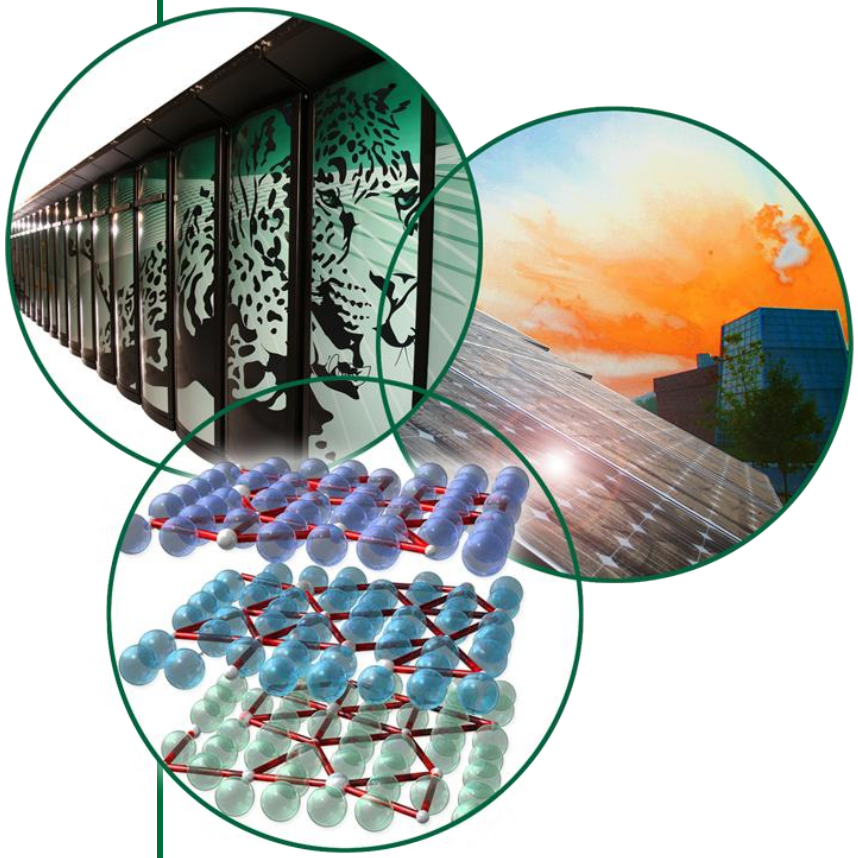
CERTS

Frequency responsive loads

Isabelle Snyder, Ph.D.

Power and Energy Systems Group

ORNL



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

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Project objective

- Study the use of load for frequency regulation:
  - Identify frequency measurement accuracies based on different approaches
  - Identify accuracy requirement for frequency responsive load applications
  - Study the impact of frequency responsive loads on a large system (ERCOT or EI)

Major technical accomplishments: overview

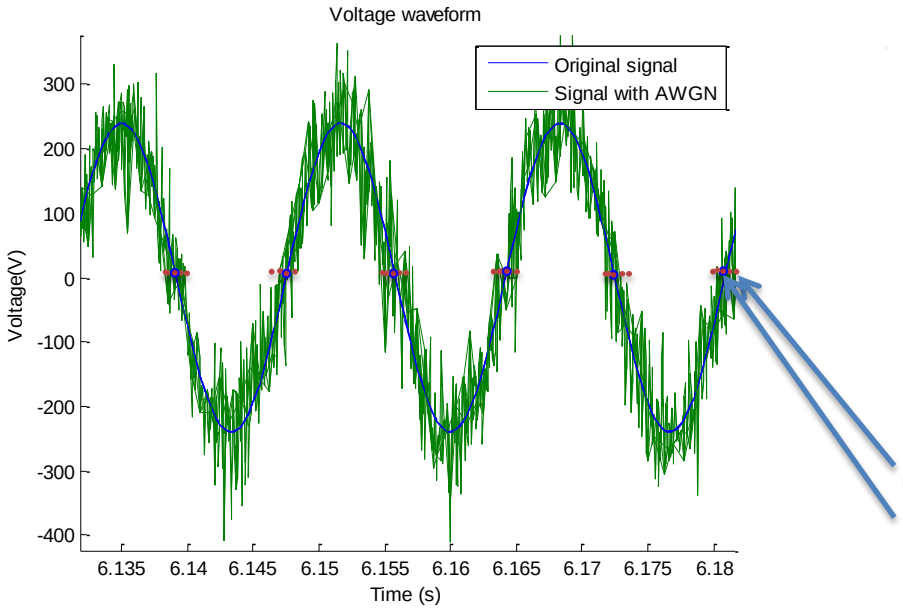
- Identified requirements of measurement devices to satisfy accuracy requirements for frequency measurement
- Initiated request for ERCOT and EI models:
  - ERCOT (market participant's concern about releasing ERCOT dynamic data)
  - EI (Dr Yilu Liu requested from TVA to extend the use of the existing EI dynamic model for frequency responsive study)

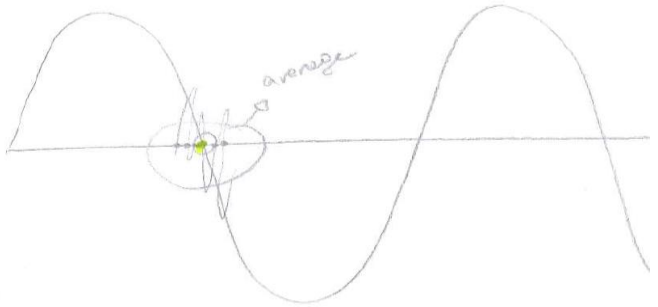
Major technical accomplishments: Frequency measurement accuracy

- Two frequency measurement algorithms developed and optimized to analyze the accuracy under:
  - Different Signal to Noise Ratio (SNR)
  - Different sampling frequency
  - Different measurement length
- Assumptions:
  - Normal frequency range: [59.98 60.02]
  - To maintain frequency at those level the measurement should have at least 0.01Hz accuracy

Major technical accomplishments: Frequency measurement accuracy

- Method 1:
  - Filtering based on averaging zero crossings detected due to noise
  - Detect all zero crossings
  - Average values if: $\frac{1}{T1 - T0} > 90Hz$



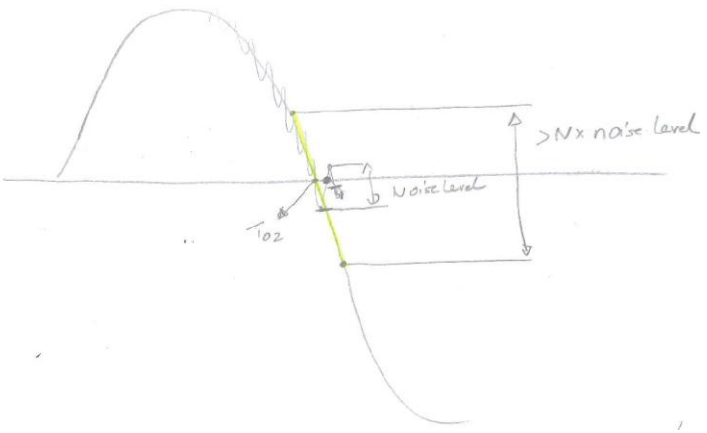


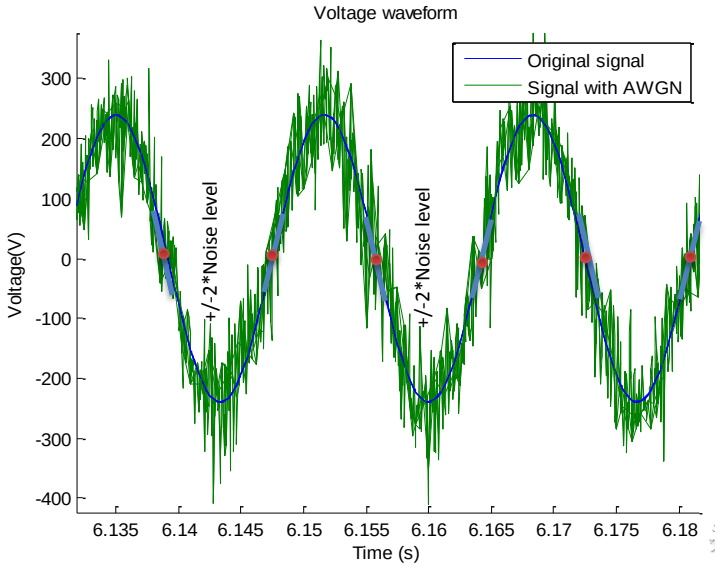
Algorithm based on finding all zero crossing and averaging the zero crossing corresponding to the same positive or negative slope.

- Represents all zero crossings
- Represents the averaging of zero crossings corresponding to an ascending or descending slope

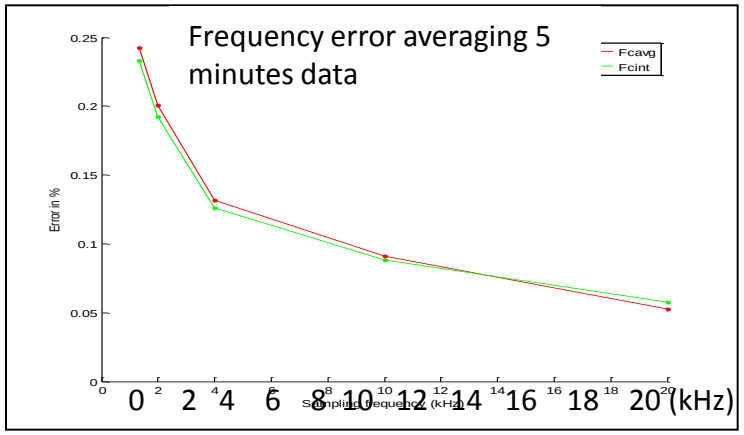
Major technical accomplishments: Frequency measurement accuracy

- Method 2:
  - Filtering is adaptive to the noise level
  - Detect all zero crossings
  - Zero crossings detected due to noise will be replaced by linear interpolation using the previous and next values on the voltage waveform that is higher than 2* estimated Noise level
  - Average values if: $\frac{1}{T1 - T0} > 90Hz$



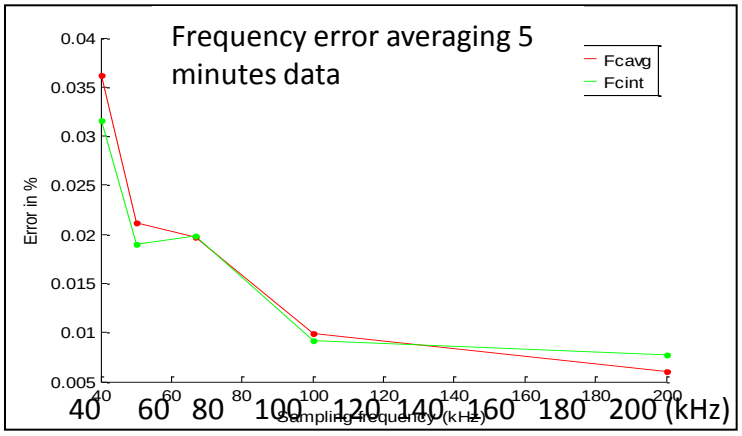


Major technical accomplishments: Frequency measurement accuracy

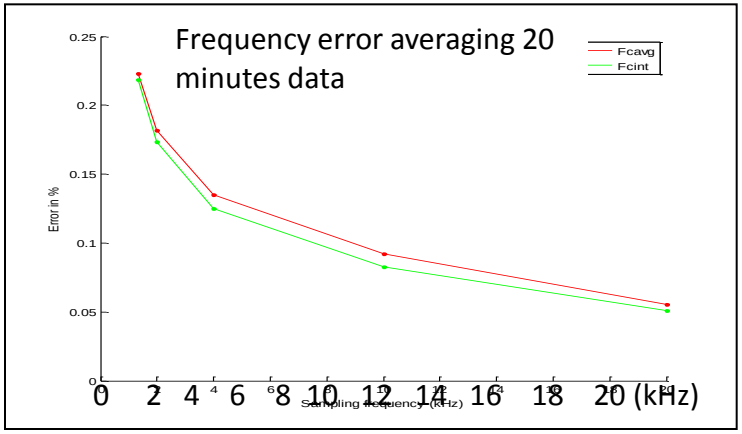


Sampling frequency 2 to 20kHz

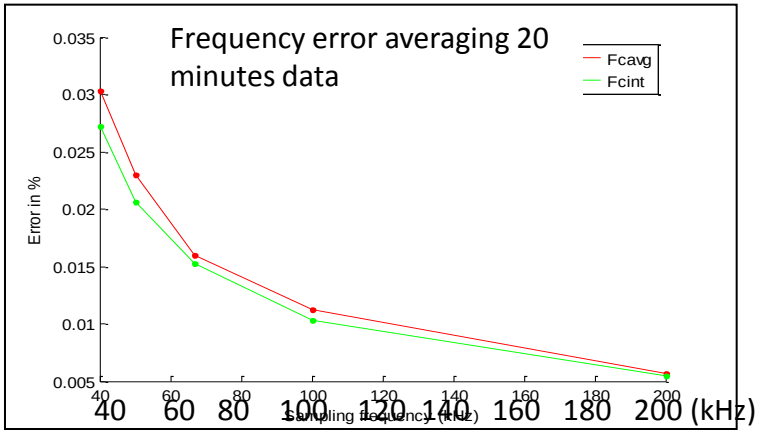
SNR=30



Sampling frequency 40 to 200kHz

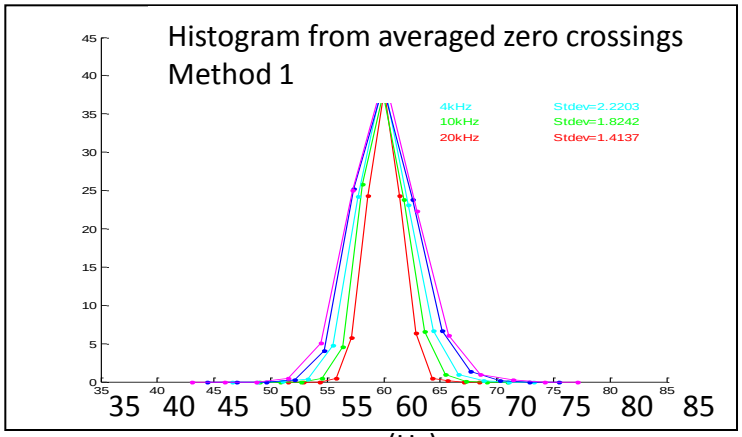


SNR=30

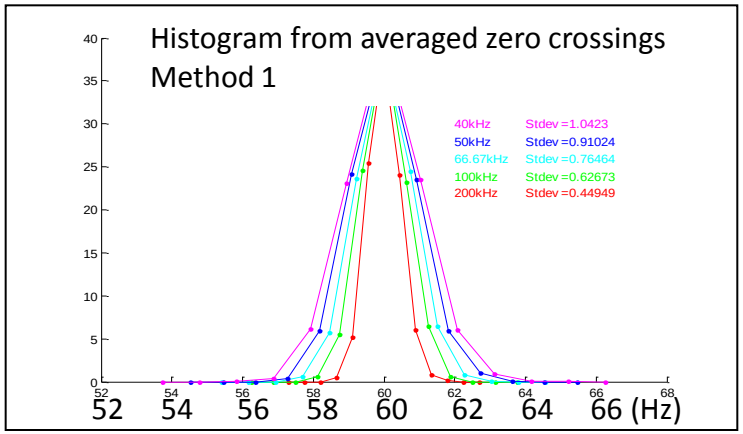


The error is about 0.005% lower with Method 2

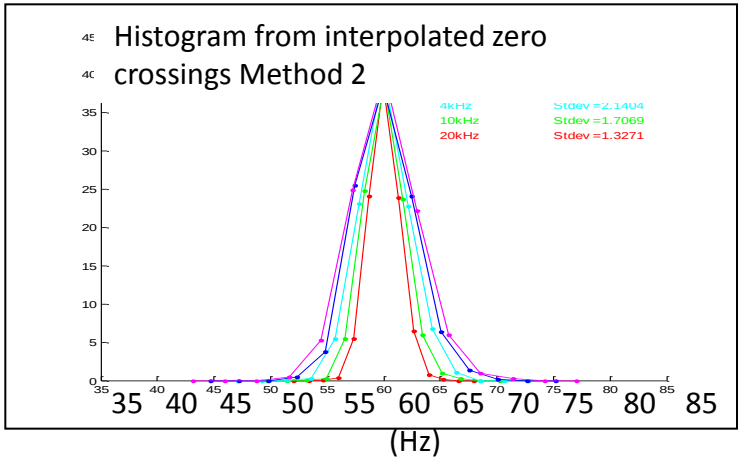
Major technical accomplishments: Frequency measurement accuracy

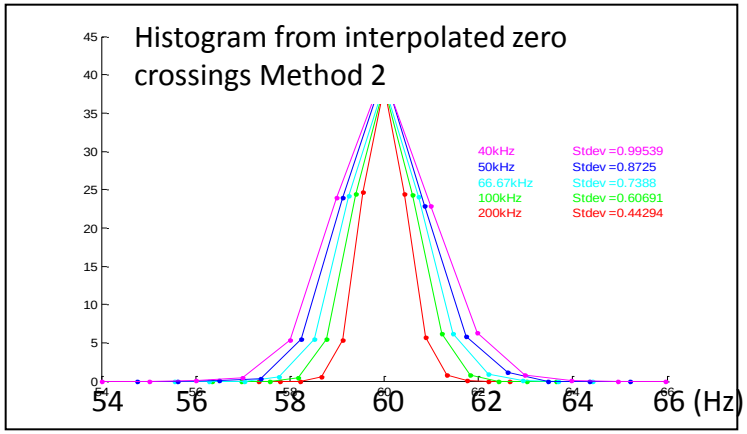


Histogram for Fs=1.33Khz to 20Khz



Histogram for Fs=40kHz to 200Khz





The repeatability is improved with higher frequency sampling frequencies and with method 2.

Major technical accomplishments: Frequency measurement accuracy

SNR=30

Error based on different sampling frequencies Fs

Sampling Frequency (kHz)	F_error% 20mn M1	F_error% 20mn M2	F_error% 15mn M1	F_error% 15mn M2	F_error% 10mn M1	F_error% 10mn M2	F_error% 5mn M1	F_error% 5mn M2
200	0.0056	0.0054	0.0062	0.054	0.0058	0.0063	0.006	0.0077
100	0.011	0.010	0.011	0.010	0.010	0.0096	0.0098	0.0091
66	0.015	0.015	0.016	0.016	0.016	0.017	0.019	0.019
50	0.022	0.020	0.023	0.020	0.023	0.020	0.021	0.019
40	0.030	0.027	0.031	0.026	0.031	0.028	0.036	0.031
20	0.055	0.050	0.056	0.054	0.056	0.059	0.052	0.057
10	0.092	0.082	0.095	0.08479	0.092	0.089	0.091	0.088
4	0.135	0.125	0.137	0.127	0.13	0.12	0.13	1.12
2	0.181	0.173	0.19	0.18	0.185	0.180	0.200	0.192
1.33	0.223	0.218	0.232	0.231	0.234	0.235	0.242	0.233

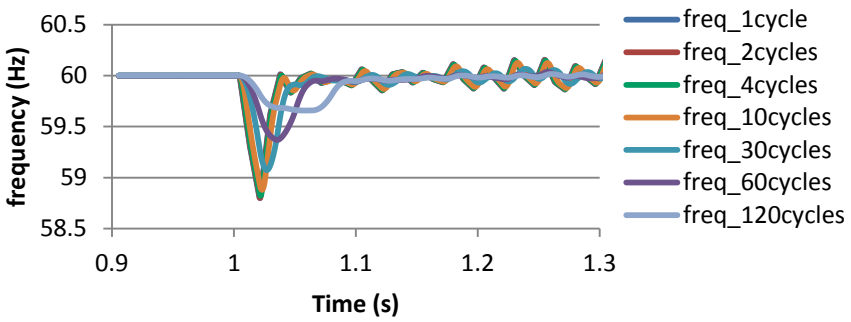
- A sampling frequency higher than 50kHz provides the 0.01Hz required accuracy
- Method 2 provide up to 0.005% accuracy improvement compared to method 1
- The accuracy is mainly driven by the sampling frequency more than the measurement length
- The measurement length will have a bigger impact on the dynamic of the response during contingencies

Standard deviation for different SNR and FS

SNR	Stdev 20kHz M1	Stdev 20kHz M2	Stdev 10kHz M1	Stdev 10kHz M2	Stdev 4kHz M1	Stdev 4kHz M2	Stdev 2kHz M1	Stdev 2kHz M2	Stdev 1.33kHz M1	Stdev 1.33kHz M2
10	1.93	1.82	2.74	2.48	3.61	3.31	4.06	3.874	4.58	4.63
20	1.61	1.49	2.14	1.96	2.61	2.44	3.08	3.00	3.36	3.35
30	1.41	1.32	1.82	1.70	2.22	2.14	2.59	2.53	2.85	2.82
50	1.22	1.17	1.49	1.39	1.78	1.75	2.08	2.06	2.22	2.22

- Method 2 provides more repeatable results than Method 1

Frequency measurement after contingency with different measurement window



Deliverables and schedule for activities to be completed under FY12 funding

- Frequency accuracy study: Completed
- Report on frequency accuracy measurement: Completed
- Paper under draft to be published

- Large system modeling: The model is not available

Risk factors

- Acquisition of a real dynamic model
  - Alternative: Use of a generated dynamic model from typical parameters should be considered

Early thoughts on follow-on work

- Frequency monitoring:
  - Long term monitoring and archiving to establish correlation between:
    - Frequency and environmental variations
    - Frequency and voltage
    - Range of frequency values
- Lab setup the frequency measurement accuracy validation:
  - Waveform generators used to validate accuracy of frequency measurement
  - Analyze frequency measurement during contingencies
- Develop large dynamic model