Analysis of Synchronization and Accuracy of PMU Measurements in an Operational Power System

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Research Motivation

- Applications of PMU measurements
  - ✓ State estimation (e. g. PMU placement, hybrid state estimator)
  - ✓ Angle stability analysis (e. g. On-line monitoring, mode estimation)
  - ✓ Voltage stability analysis(e. g. Real-time voltage instability identification)
  - ✓ Other applications (e. g. Model validation, fault detection and location)

- The basic issue: Test the synchronization and accuracy of actual PMU measurements
  - ✓ Whether the synchrophasors are exactly synchronized?
  - ✓ Whether the high level of accuracy is achieved?

Outline

- Analysis of synchronization of PMU measurements

  Identification of the time skew problem

  Compensation for the time skew error

- Analysis of accuracy of PMU measurements

  Identification of inconsistency between PMU measurements and transmission line parameters

  Correction factors for PMU measurements

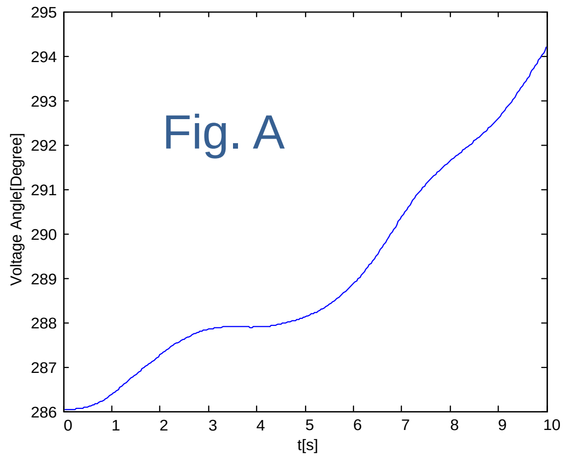
Time skew problem review

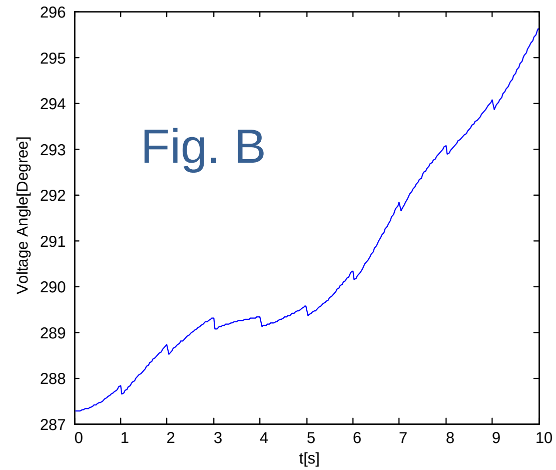
- The PMUs in the SRP system can provide 30 measurements per second.
- All the clocks associated with PMUs are synchronized using the 1 pps signal from the GPS.
- The one second interval is divided evenly into 30 subintervals by a clock associated with the PMU.
- At the “top” of each second, all clocks are synchronized. But in the ensuing 29 subintervals, all the clocks are not continuously synchronized. Upon reaching the next integral second (i.e., the “top of the second”), the clocks are resynchronized.

Examples of voltage phase angle measurements from different PMUs

PMU with a more accurate clock

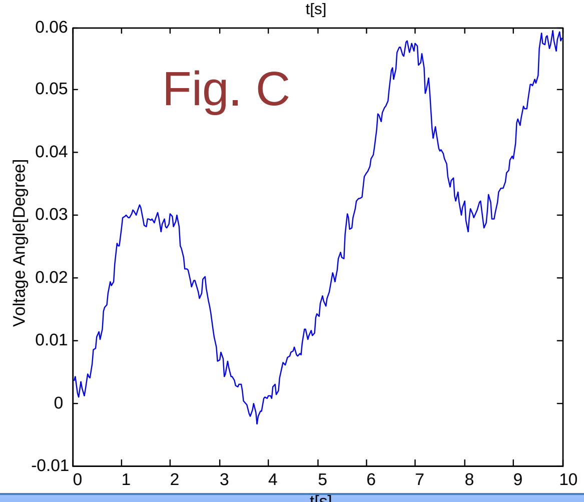
PMU with a less accurate clock

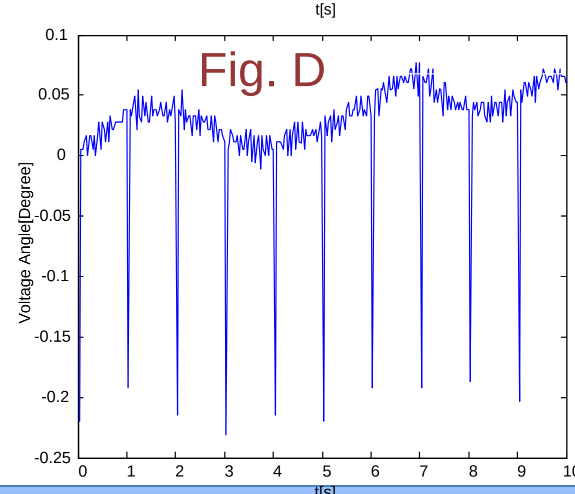




Figs. A and B

Plot of voltage phase angle measurements shown by Fig. A is smooth.
Steps are observed from plot of voltage phase angle measurements shown by Fig. B.



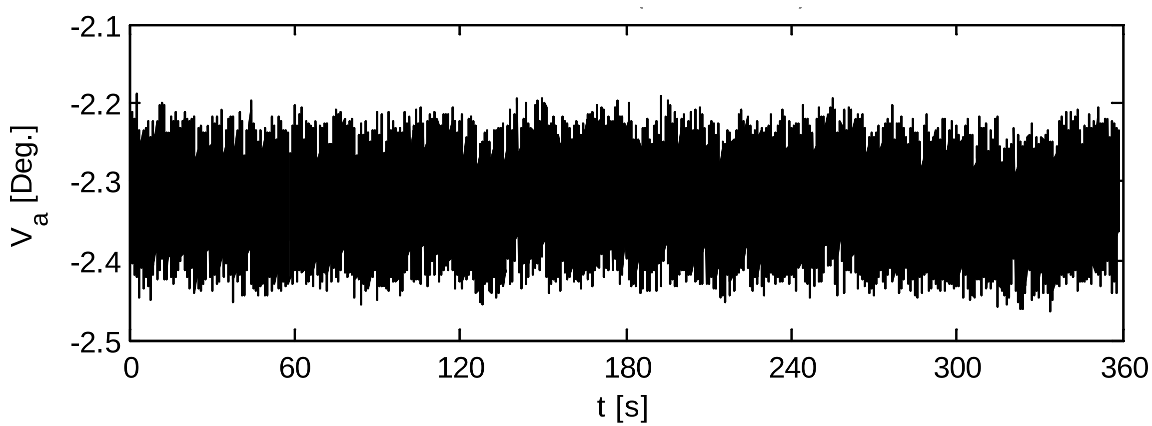


Figs. C and D

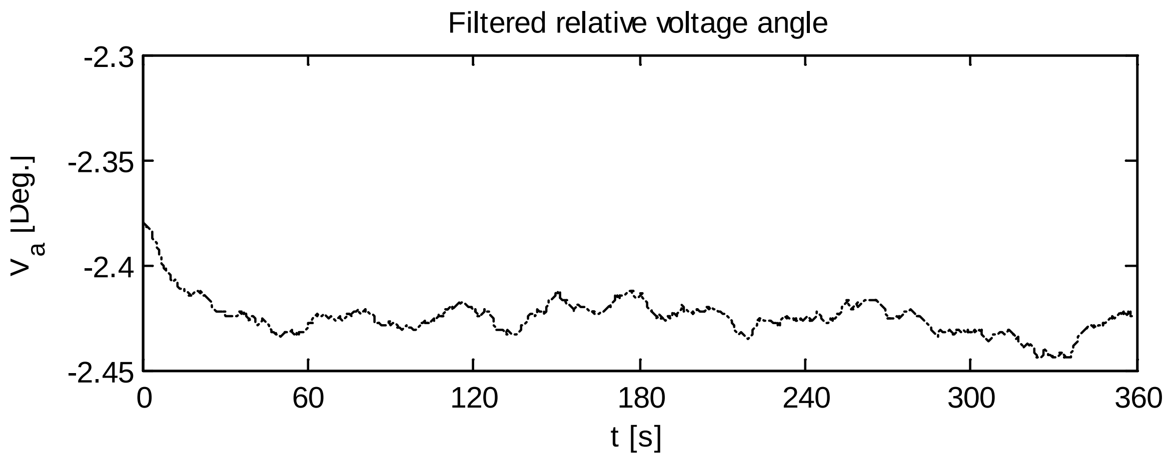
The voltage phase angle changes are relatively small in the range of **(0, 0.06)** degrees in Fig. C.

Relatively large voltage phase angle changes are observed every second in Fig. D. The value of the large voltage phase angle change is about **-0.2** degrees.

Voltage phase angle data from the SRP system



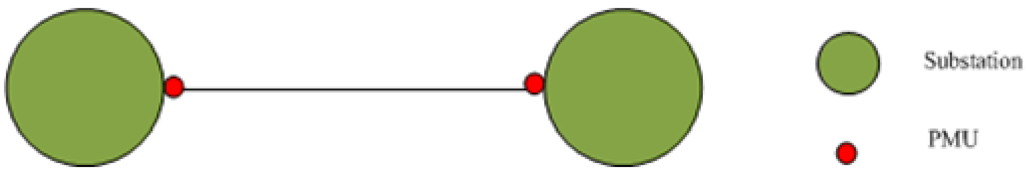
The upper figure shows the raw PMU measurement data with the time skew problem. The relative voltage angle is in a range between -2.4 and -2.2 degrees.



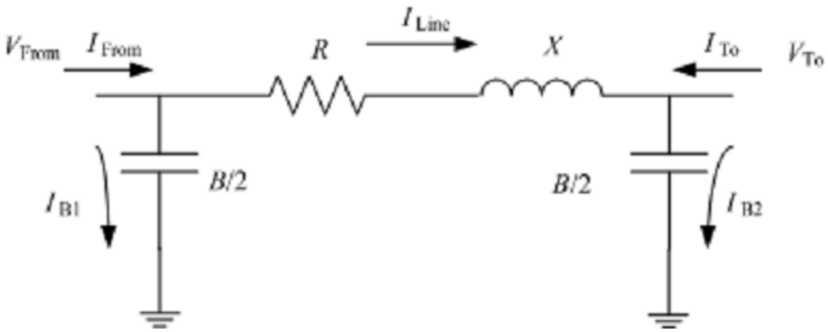
The lower figure shows the processed PMU measurement data by a filter considering the time skew problem

Analysis of accuracy of PMU measurements

Identification of inconsistency



PMU measurements
V_{From} I_{From} V_{To} I_{To}



Base on basic circuit law, the transmission line parameters could be calculated by PMU measurements.

$$I_{Line} = \frac{V_{From} - V_{To}}{R + jX}$$
$$I_{From} = I_{Line} + I_{B1}$$
$$I_{To} = -(I_{Line} - I_{B2})$$

$$Z = \frac{(V_{From} - V_{To})(V_{From} + V_{To})}{I_{From}V_{To} - I_{To}V_{From}}$$
$$j\frac{B}{2} = \frac{I_{From} + I_{To}}{V_{From} + V_{To}}$$

Identification of inconsistency

Test case: Transmission line I - L

Data Source	$R\,(\Omega)$	$X\,(\Omega)$	$B/2$ (siemens)
*Power flow file	2.03665	17.75324	0.000117
#1-1	-7.2432	25.7345	0.000124
#1-2	-5.2347	30.0084	0.000123
#1-3	-15.5523	30.7044	0.000123
#1-4	-6.2484	39.7526	0.000123
#2-1	-3.9426	21.5384	0.000125
#2-2	-4.0367	21.4644	0.000125
#2-3	-3.9621	21.5463	0.000125
#2-4	-3.9263	21.5569	0.000125
#2-5	-3.9982	21.6224	0.000124
#3-1	-6.1083	23.0640	0.000124
#3-2	-9.2601	20.9250	0.000124

* TL parameters are from planning data.

- Discrepancies are observed between the calculated impedance and TL parameters from planning data file
- The raw PMU measurements need to be calibrated
- TL parameters from planning data file are used

Inconsistency

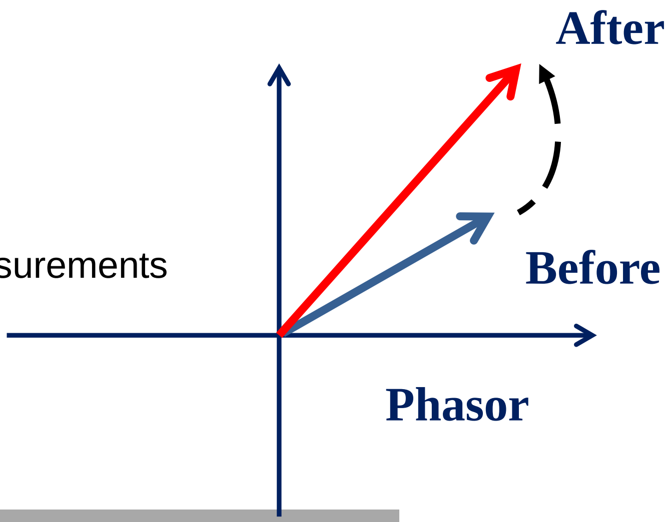
$$I_{From\_m} \neq \frac{V_{From\_m} - V_{To\_m}}{R + jX} + V_{From\_m} jB_1$$

$$I_{To\_m} \neq \frac{V_{To\_m} - V_{From\_m}}{R + jX} + V_{To\_m} jB_2$$

Proposed calibration method

- Correction factors (CFs, i.e., T_{I_from}, T_{I_to}, …)
  - Complex numbers
  - Calibrating current and voltage at the same time
  - Possible errors in magnitude and angle of the phasor measurements
- Criteria

$$P_{mismatch} = P_{From} + P_{To} - P_{loss}, where\ P_{loss} = I^2 R$$
$$Q_{mismatch} = Q_{From} + Q_{To} - Q_{loss} - Q_{BFrom} - Q_{BTo}, where\ Q_{loss} = I^2 X$$



$P_{mismatch}$ and $Q_{mismatch}$ should be zero under ideal conditions with accurate measurements and accurate transmission line parameters.
Smaller $P_{mismatch}$ and $Q_{mismatch}$ indicate more accurate measurements.

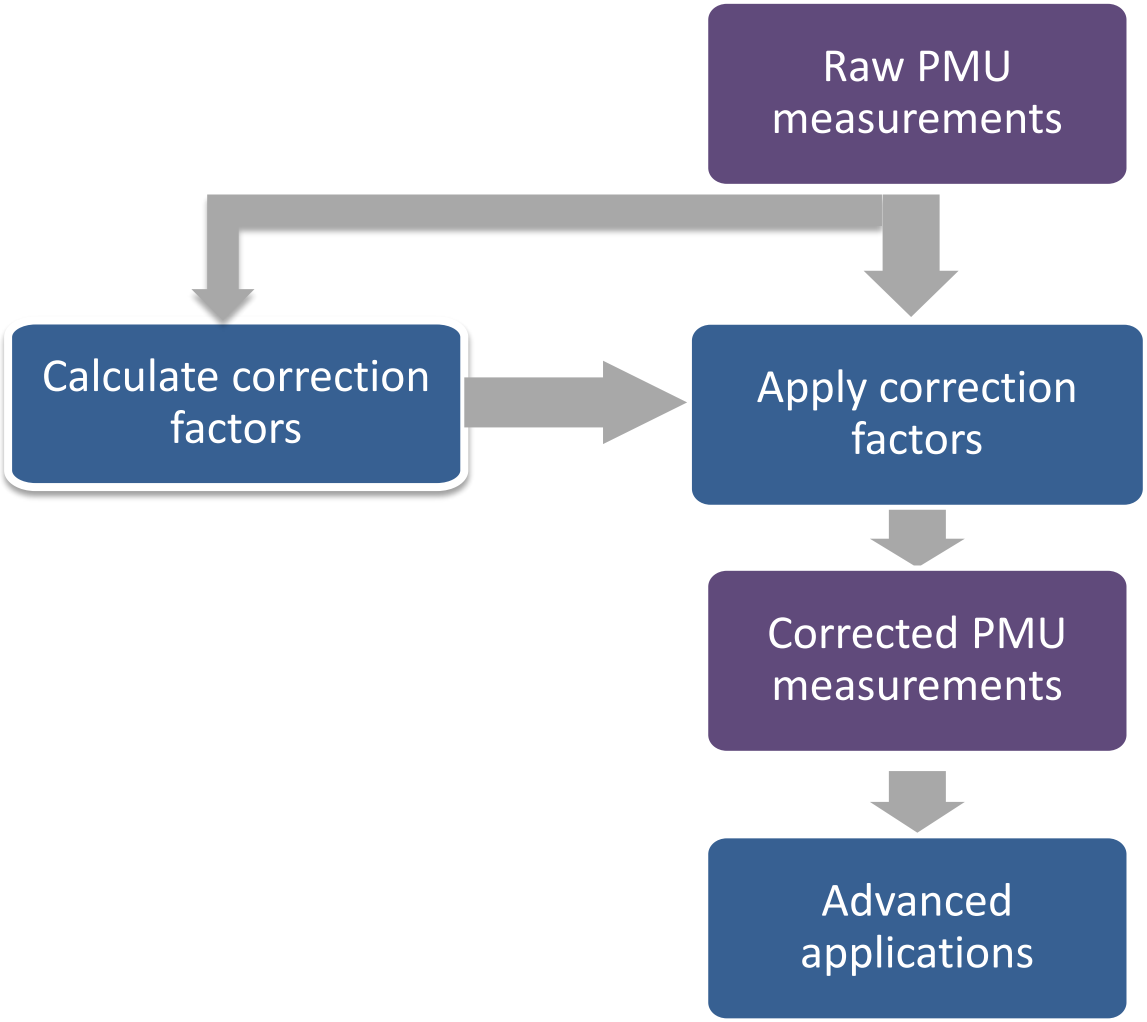
After calibration:

$$I_{From\_m} \cdot T_{I\_From} = \frac{V_{From\_m} \cdot T_{V\_From} - V_{To\_m} \cdot T_{V\_To}}{R + jX} + V_{From\_m} \cdot T_{V\_From} jB_1$$

$$I_{To\_m} \cdot T_{I\_To} = \frac{V_{To\_m} \cdot T_{V\_To} - V_{From\_m} \cdot T_{V\_From}}{R + jX} + V_{To\_m} \cdot T_{V\_To} jB_2$$

$$Correction\ factors: T_{I\_From} \quad T_{I\_To}$$
$$T_{V\_From} \quad T_{V\_To}$$

Implementation of correction factors (CFs)



Conclusions

- The basic issue concerning the two important features (i. e. synchronization and accuracy) of PMU measurements is addressed.
- Time skew exists between measurements from different PMUs.
- Time skew error in PMU measurements should be compensated .
- Large discrepancy is observed between PMU measurements and transmission line parameters.
- A method is proposed to calibrate PMU measurements in specific installation scenarios.