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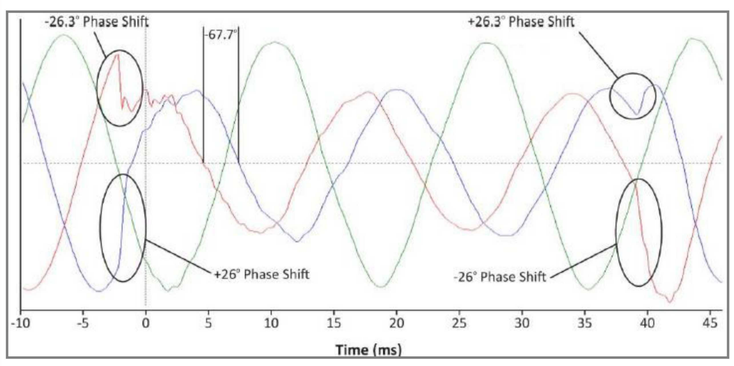
Frequency Estimation Algorithms to Enable Synthetic Inertia

David Schoenwald,[1] Josh Wold[2], and Felipe Wilches-Bernal[1]

Purpose and Motivation

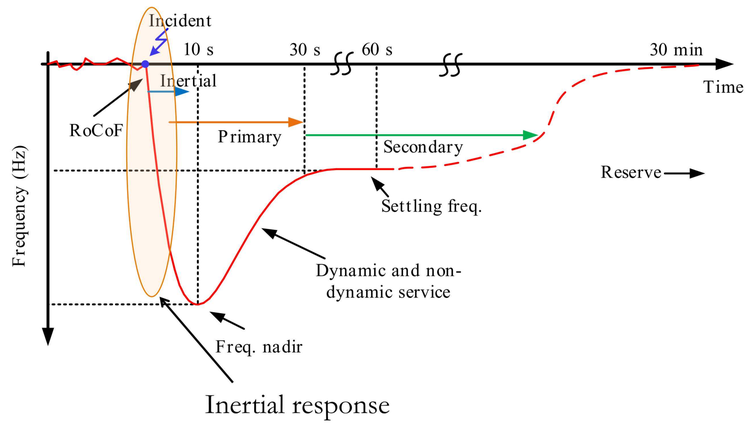
- The increase of converter interfaced generation (CIG) both at the transmission and distribution levels is creating unprecedented challenges to the grid operation.
- Frequency is a key indicator of network stability and the balance between generation and consumption (plus losses).
- In critical occasions, determining frequency from electrical waveforms is challenging.



- **Key research question:** For a corrupted (distorted, noisy) waveform, what is frequency?

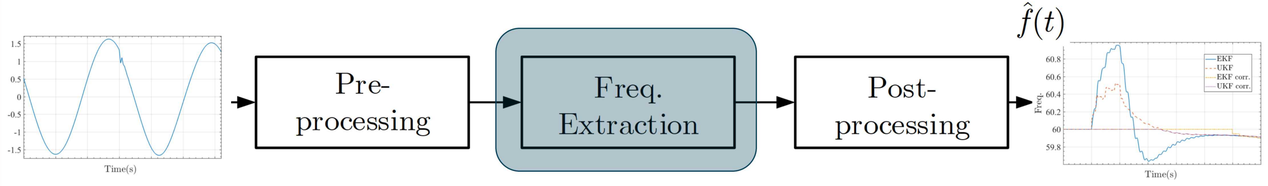
Figure from *1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report Southern California 8/16/2016 Event* NERC Report

- Traditionally, power system stability is dependent on the inertia present in the system.
- The advent of converter interfaced generation (such as wind or solar) has reduced the amount of inertia present in the system as this type of generation typically does not respond to frequency fluctuations.



- **Problem:** Inertial response and primary frequency regulation of the system is affected (stability of the system is threatened)
- **Solution:** Fast power injection controllers (or *synthetic* inertia) using CIG

Technical Approach & Accomplishments



Input:
- Single phase
- Three phase
- Multisignal

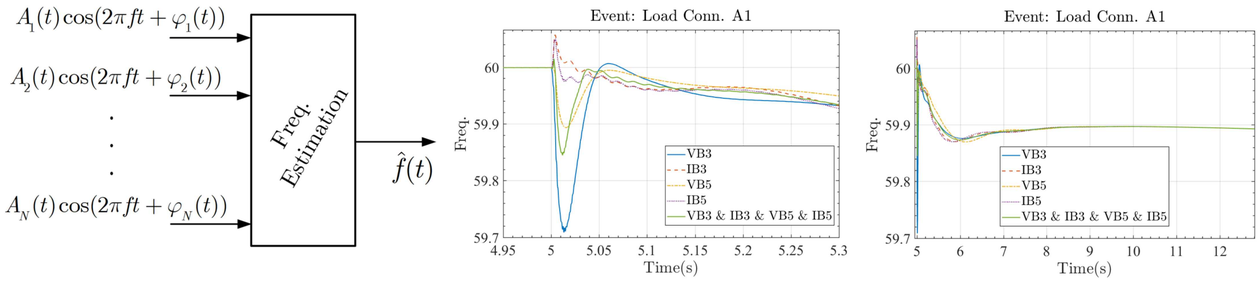
Preprocessing (optional)
Filtering to reduce noise and distortion

Estimation algorithms
- DFT based
- Kalman Filter (KF) based
- Phase-locked loop (PLL) based
- Adaptive Notch Filter
- Least squares based

Postprocessing (optional)
Filtering to reduce noise
Correction of faulty estimates

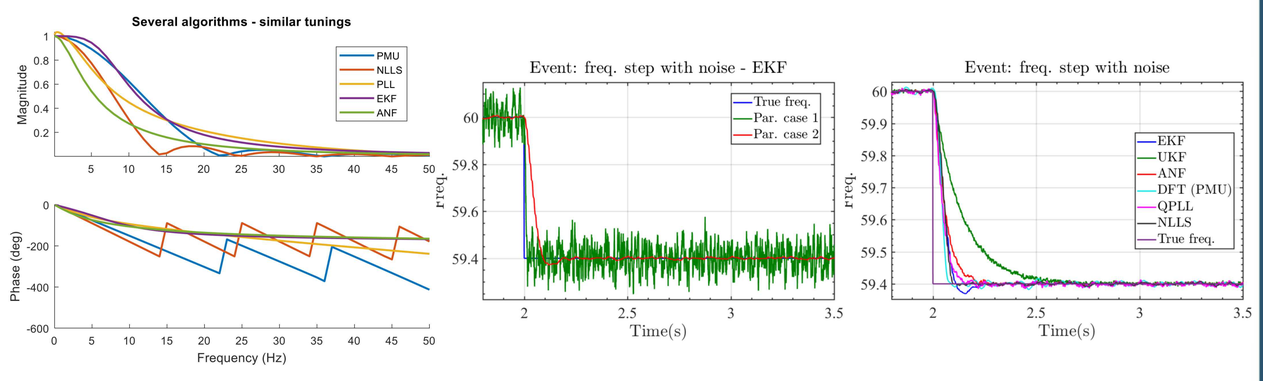
Multisignal Input

- Model: input is a vector of dimension N
- Based on the idea that frequency information is redundant in the system (present in many signals, e.g. voltages and currents). It has an inherent noise reduction advantage over single signal (one phase) approaches.
- *Immune* to phase imbalances and phase losses.



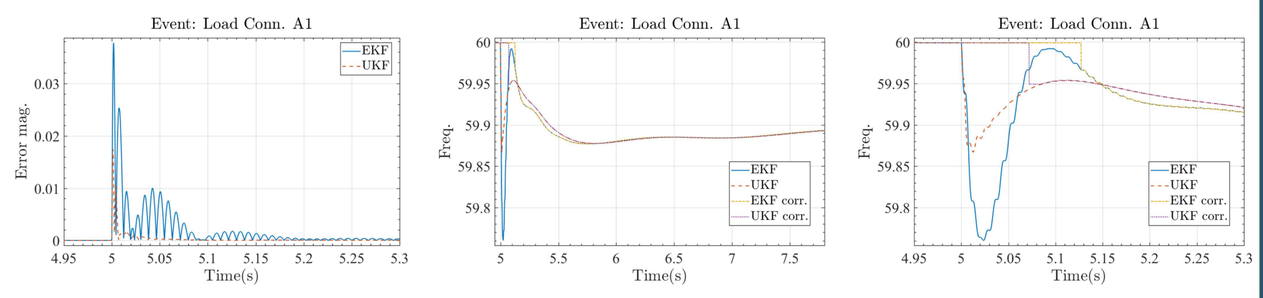
Algorithm Tuning

- Algorithm sensitivity to noise is unavoidably linked and traded against bandwidth (speed of response to changes in actual frequency).
- Managing this tradeoff is called 'tuning' and an important characteristic of any algorithm is tuning difficulty.



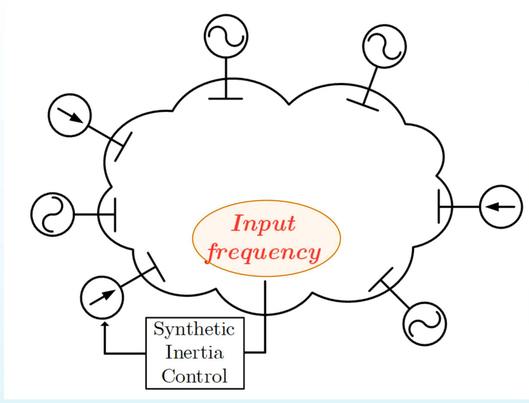
Frequency correction

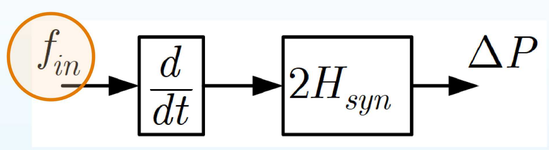
- Based on the idea that some corruptions in the point-on-wave data are only temporary (sometimes very fast, e.g. phase jumps) but their effect on the frequency estimate can linger for a longer time (depending on the tuning).
- Use "residual" or "goodness of fit" of estimation algorithms to determine inaccurate estimates.



Next Steps

- This research has implemented a detailed model of a two-area power system in Simscape (for dynamic simulation with electromagnetic transient, not positive sequence).
- The model has been modified to accommodate up to 50% of converter interfaced generation.
- Next step is to control the converter interfaced units with synthetic inertia controllers where the frequency is based on the algorithms studied so far (Year 1).





Conclusions

- Integration of converter interfaced generation is affecting the power quality of power system waveforms and the primary frequency regulation of the system.
- Estimating frequency is becoming a more challenging task.
- There are multiple ways of estimating frequency in power systems and because the approaches are tunable, similar results can be achieved with them.
- All approaches have a tradeoff between noise rejection and bandwidth; difficulty in tuning to manage the tradeoff varies across algorithms.
- Including multiple signals can help mitigate this trade-off.
- Certain disturbances (phase shifts) cause large estimation errors for all algorithms, and heavier filtering is not an acceptable remedy in real-time control applications.
- Post processing in the form of frequency correction is a promising approach for generating cleaner signals to perform control actions.

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contact: daschoe@sandia.gov [1]Sandia National Laboratories [2]Montana Technological University