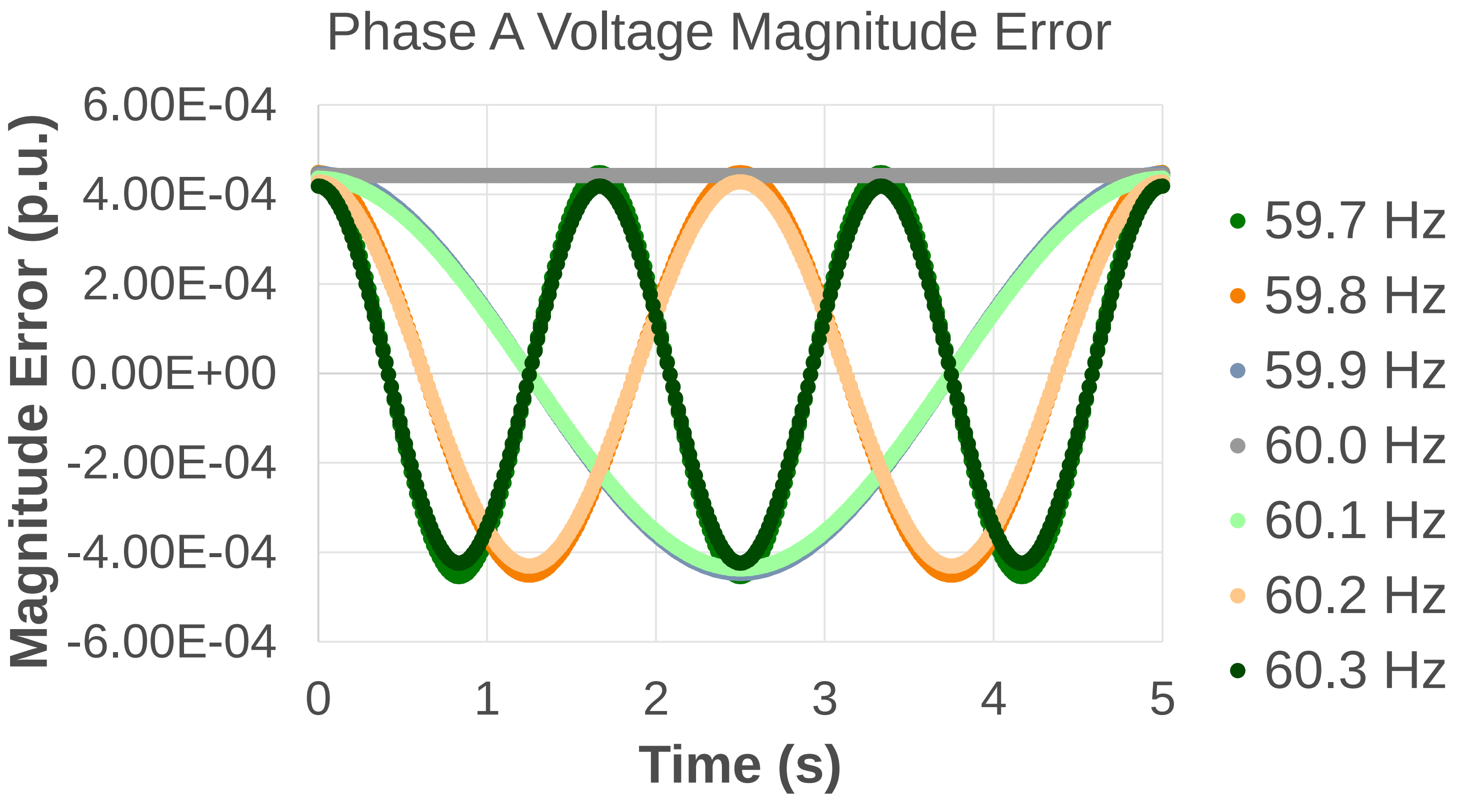
Principle & Example

- **Principle:**
  - **Accurate:** represent real PMU behavior
  - **Generic:** describe PMU error upon all parameters and inputs
  - **Concise:** computationally attractive

- **PMU:** DFT-based algorithm provided in C37.118.1 Annex

Steady State: Frequency Range

- Input: steady signal with different in-band frequency
- Frequency range: 55 Hz to 65 Hz



Magnitude Error

- Use sinusoidal function to describe.

$$|X|_{err} = \frac{|X|}{70}[a_1 \cos(2\pi f_{err} t + \theta) + a_2]$$

$$f_{err} = 2 \cdot (f_0 - f)$$

- Parameters obtained by least square regression

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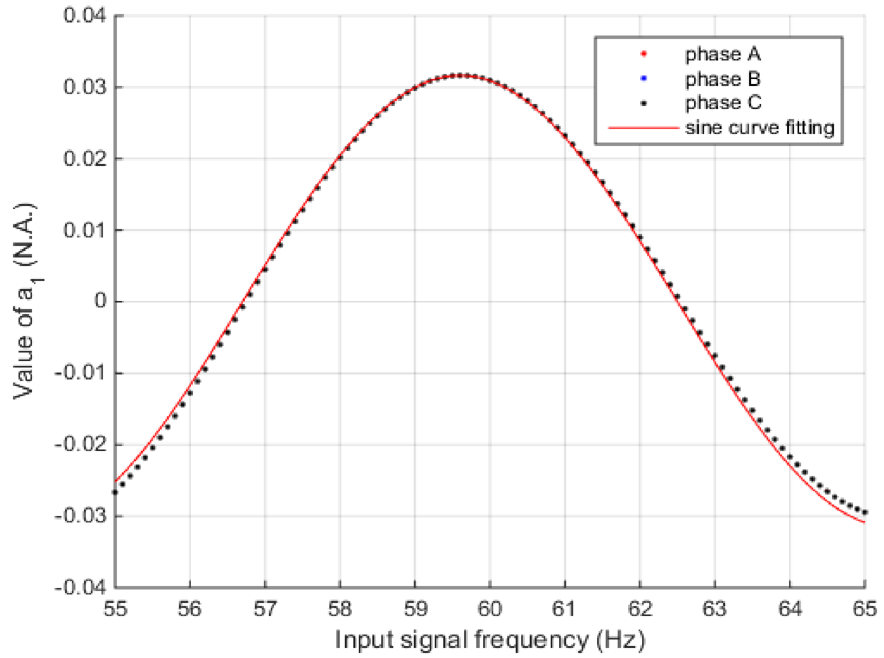
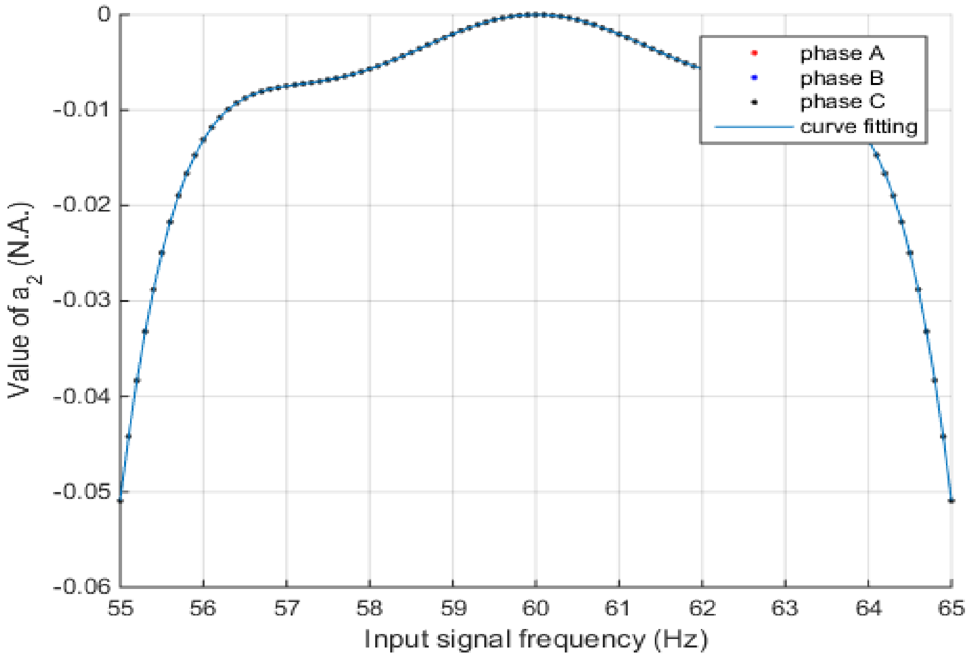
Magnitude Error

- $a_1 = 0.03163 \sin\left(2\pi \cdot \frac{1}{11.6} \cdot (f - 56.7)\right)$
- a_2 relates to magnitude-frequency response of the filter



a_1



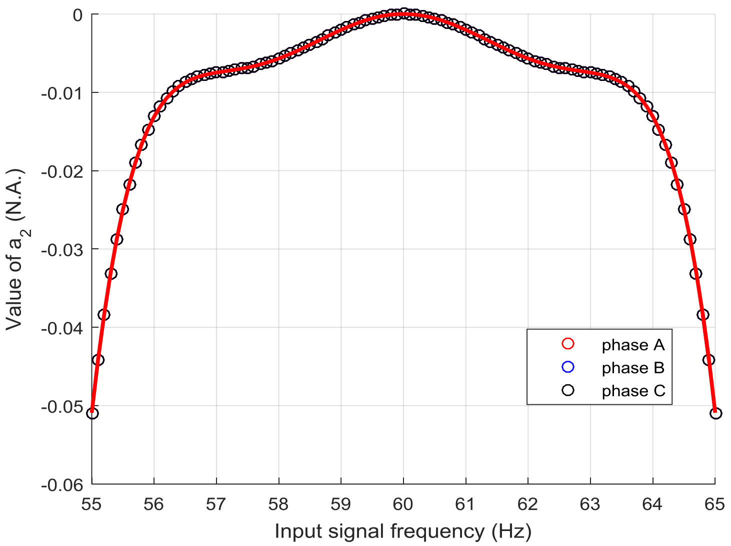
a_2

Filter

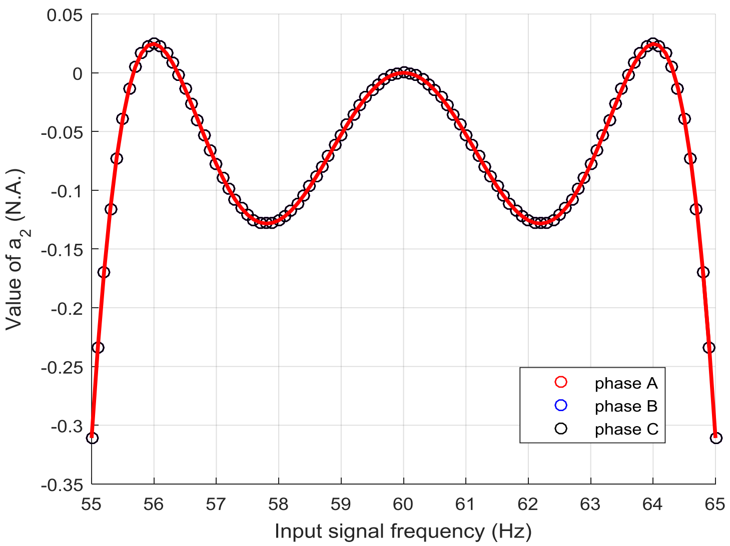
Reporting Rate
PMU Type

Filter Parameters

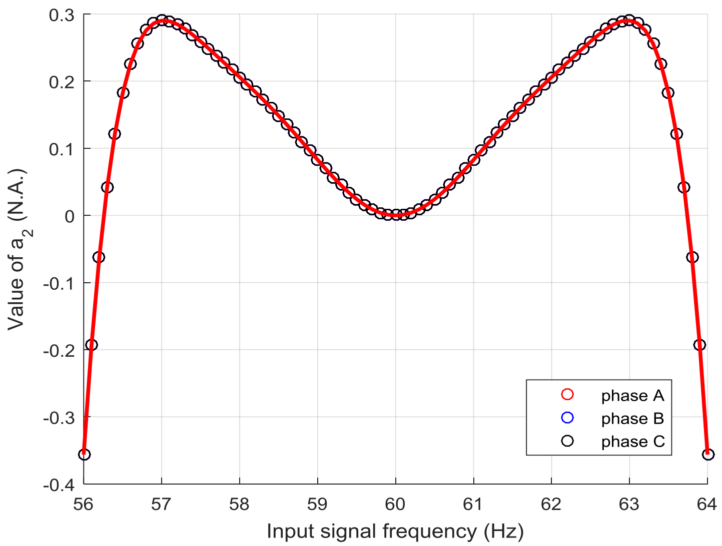
Measurement Error



f_s = 60 Hz



f_s = 30 Hz



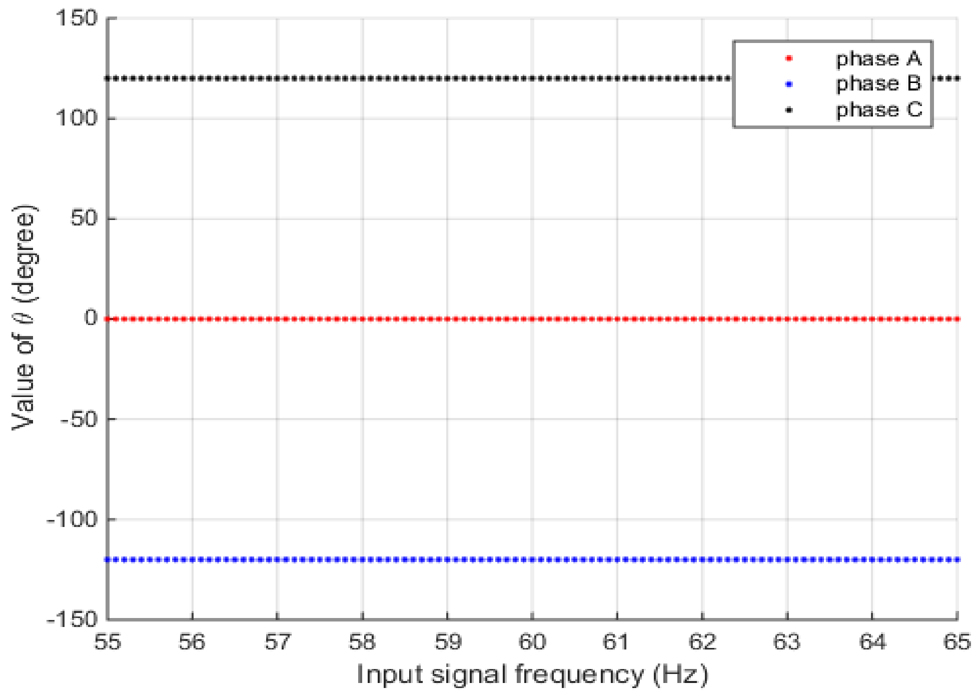
f_s = 20 Hz

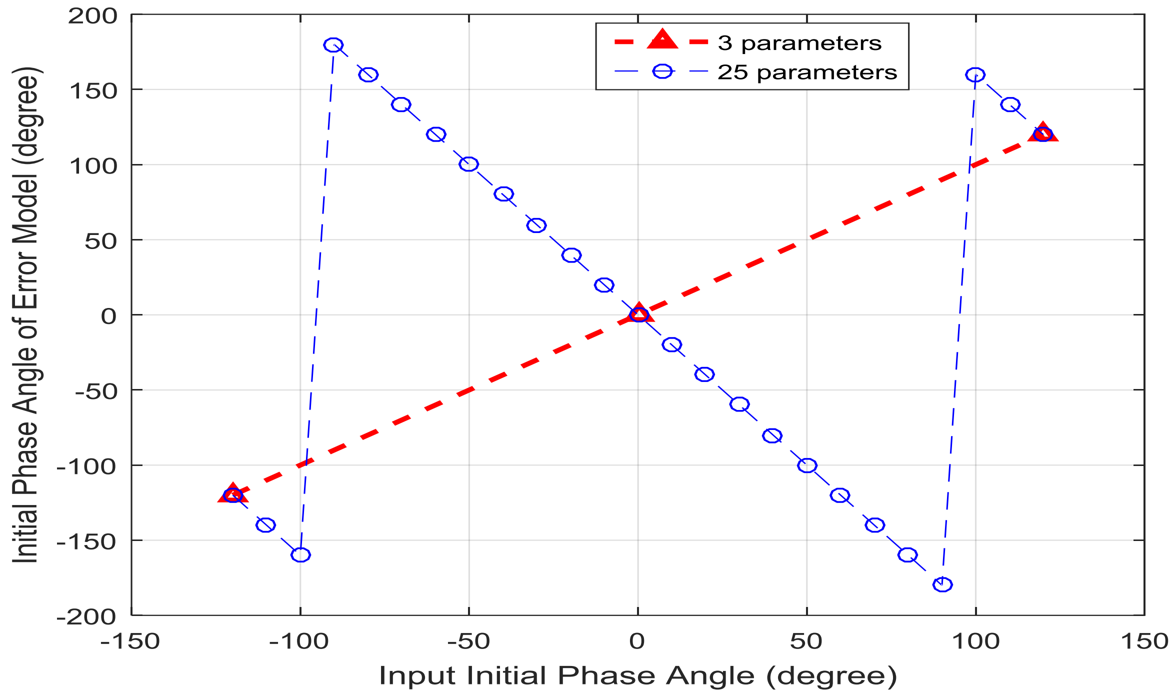
Magnitude Error

- Initial phase angle

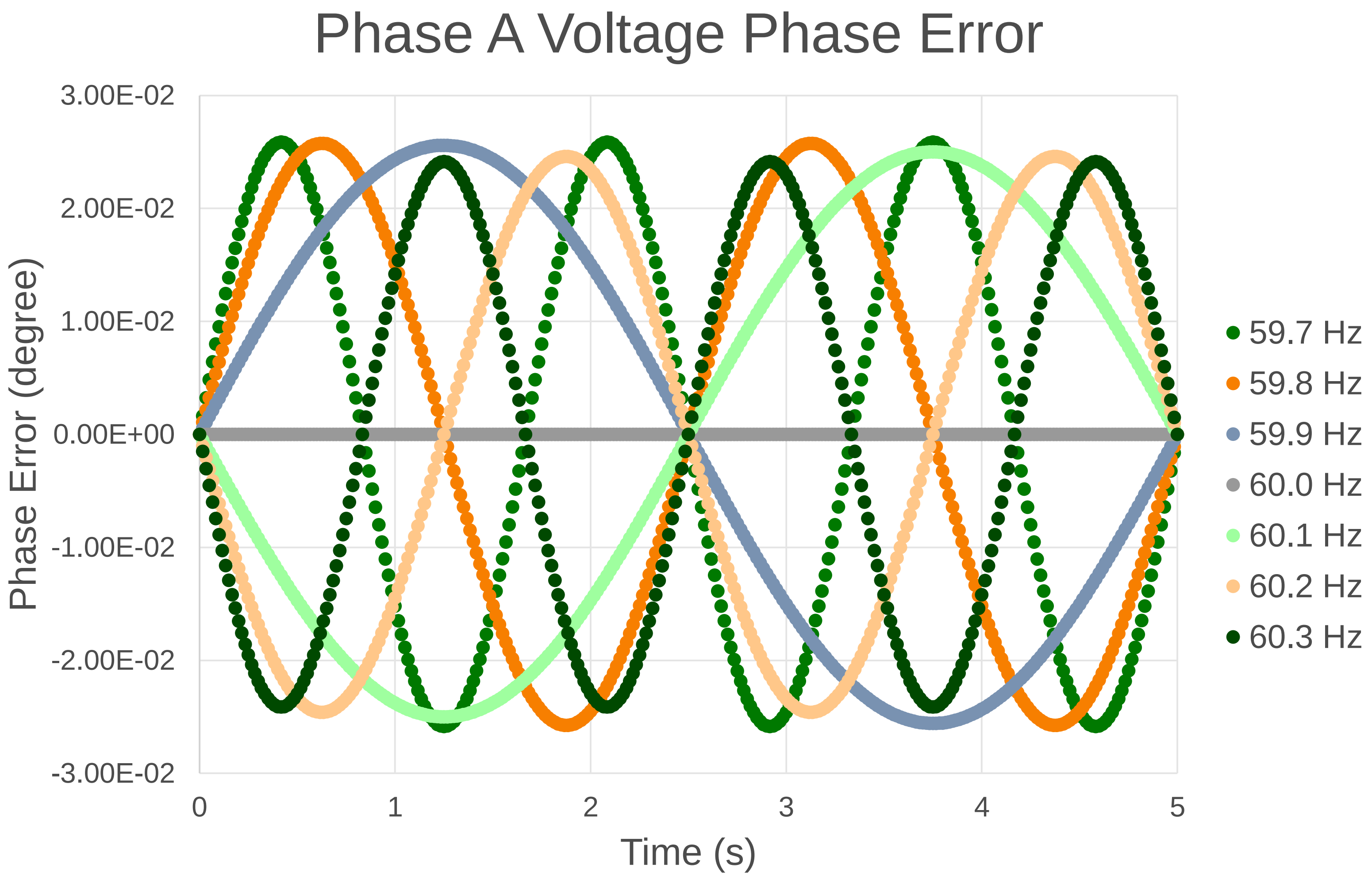
$$\theta = -2\theta_0$$

$$|X|_{err} = \frac{|X|}{70}\left[a_1 \cos(2\pi f_{err} t - 2\theta_0) + a_2\right]$$





Phase Angle/Frequency/ROCOF Error

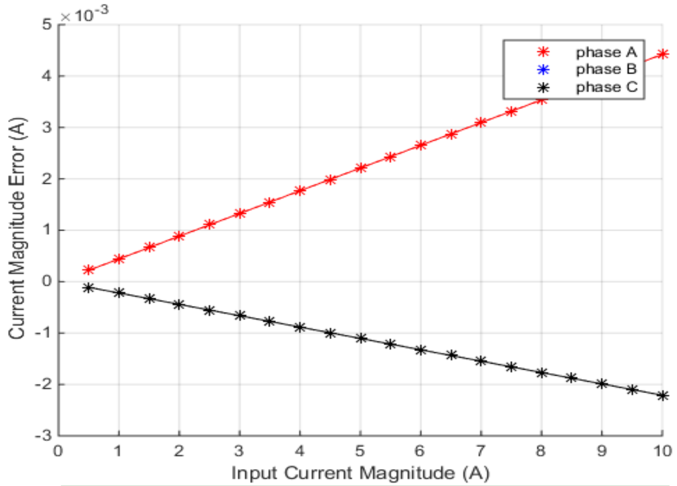


$$\phi_{err} = b_1 \cos(2\pi f_{\phi err} t + \theta)$$

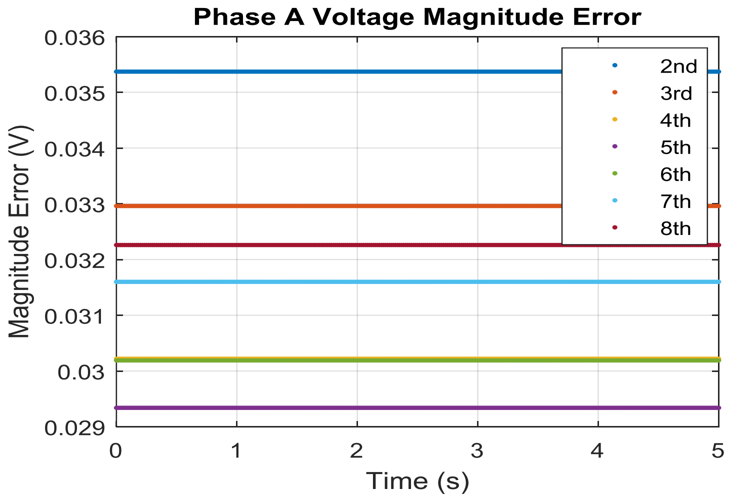
$$f_{err} \cong 0$$

$$ROCOF_{err} \cong 0$$

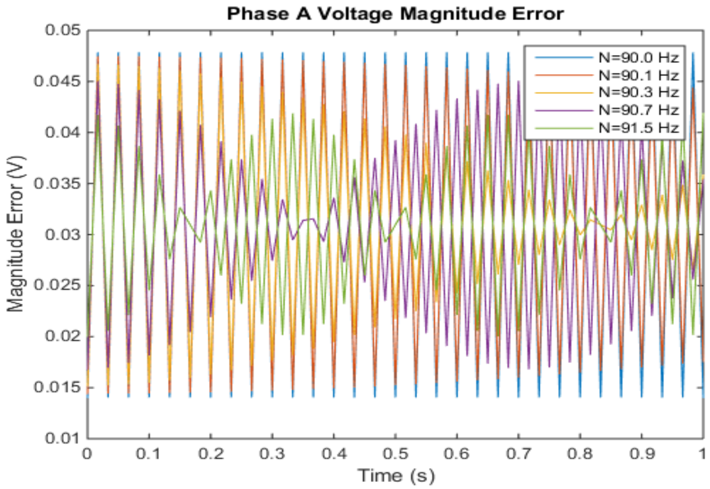
Model on Other Tests



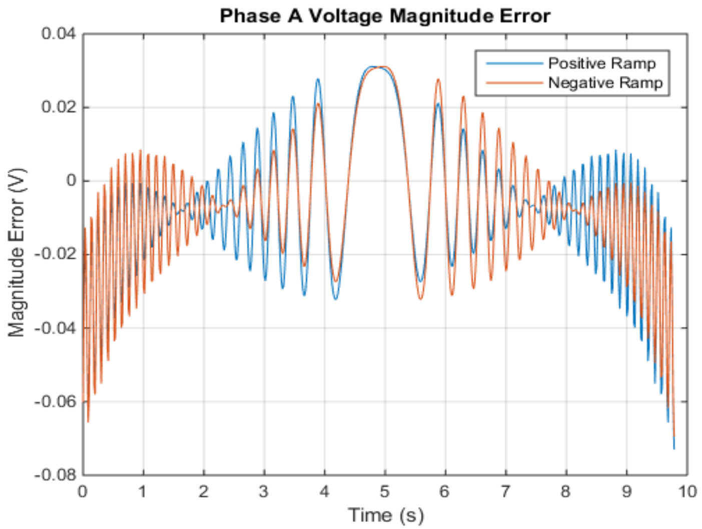
Magnitude Range



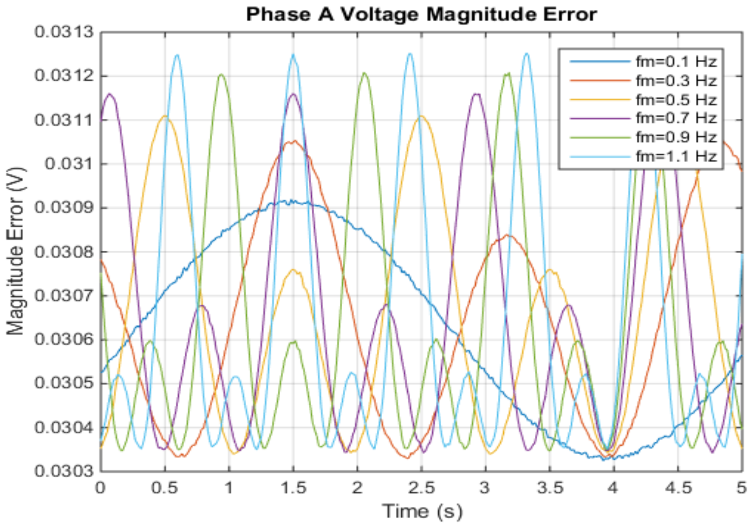
Harmonics



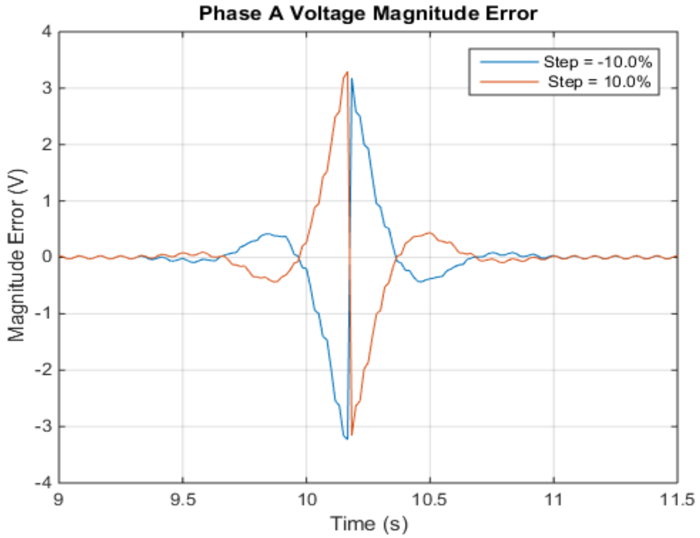
Interharmonics



Frequency Ramp



Modulation



Step Change

Conclusion

- Model of 4 types of PMU measurement errors
- Based on 9 basic PMU testing results following standard
- Model closely represents the real PMU

- Usage
  - Application verification
  - PMU model for simulation
  - Self-reporting error PMU

Future Work

- Generic model for all PMU types
  - This is one of several PMU impairment models available in the PARTF test framework
  - Users can add their own models including actual PMU estimation algorithms under development
- Response of arbitrary input signal
- Verify PMU-based applications

Questions?