Research on Phasor Measurement Accuracy in a Real Power Grid Environment at the Distribution Level

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San Mateo, CA

Is PMU Standard enough?

IEEE PMU Standard
C37.118.1-2011
C37.118.1a-2014

Steady-state tests
1. Signal frequency range test
2. Signal magnitude test
3. Harmonic distortion test
4. Out-of-band interference test

Dynamic tests
1. Frequency ramp test
2. Modulation test (magnitude, angle)
3. Step change test (magnitude, angle)

Suitable for distribution level?

Data acquisition of power grid waveforms

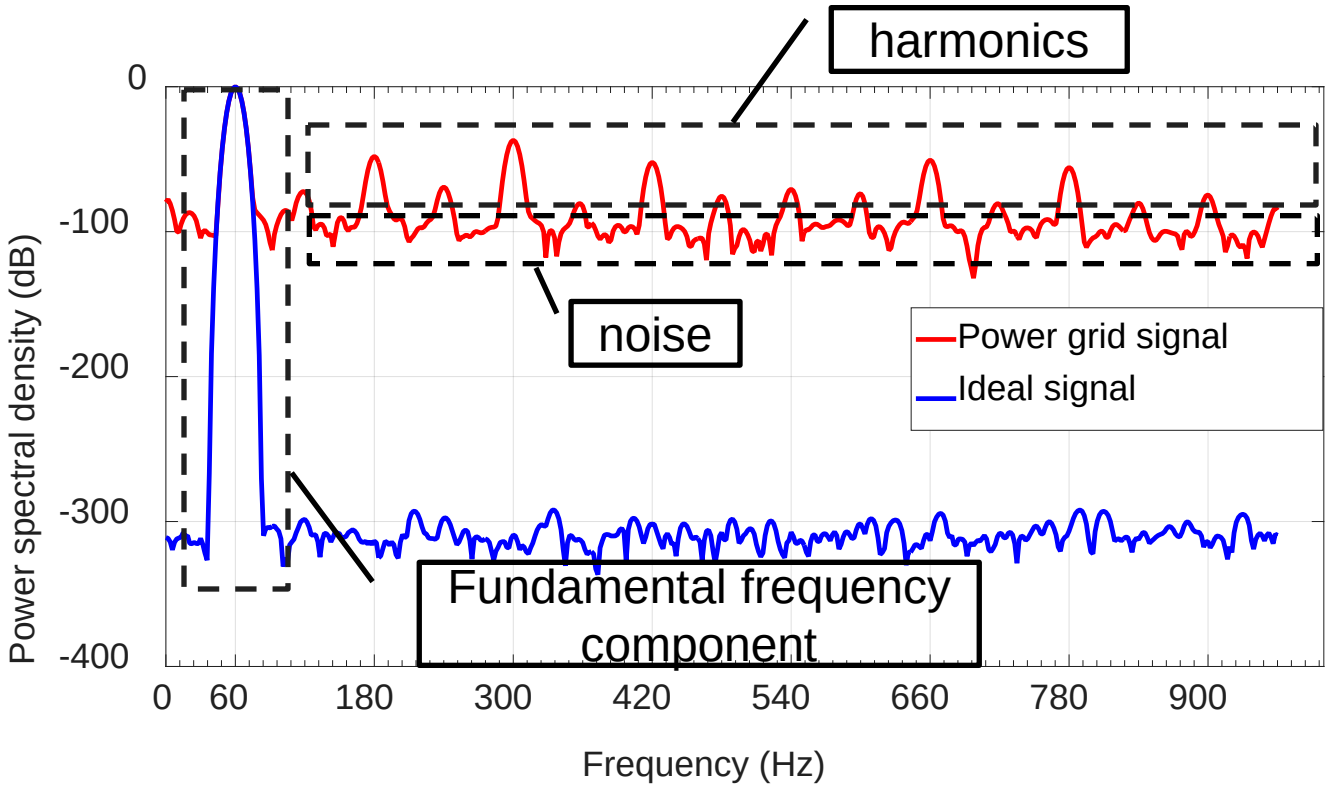
Power grid waveforms at the distribution level (120-V) are sampled using the prototype Universal Grid Analyzer (UGA).

Prototype UGA[1]

- High-accuracy single phase PMU, power quality analyzer.
- Signal to Noise Ratio (SNR) detection capability: 90 dB

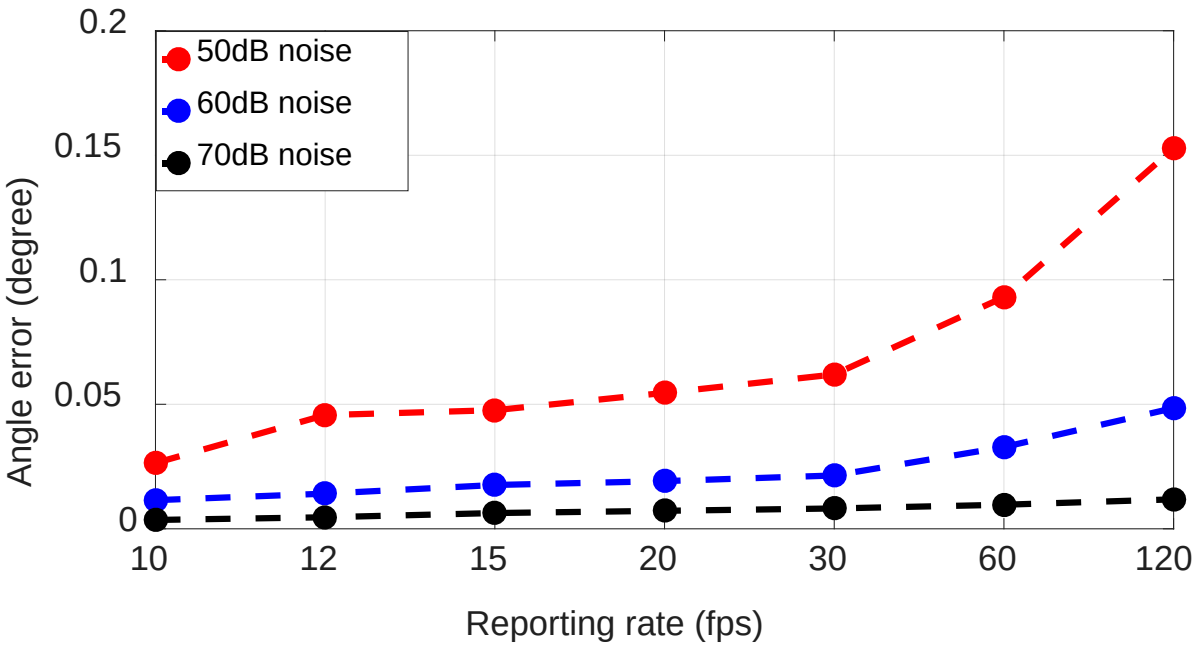
[1] Lingwei Zhan, et al., "Universal Grid Analyzer Design and Development", *in Proc. 2015 IEEE Power and Energy Society General Meeting*, accepted.

Distortion of power grid waveforms

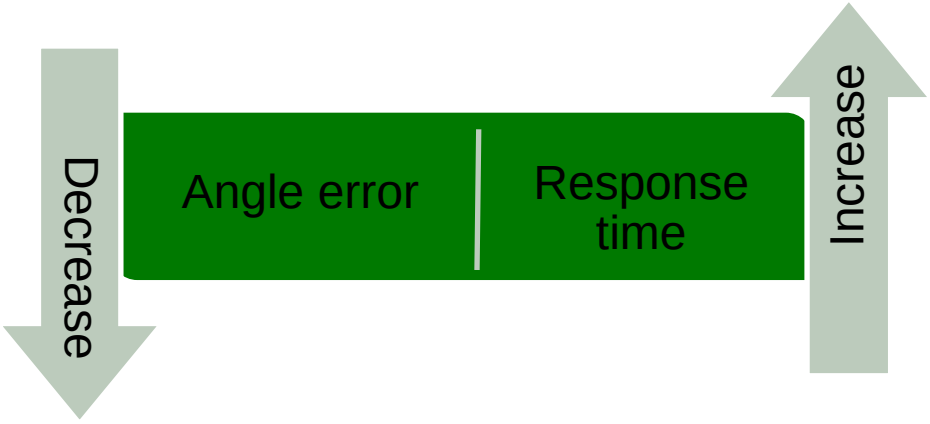


- Power grid waveforms are distorted by harmonics and noise.
- PMU Standard C37.118.1 has no requirements for
  - Noise
  - Harmonics (the fundamental frequency deviates from 50/60Hz).

Phasor measurement accuracy under noise condition



fps	response time	No. of cycles
10	0.7s	60.6
12	0.58	51.1
15	0.47	41.4
20	0.35	31.4
30	0.23	19.2
60	0.12	10.3
120	0.06	4.4



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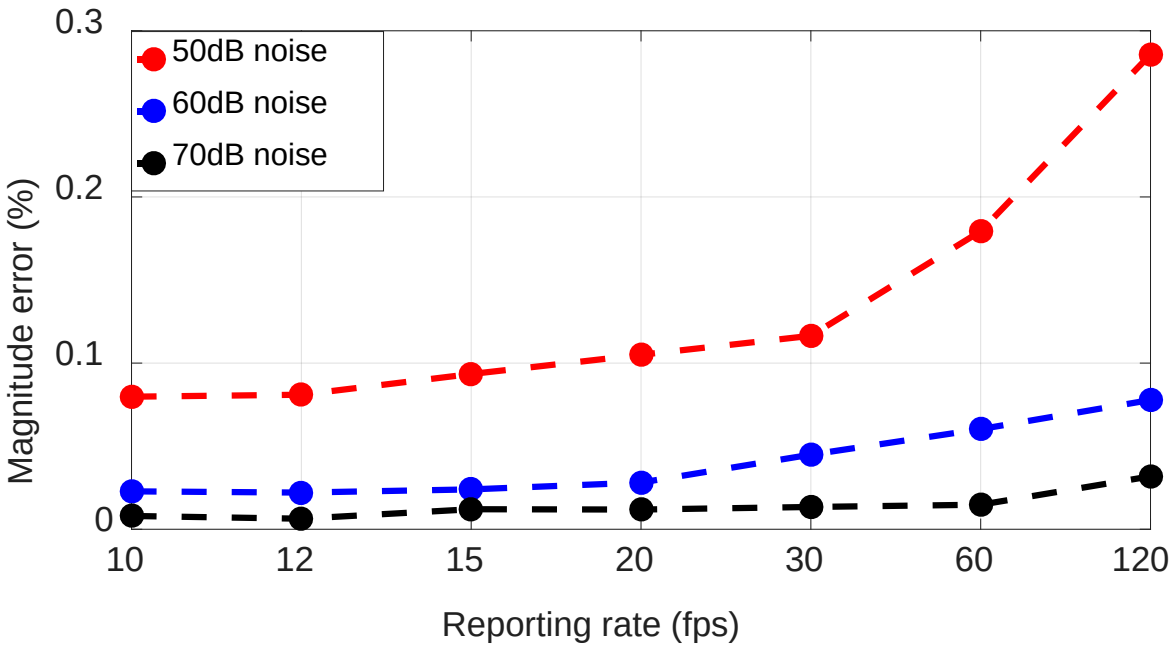

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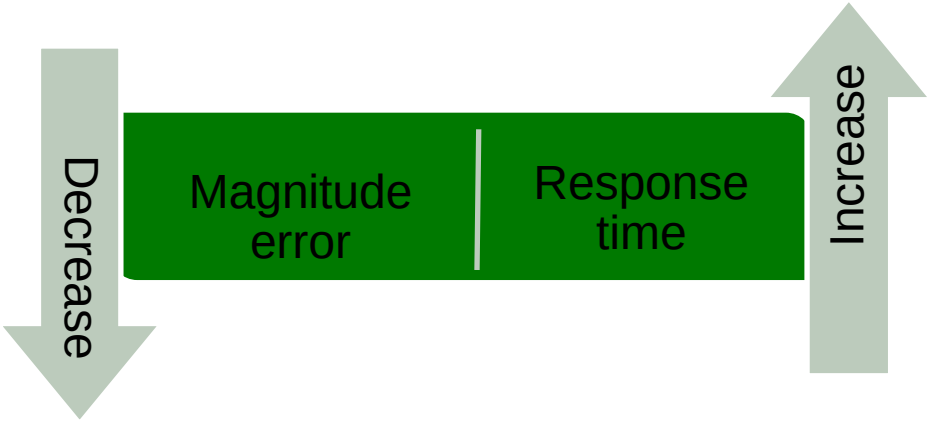
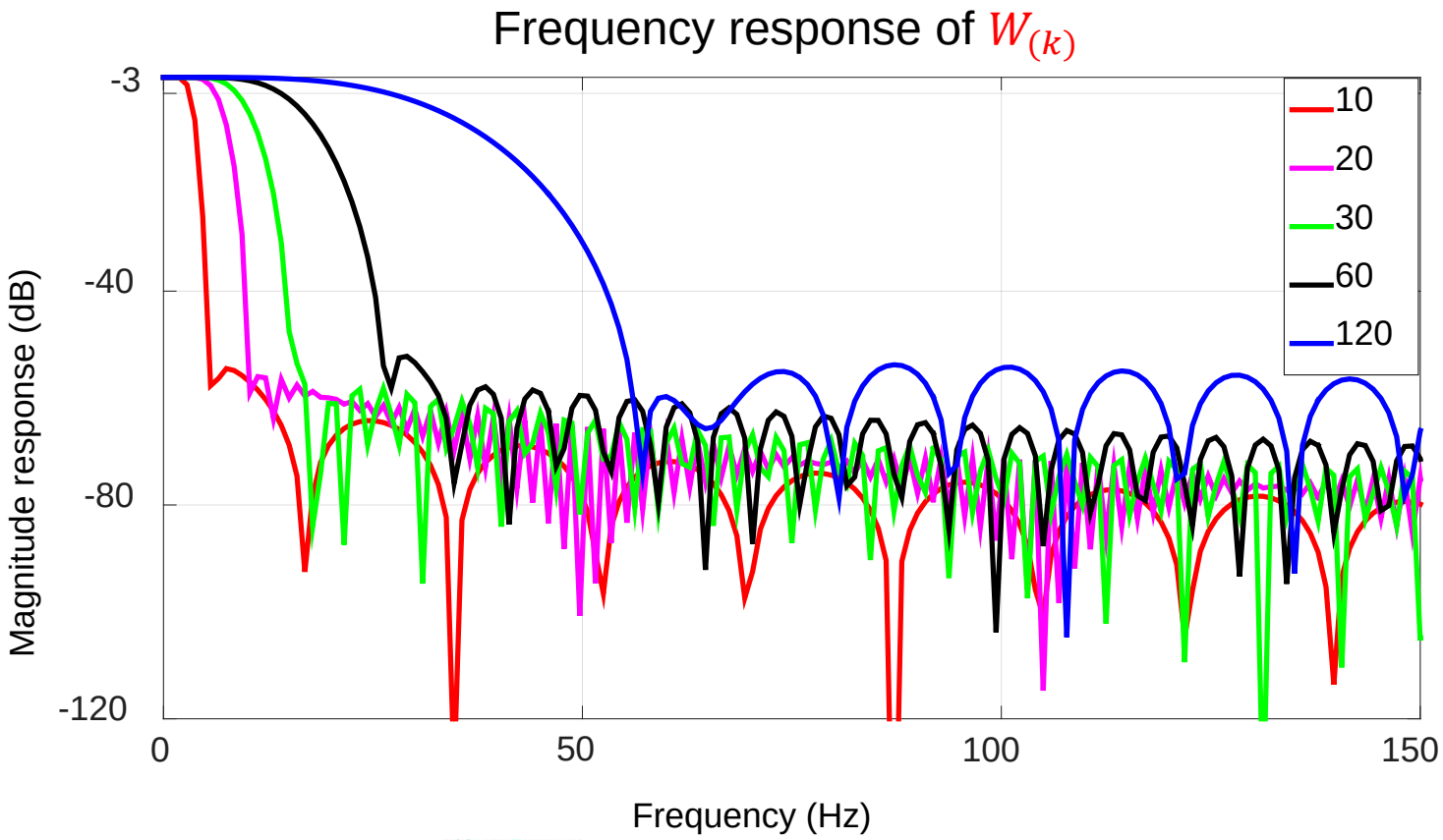


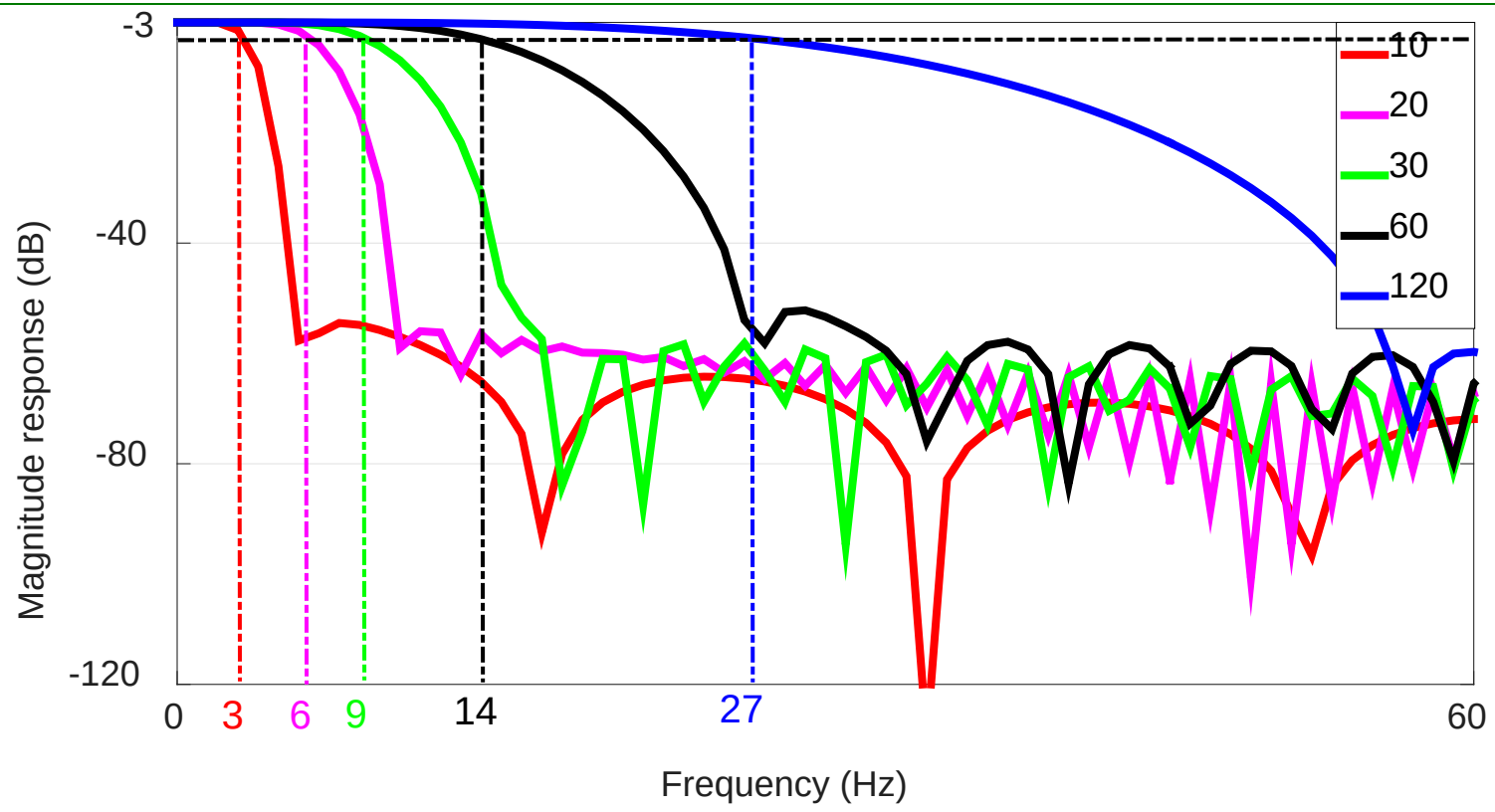
Explanation

Phasor estimation equation in Annex C of C37.118.1-2011

$$X(i) = \frac{\sqrt{2}}{Gain}\sum_{k=-N/2}^{N/2} x_{(i+k)} \times W_{(k)} \times \exp(-j(i+k)\Delta t \omega_0) \qquad \text{(C.1)}$$



Explanation: main lobe



Increase

Reporting rate

Increase

main lobe width (3dB bandwidth)

Noise rejection

Decrease

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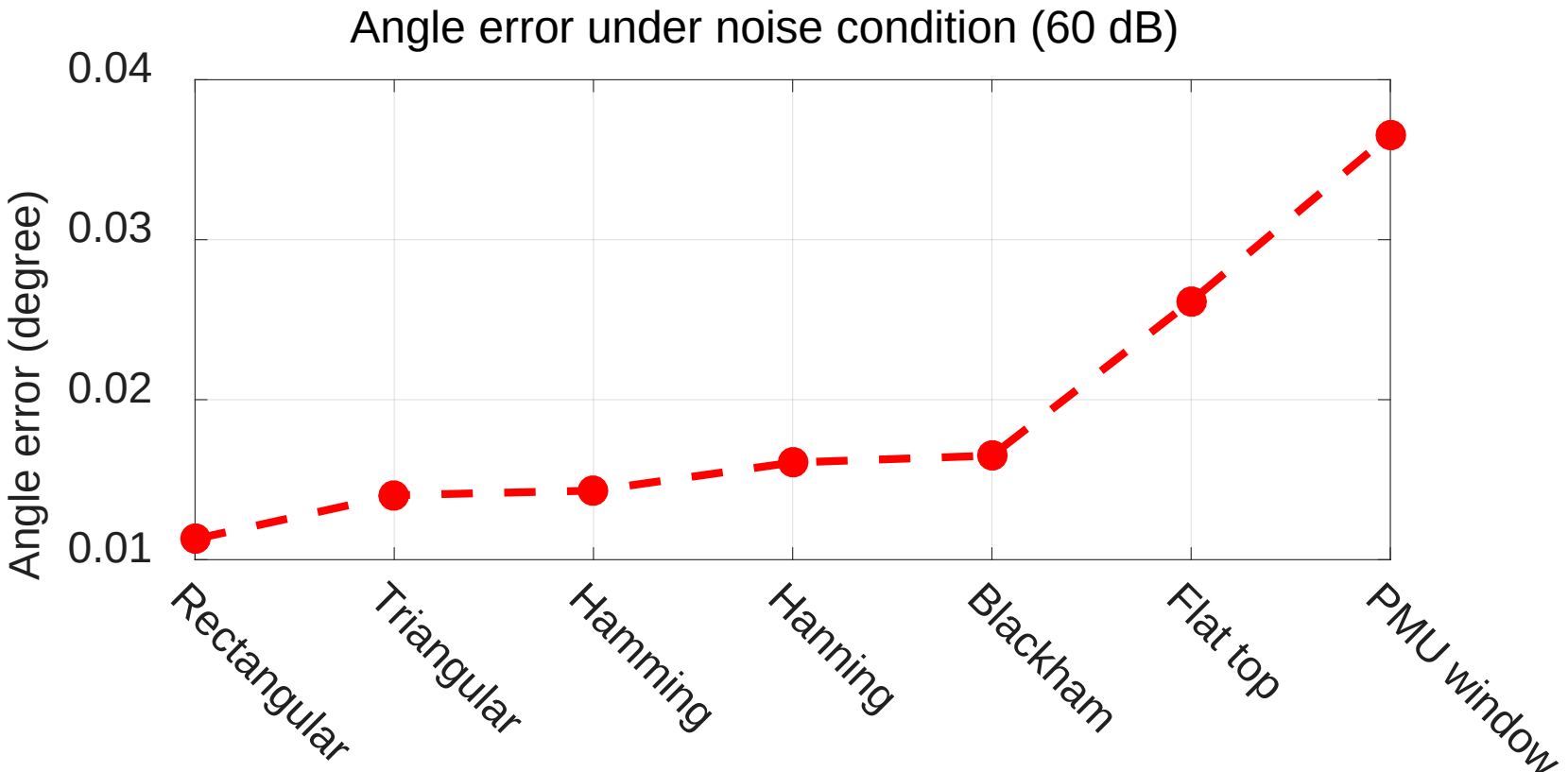
Non-PMU filter windows

$$X(i) = \frac{\sqrt{2}}{Gain}\sum_{k=-N/2}^{N/2} x_{(i+k)} \times W_{(k)} \times \exp(-j(i+k)\Delta t\omega_0) \qquad \text{(C.1)}$$

$W_{(k)}$ is replaced with other windows.



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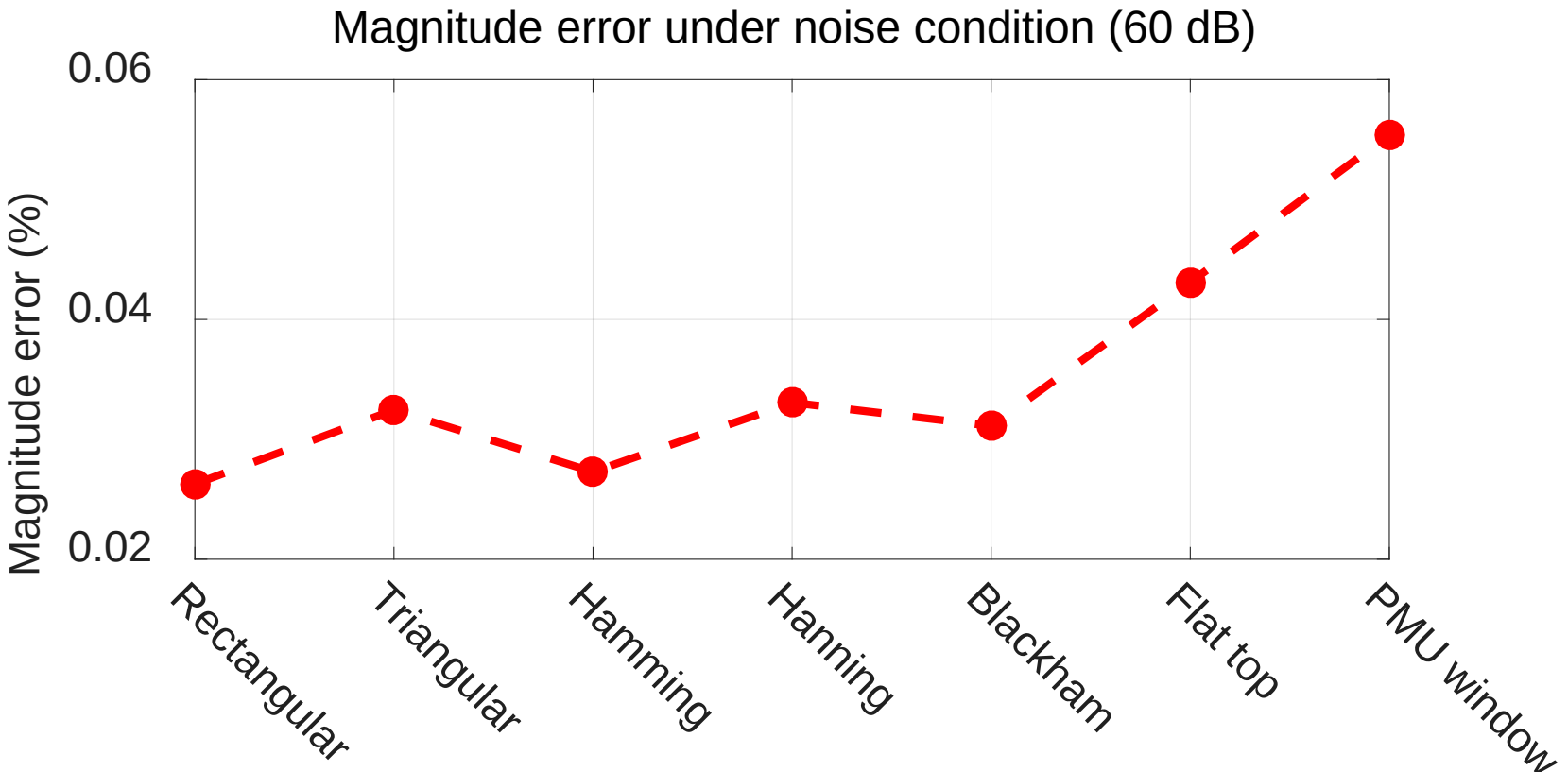

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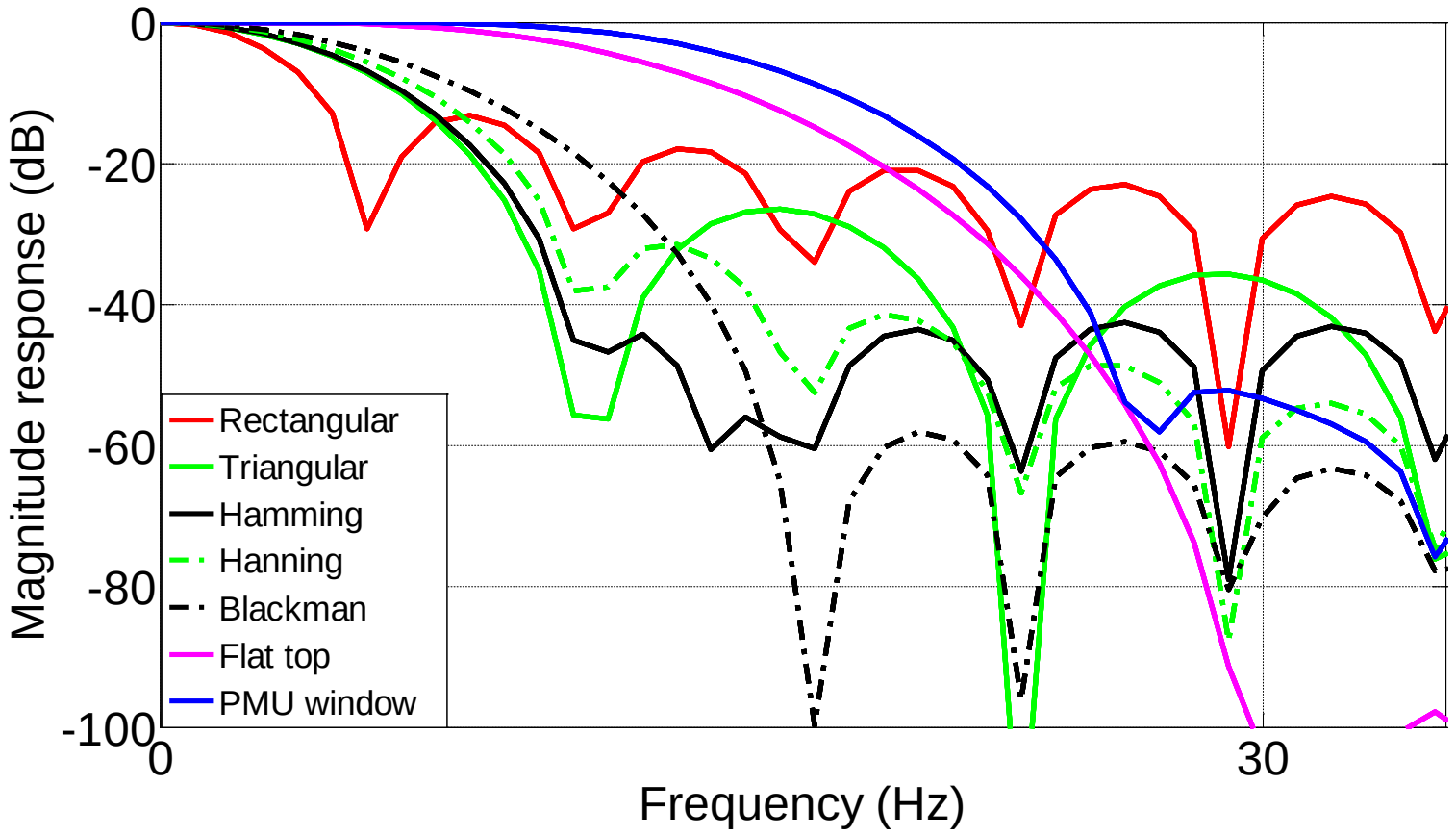
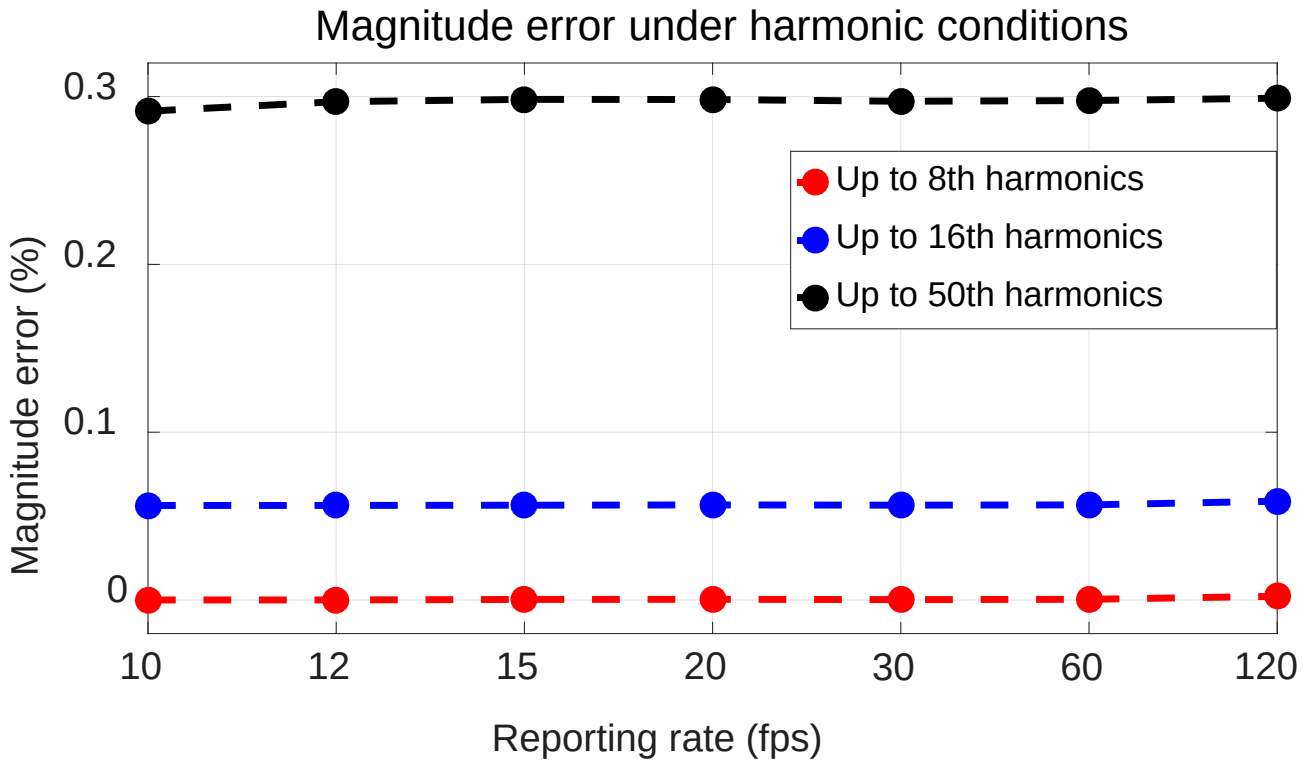


- Rectangular window has narrowest main lobe width (3dB bandwidth), therefore has best noise rejection performance;
- PMU window has widest main lobe width, therefore has worst noise rejection performance.

Phasor measurement accuracy under harmonic conditions

Different from the harmonic testing in the PMU Standard (C37.118.1-2011 and C37.118.1a-2014)

- Fundamental frequency is not equal to nominal frequency;
- Multiple-harmonics are added, not only individual harmonics;
- Harmonic levels are determined by practical measurements.



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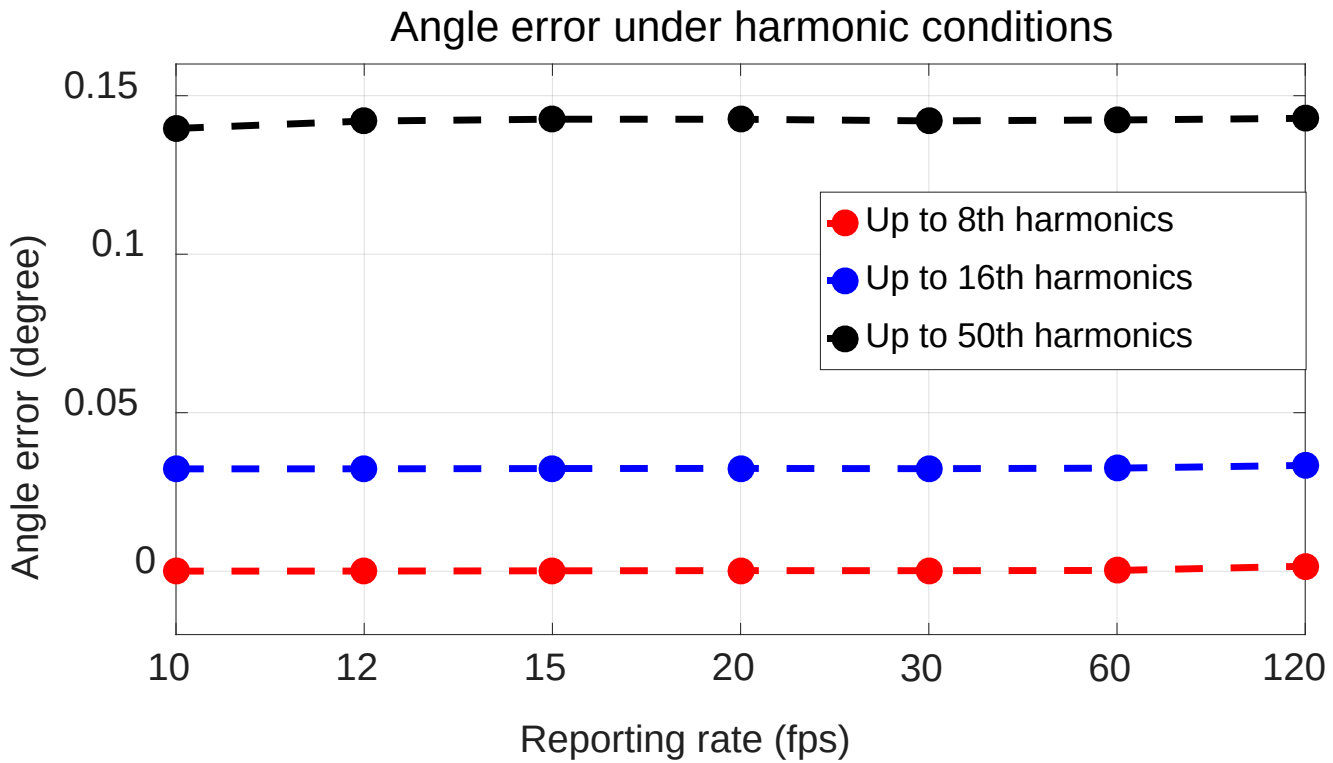

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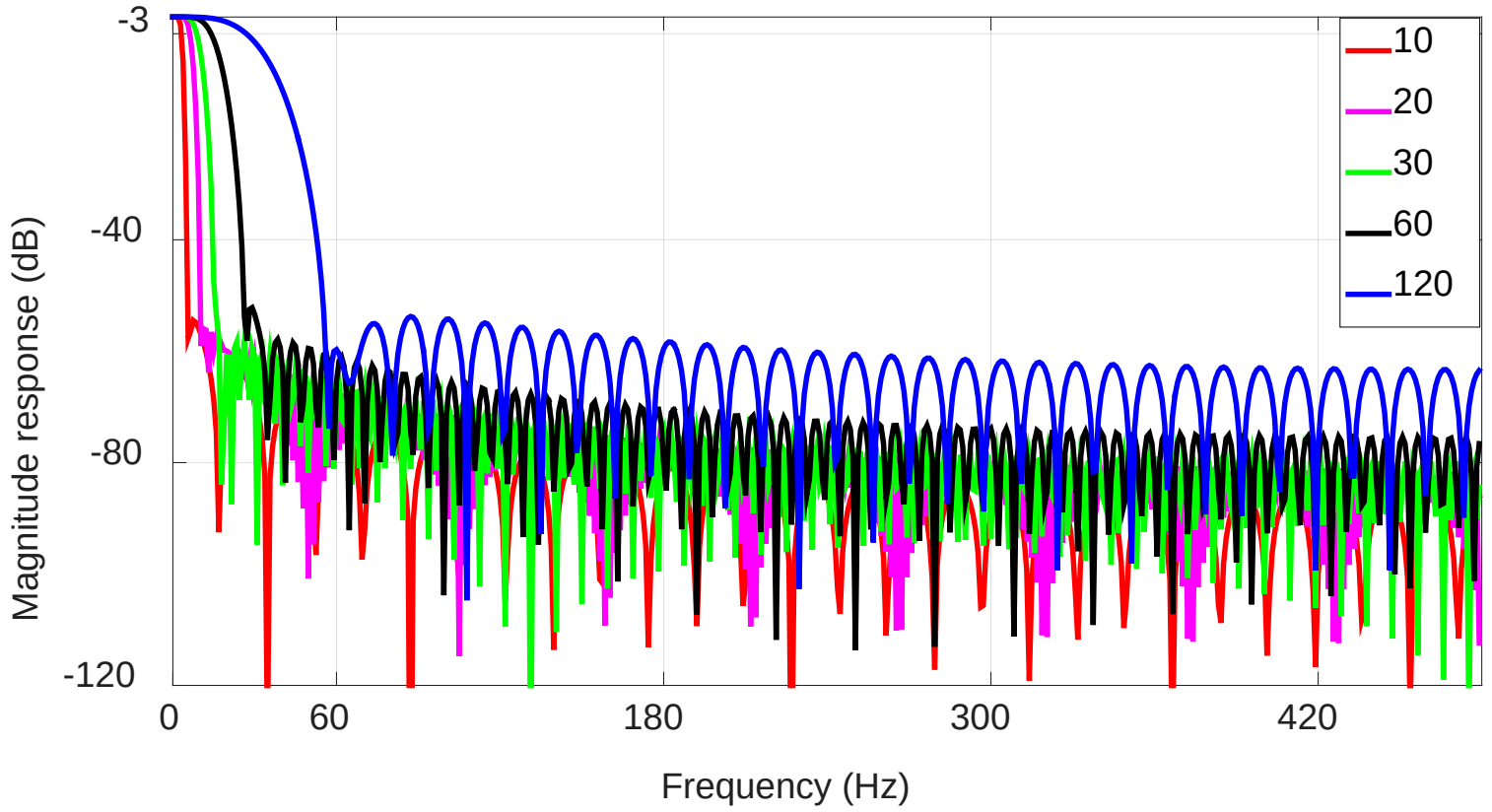
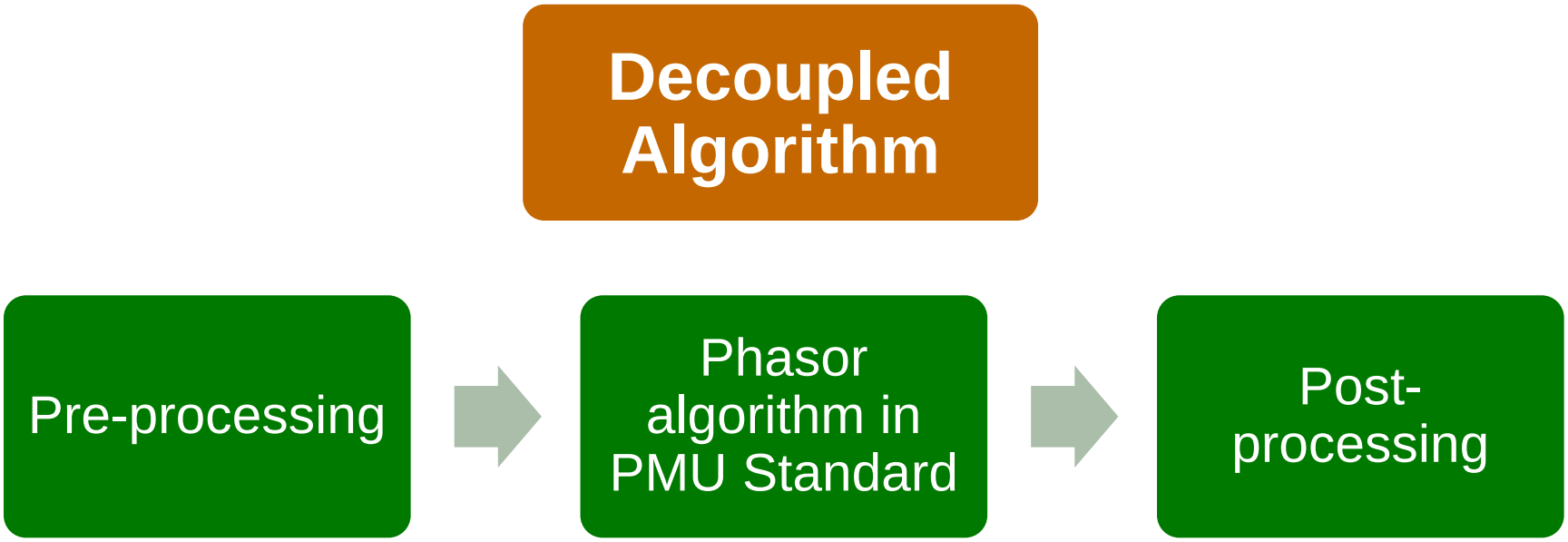


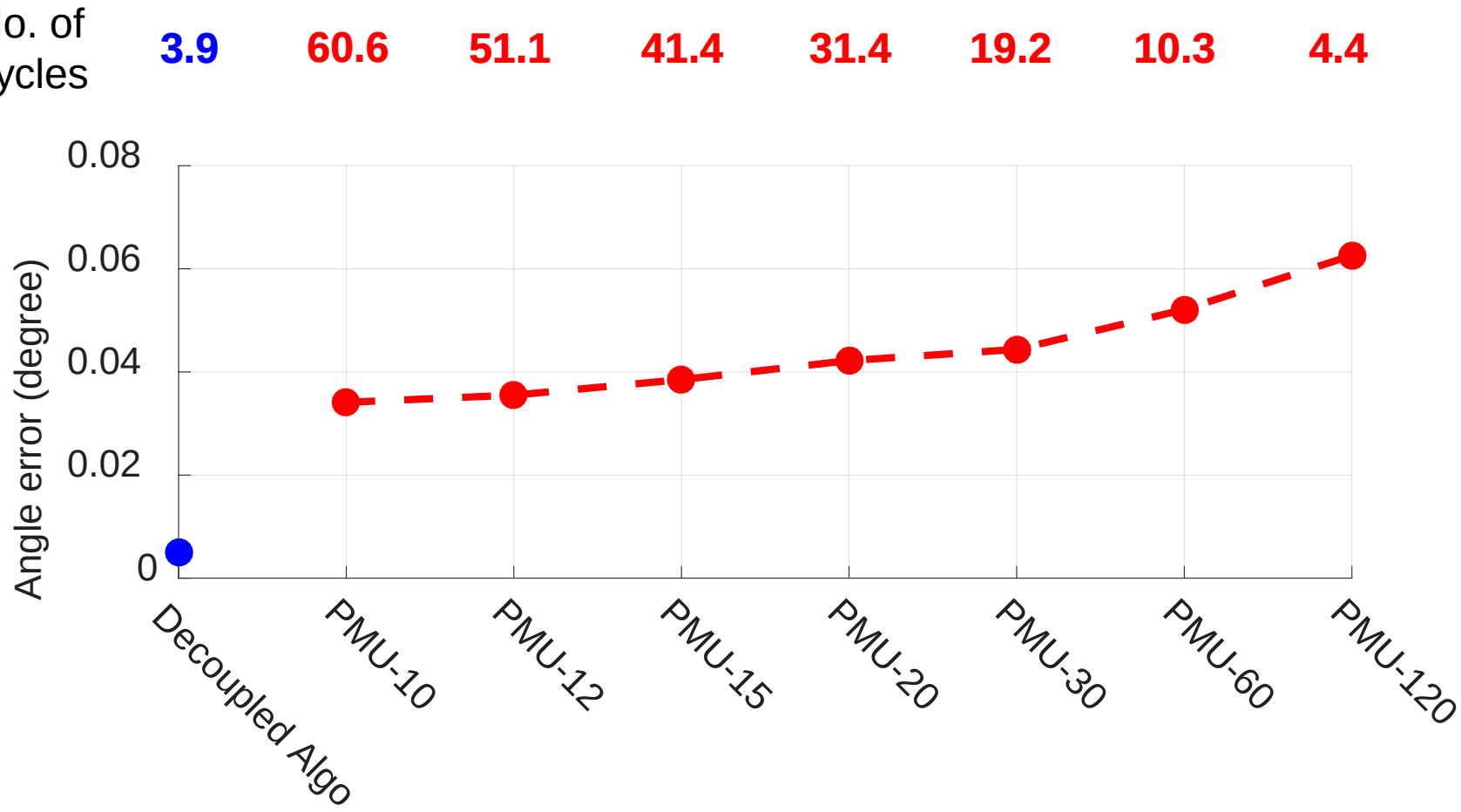
- Filters for different reporting rate have similar harmonics reduction performance.
- The attenuation of one filter to different harmonics is close to each other.

Decoupled algorithm



- Pre-processing: digital filter to filter the noise in time domain
- Post-processing: digital filter to reduce the errors caused by harmonics in phasor domain (*The filter is a multiple-steps filter to improve dynamic measurement performance*)

Decoupled algorithm[2] vs PMU algorithm



[2] Lingwei Zhan, et al., "Dynamic Single-Phase Synchronized Phase and Frequency Estimation at the Distribution Level," *Smart Grid, IEEE Transactions on* , vol. PP, no.99, pp.1,1

Conclusions

- The noise rejection performance decreases with the increase of reporting rate.
- PMU filter window has worst noise rejection performance.
- PMU filter windows for different reporting rates have similar harmonics rejection performance.
- The effect of noise and harmonics on measurement accuracy needs to be considered for phasor measurement algorithm, particularly at the distribution level.
- A decoupled algorithm was proposed to improve phasor measurement accuracy at the distribution level.

Acknowledgements

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Thanks