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AI-based Transient Frequency Estimation

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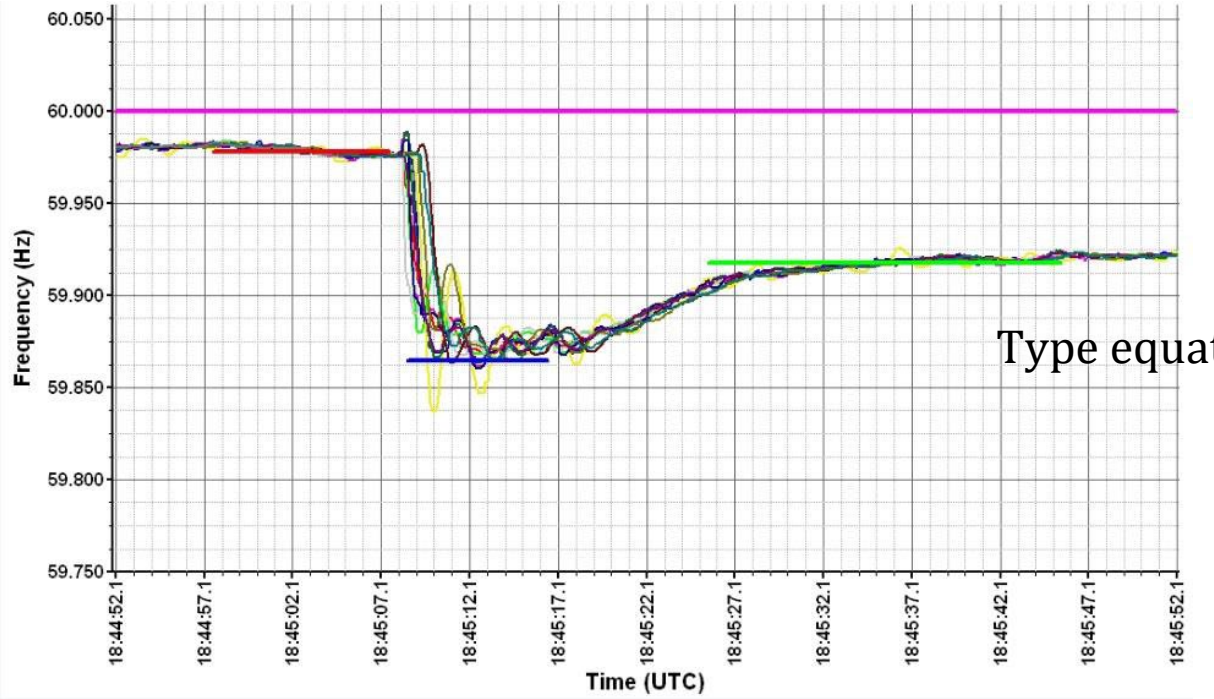
4/14/2026

Introduction



Frequency Measuring Network Data for Large Resource Loss Event (August 16, 2016, The Blue Cut Fire Event), "NERC 1,200 mw fault induced solar photovoltaic resource interruption disturbance report," 2017.

Type equation here.

- **PLL detected frequency < 57Hz → 700 MW inverter loss**
- **Actual grid frequency – 59.8Hz >57Hz**

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Limitations of Traditional Frequency Estimation Methods

TABLE I
P-PMU STANDARD TEST DETAILED RESULTS – BEST PERFORMERS. EACH CELL SHOWS THE NUMBER OF TESTS PASSED.

60255-118-1 standard test	Requirement	DFT fit + detector 3ph unfiltered	MATLAB PLL 3ph filtered	EKF + corrector 3ph filtered	ANF + corrector 3ph filtered	Standard DFT 3ph unfiltered	PSCAD PLL 3ph filtered
Steady 60,58 & 62 Hz	max |FE| < 5e-4 Hz	/ 1	+ 3	+ 3	+ 3	+ 3	+ 3
Harmonics, 2nd-50th	max |FE| < 5e-4 Hz	+ 49	+ 49	+ 49	/ 48	+ 49	/ 33
Phase mod, 0.1-2 Hz	max |FE|<0.06 Hz	+ 20	+ 20	/ 17	/ 17	/ 15	+ 20
Amp mod, 0.1-2 Hz	max |FE|<0.06 Hz	+ 20	+ 20	+ 20	+ 20	+ 20	+ 20
±1 Hz/sec ramp	max |FE|<0.01 Hz	- 0	- 0	- 0	- 0	- 0	- 0
±0.1 Amplitude step	Response time < $4.5/f_0$	+ 2	+ 2	+ 2	+ 2	+ 2	+ 2
±10 deg phase step	Response time < $4.5/f_0$	+ 2	- 0	- 0	- 0	/ 0 - failed by only 3 ms	- 0

\+ Passed all subtests / Passed some subtests - Failed all subtests

- **Good in steady-state**
- **Poor under transient conditions (Ramp signals, phase step signals)**

Performance of Traditional Frequency Estimation Methods under PMU Standard Tests (J. Ting and et al, “Evaluating methods for measuring grid frequency in low-inertia power systems,” in KPEC, pp. 1–6, 2022.)

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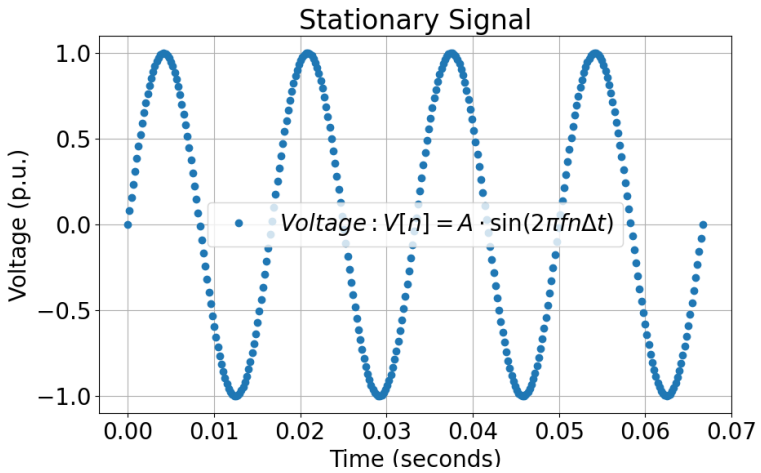
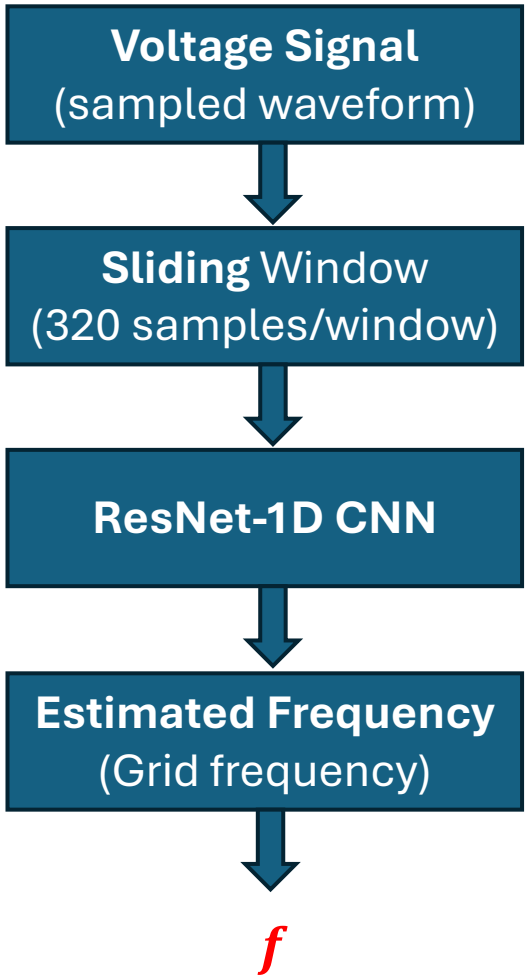
Method : ResNet-1D CNN



$$Training\ Signal\colon\ V\ [n] = A\ \cdot \sin(2\pi f n \Delta t)$$



- Supervised learning
- Fixed frequency for each channel of the training data
- Sampling rate: 4800Hz
- Training frequency range: 58-62Hz

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Test Results I

P-PMU Standard

60255-118-1 Standard Test	Requirement
Steady (58-62 Hz)	$\max\|FE\| < 0.0005$ Hz
Phase Modulation (0.1-2 Hz)	$\max\|FE\| < 0.006$ Hz
Amplitude Modulation (0.1-2 Hz)	$\max\|FE\| < 0.006$ Hz
Ramp ($\pm$ 1 Hz/sec)	$\max\|FE\| < 0.01$ Hz
Amplitude Step ($\pm$ 0.1)	Response time $< 4.5/f_0$
Phase Step ($\pm$ 1 degree)	Response time $< 4.5/f_0$

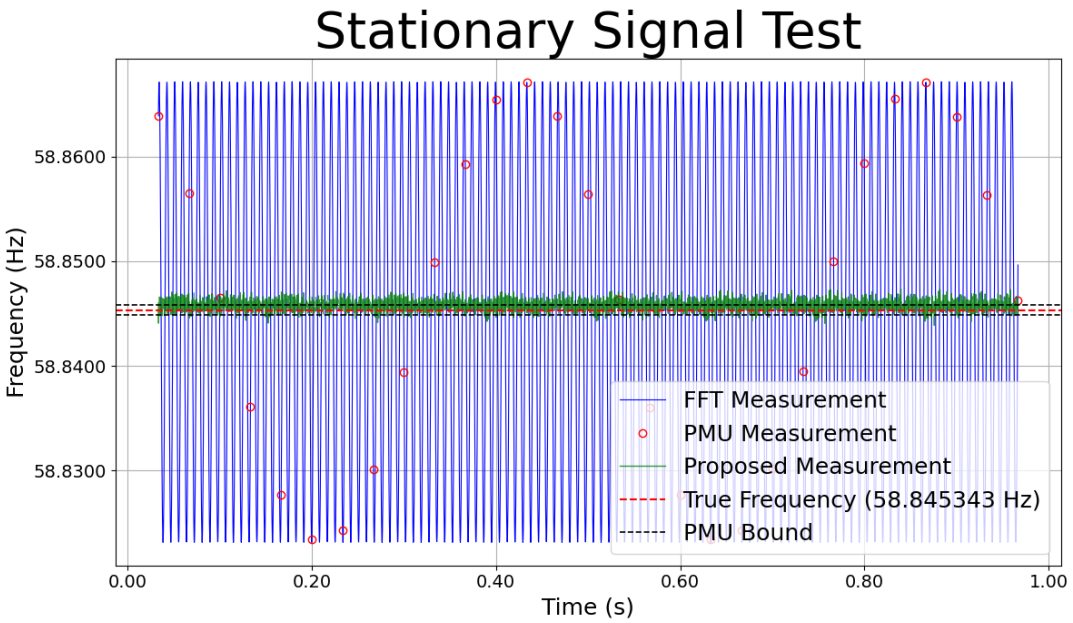
Test Results

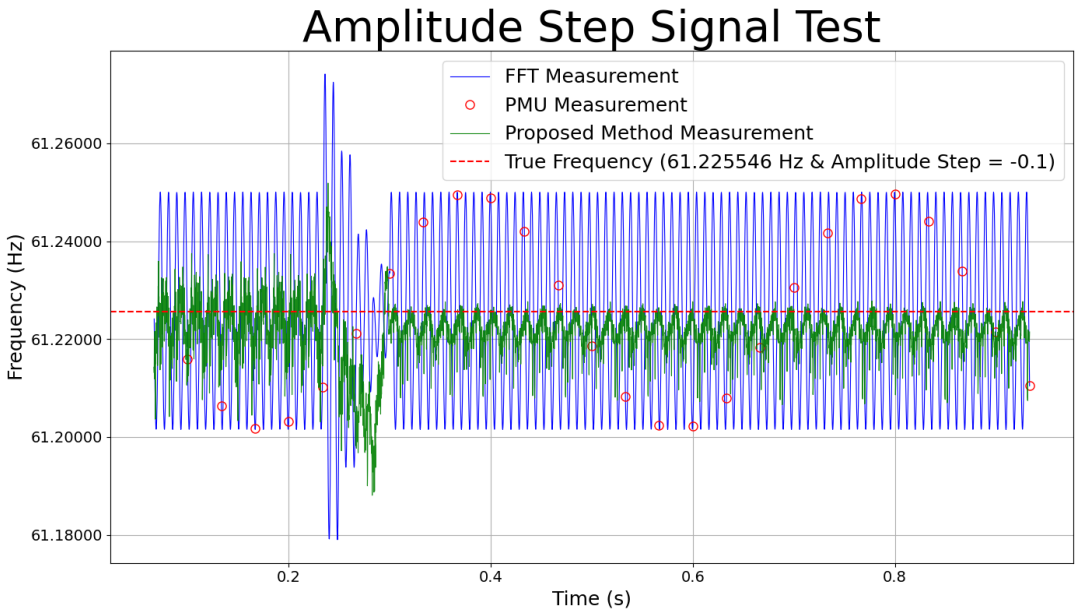
Tested Signals	Error
Stationary Signal (60.147748 Hz)	0.00030 Hz
Phase Modulation (0.1 Hz)	0.00129 Hz
Amplitude Modulation (2 Hz)	0.00486 Hz
Ramp Signal (2Hz/s)	0.00223 Hz

- After training, the final mean error of tested stationary signal was approximately **0.0005 Hz** that meet PMU requirement.
- The model performed well noy only for stationary signal, but also for the transient signals.

C. Sun, X. Guo, M. Alamaniotis, Y. Guo and B. Wang, "ResNet-1D CNN-based Grid Frequency Estimation," 2025 IEEE Power & Energy Society General Meeting (PESGM),

Test Results II





- **The performance of proposed method is more accuracy than traditional method**

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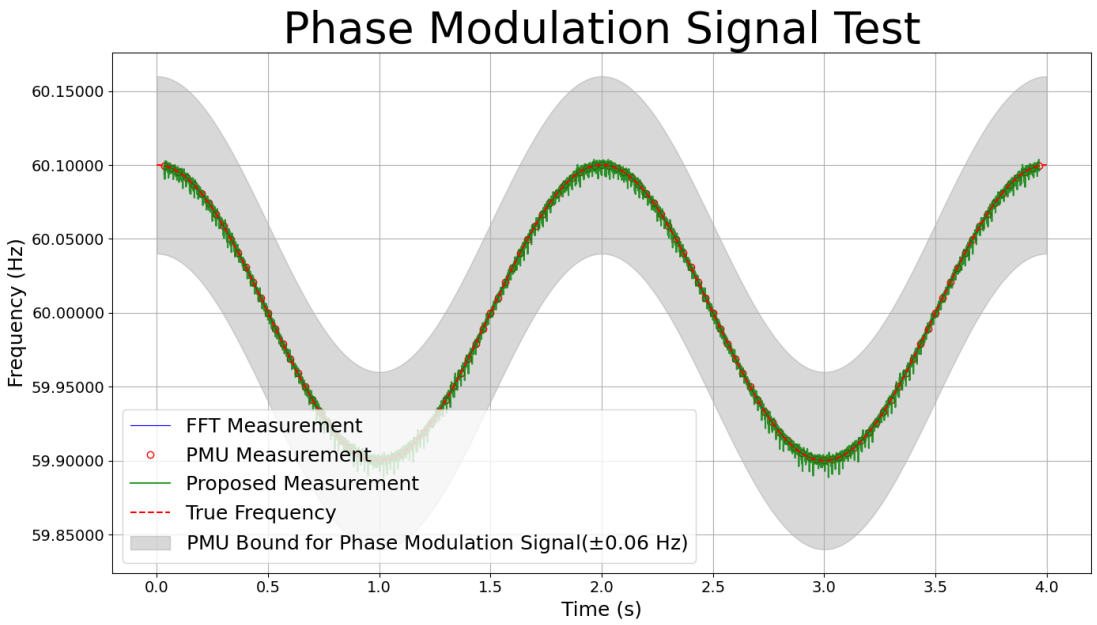
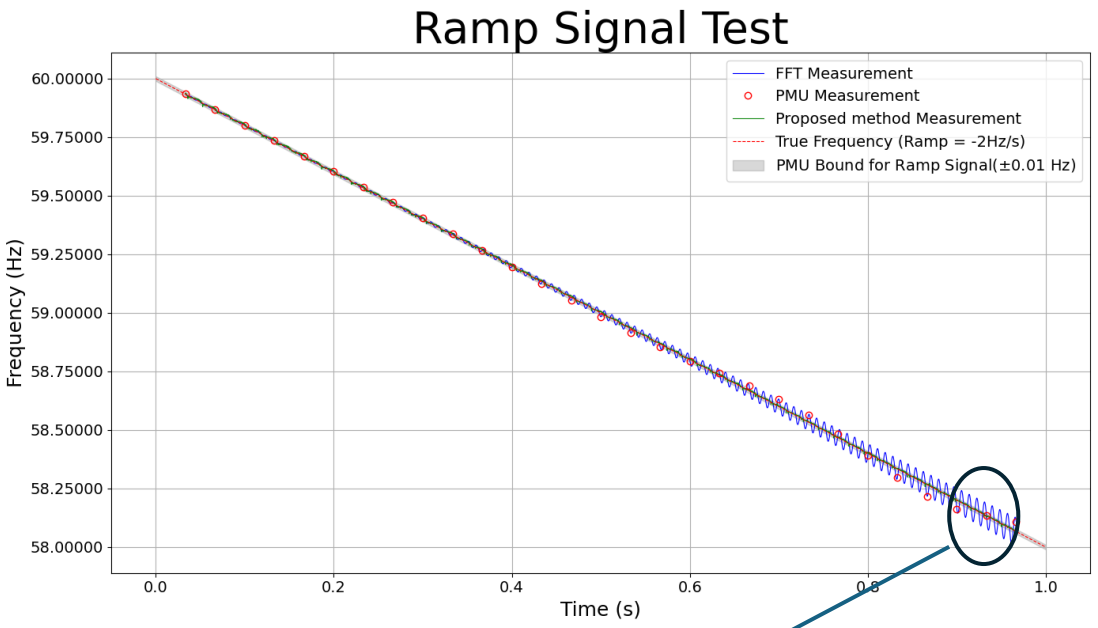
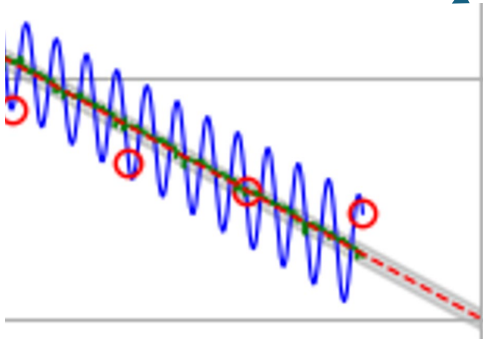
Test Results III







- **The results show that the model also performs very well for the signals with a dynamic frequency.**

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Conclusion

- The first effort applying AI to transient frequency measurement in power systems
- Proposed AI-based frequency estimation using ResNet-1D CNN
- Accurate for both steady-state and transient signals

Future work:

- To explore advanced AI models (e.g., Transformer) for improved performance
- To test the method using simulation data (e.g., PSCAD)
- To use more different signals as the training data

Thank you

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