Frequency Measurement in Protective Relays and Impact by Renewable Energy Resources

Tirath Bains, Ilia Voloh, Venkatesh Chakrapani – GE Grid Solutions
Presenter: JC Theron – GE Grid Solutions

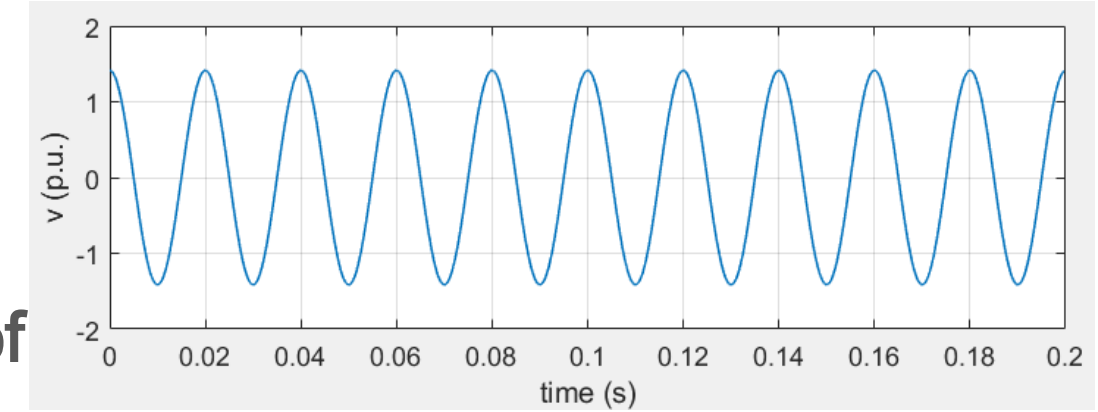
Frequency

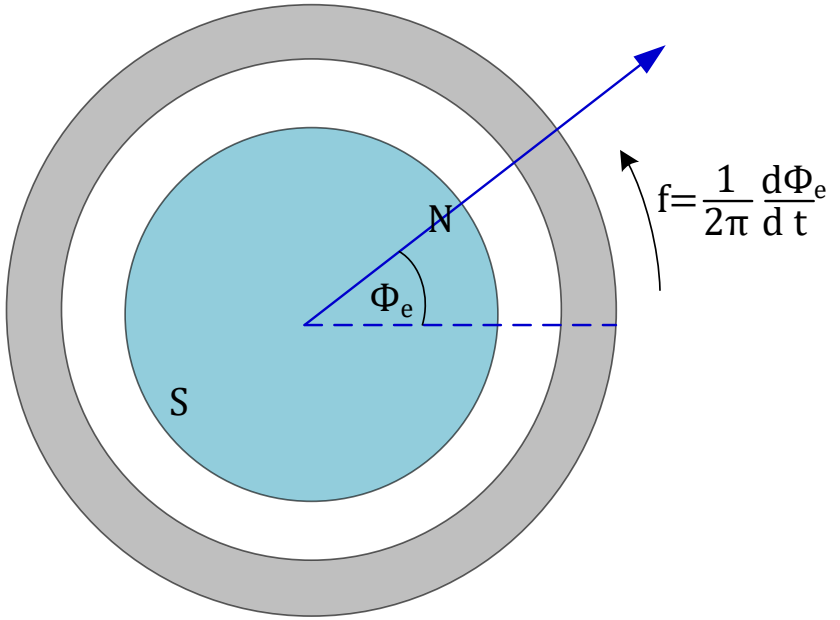
Frequency can be understood as:

- Number of cycles over a unit time period (over a time window).

OR

- Rate of change of electrical angle of the synchronous machine (real-time/instantaneous frequency).





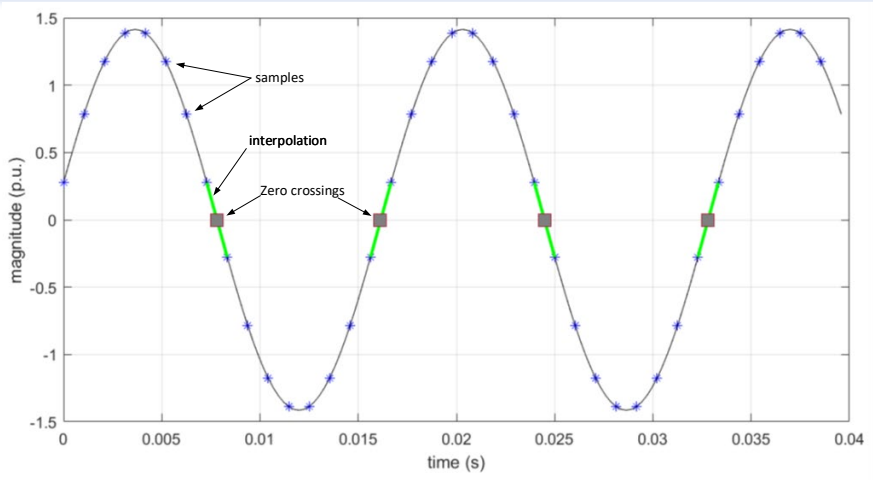
Importance of Frequency

- Frequency indicates the state of balance between power generation and power consumption. (OF, UF, ROCOF)
- Frequency is used to provide he overexcitation protection (V/Hz) for generators and transformers.
- Accuracy of measured frequency is vital to the accuracy of phasors and phasor-based protection.

Frequency Measurement Algorithms

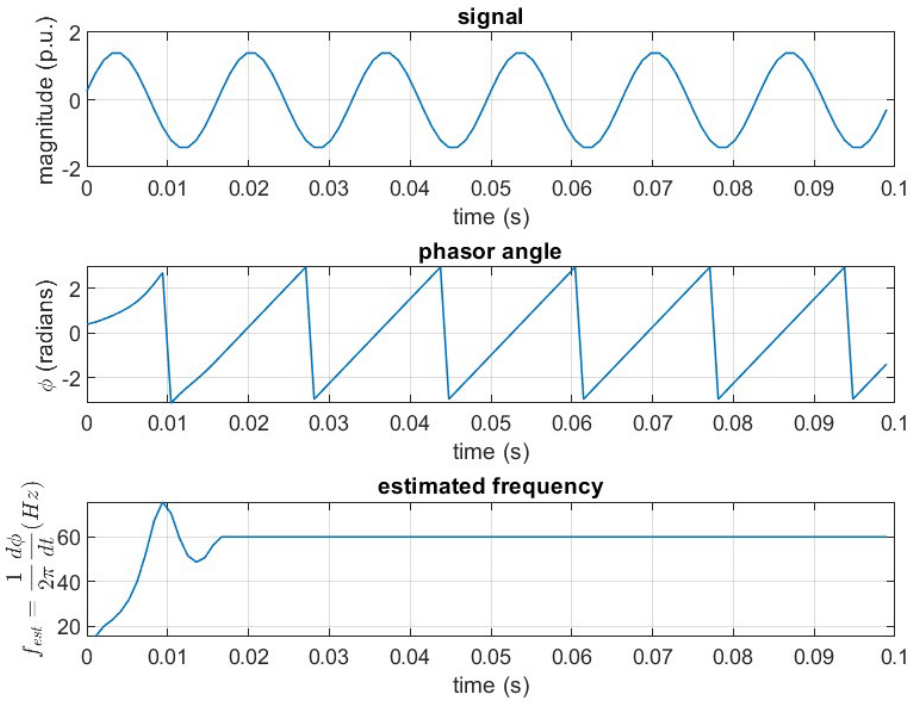
Zero Crossing method (ZC):

$$f_{est} = \frac{1}{T_3 - T_1} = \frac{0.5}{T_2 - T_1}$$



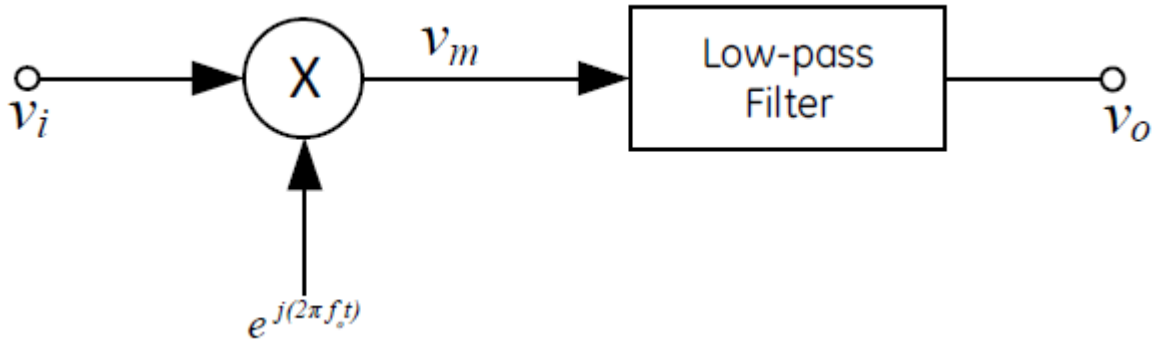
DFT Method

$$f_{est} = \frac{1}{2\pi}\frac{d\varphi}{dt}$$



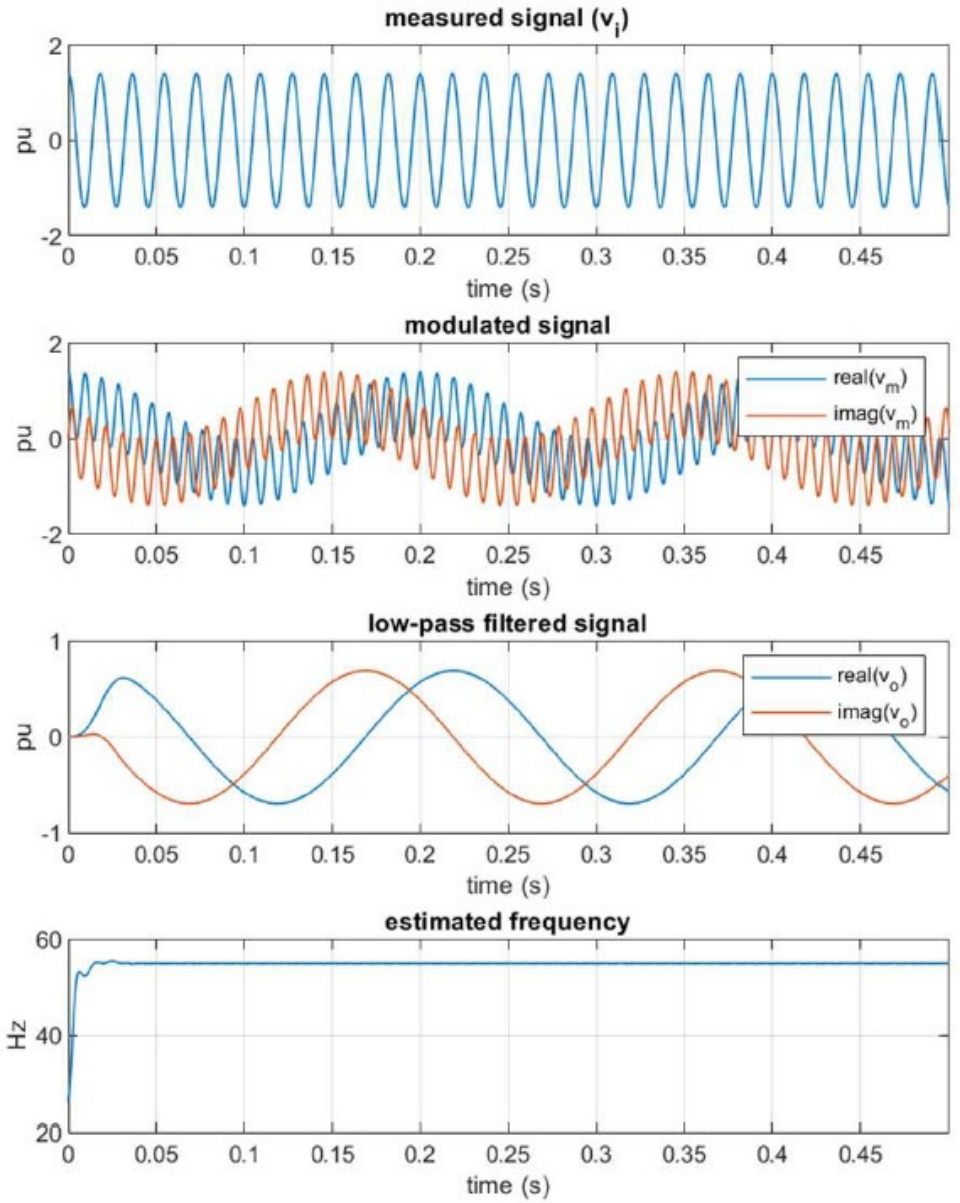
Frequency Measurement Algorithms

Signal Demodulation Method (SDM):



$$A\cos(2\pi f_0 t + \varphi_o).\cos(2\pi f_1 t)$$

$$= \frac{A}{2}[\cos(2\pi(f_0 - f_1)t + \varphi_o) + \cos(2\pi(f_0 + f_1)t) + \varphi_o]$$



Synchronous generator vs IBR

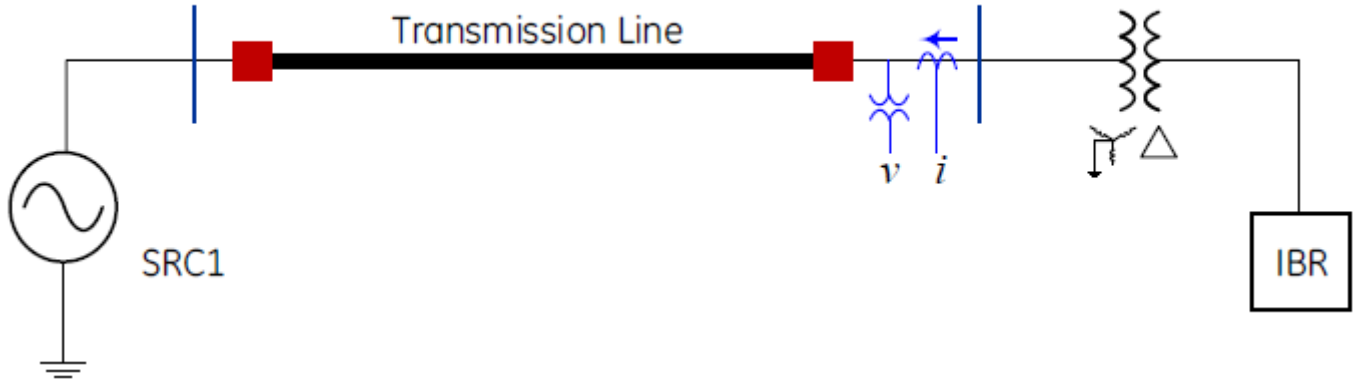
Synchronous Generator

- The synchronous generators have been used since several decades.
- The design hasremained consistent across the globe.
- The turbine and excitation control systems are relatively slow.
- The synchronous generators have massive rotating inertia.

Inverter-based Resources (IBR)

- Large scale integration of IBRs to the grid started recently
- The control design for power electronics interface varies from vendor to vendor and the type of the IBR.
- The IBR control systems are very fast acting.
- No rotating inertia is associated with IBRs.

Simulated System



The model of real commercially available controllers employed in the field were used.

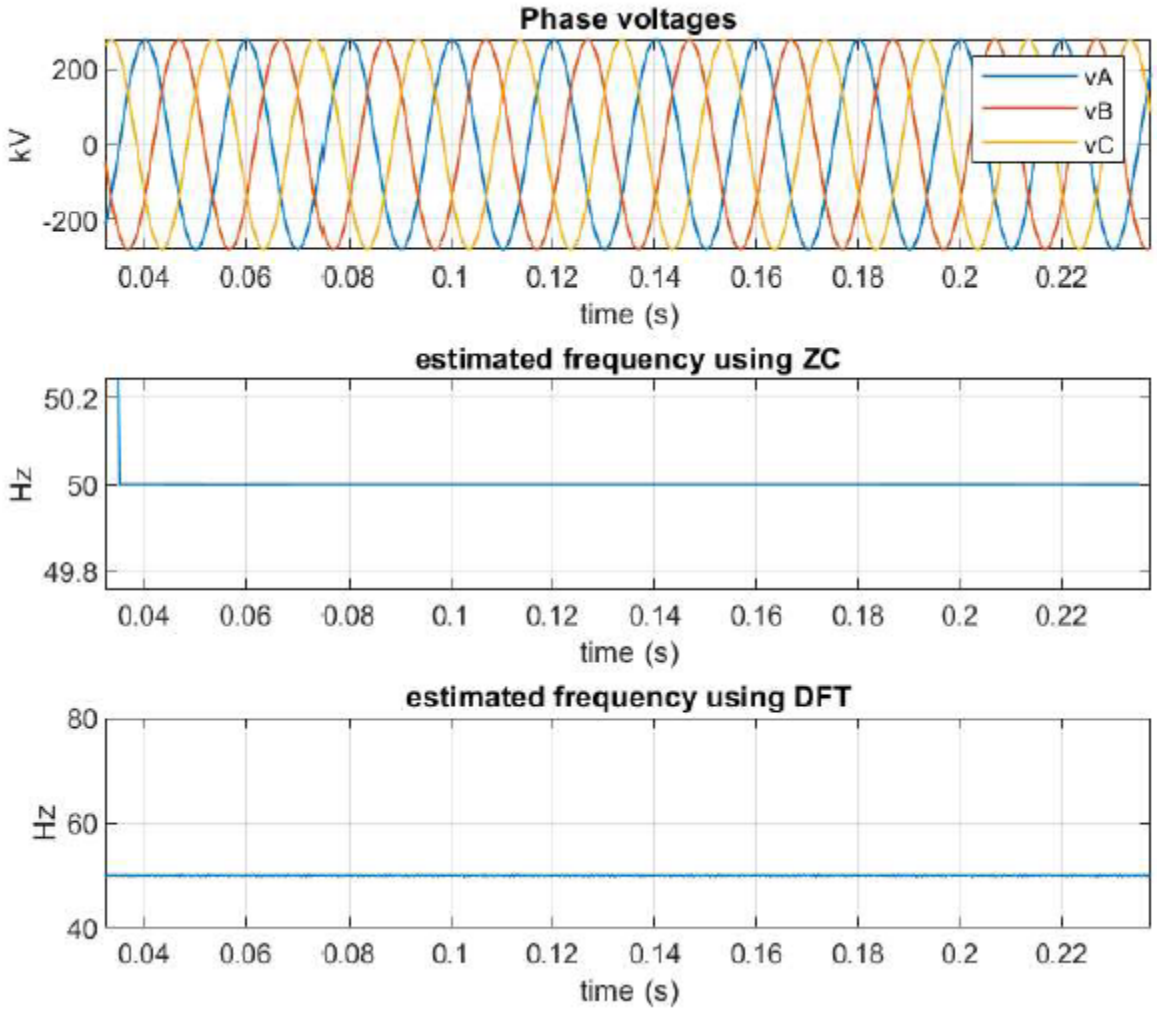
The types of IBR studied are:

1-Type-3 wind turbine generator (WTG);

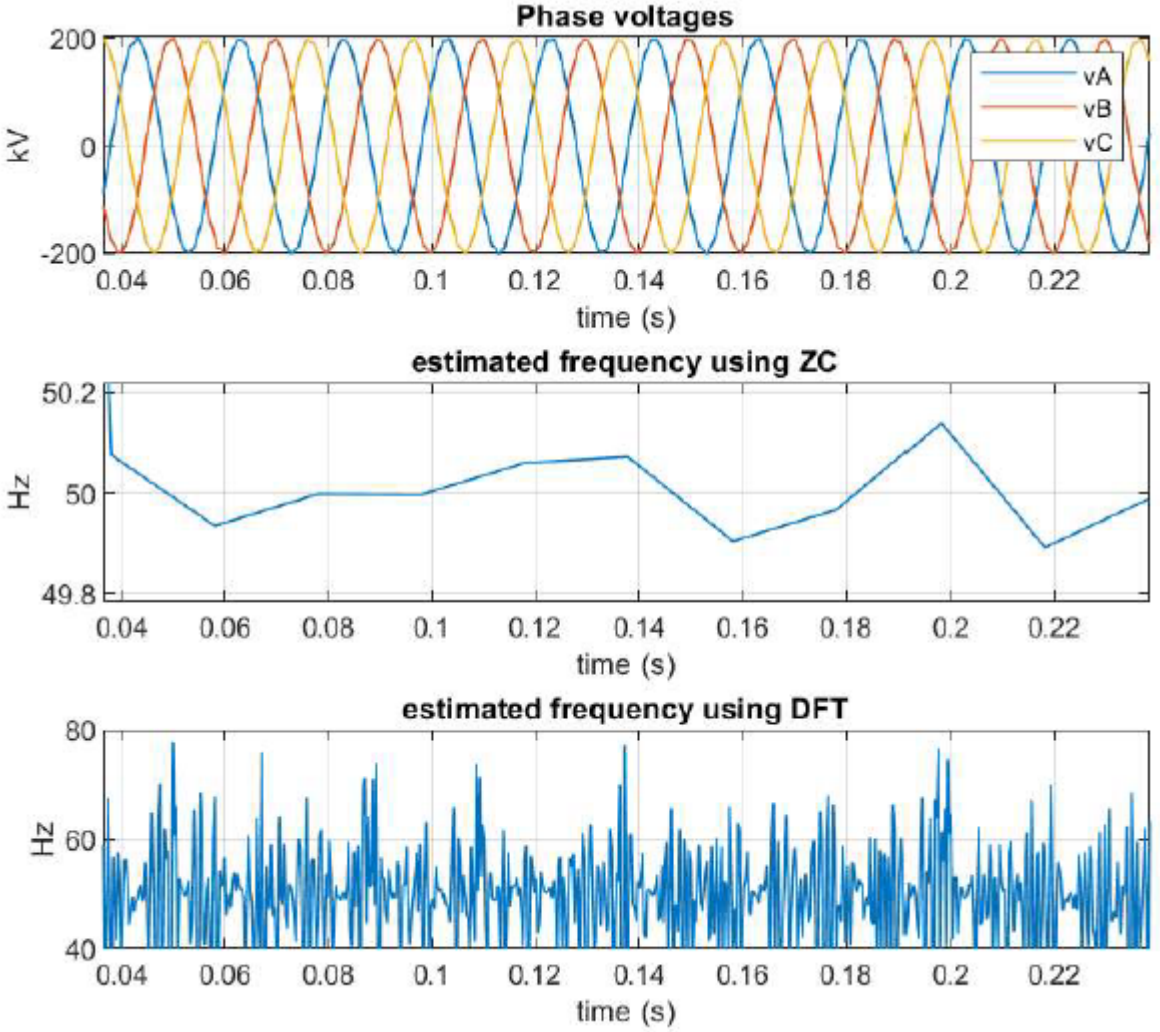
2- Battery energy storage system;

3-Type-4 off-shore WTG.

Frequency and IBRs: Prefiltering

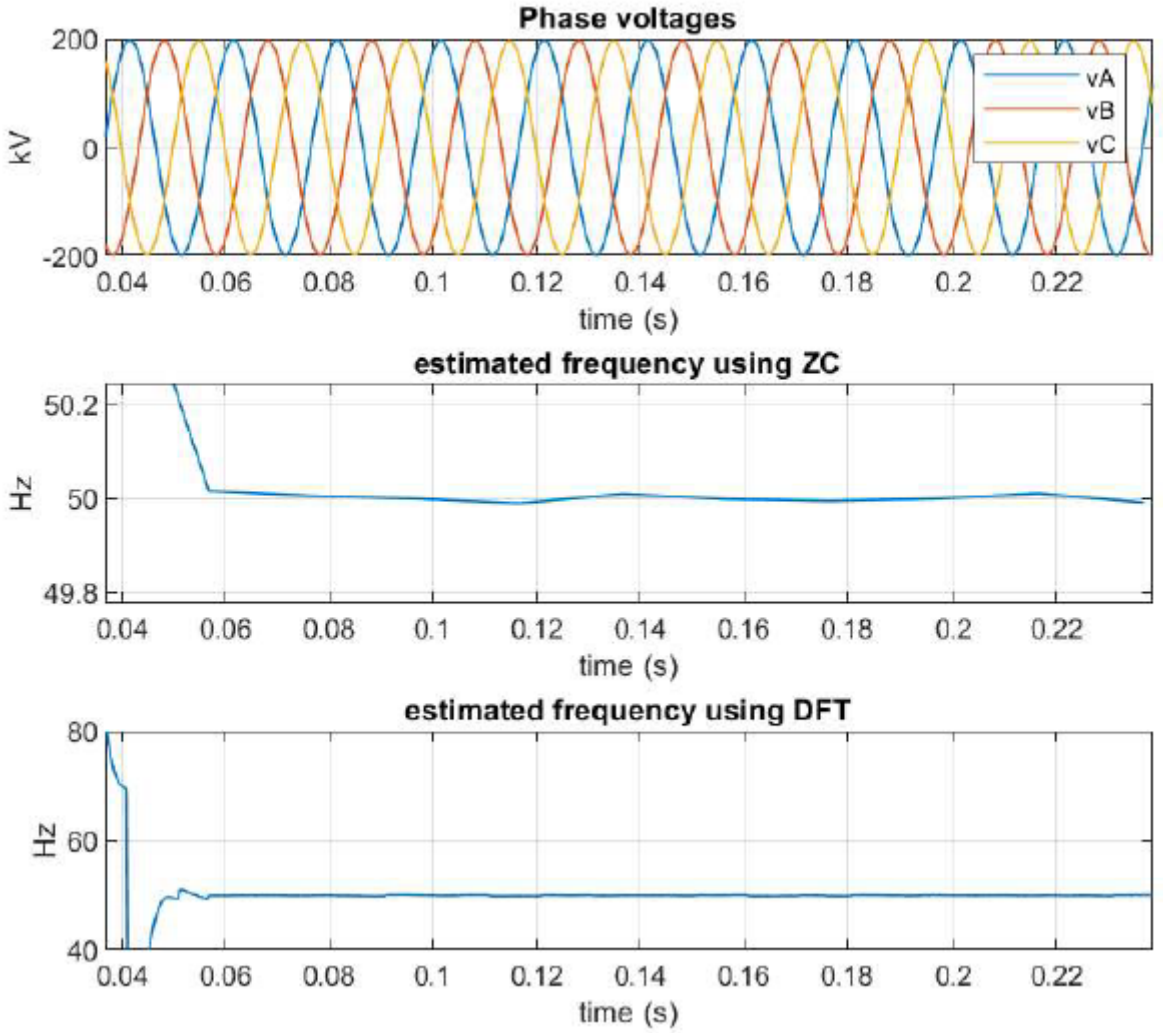


Conventional system (without filtering)



IBR-dominated system (without filtering)

Frequency and IBRs: Prefiltering



IBR-dominated system (with low band pass filtering)

Frequency and IBRs: System Strength

- DFT method is a‘short window’ method which aims to estimate the frequency from the 3 consecutive phasor measurements
- SDM and ZC methods are essentially‘long-window’ methods.
- ‘Long window’ methods produce lower frequency excursions than ‘short window’ methods.
- Still, the relaxation of ‘Sanity-checks’ of the frequency measurements might be required.

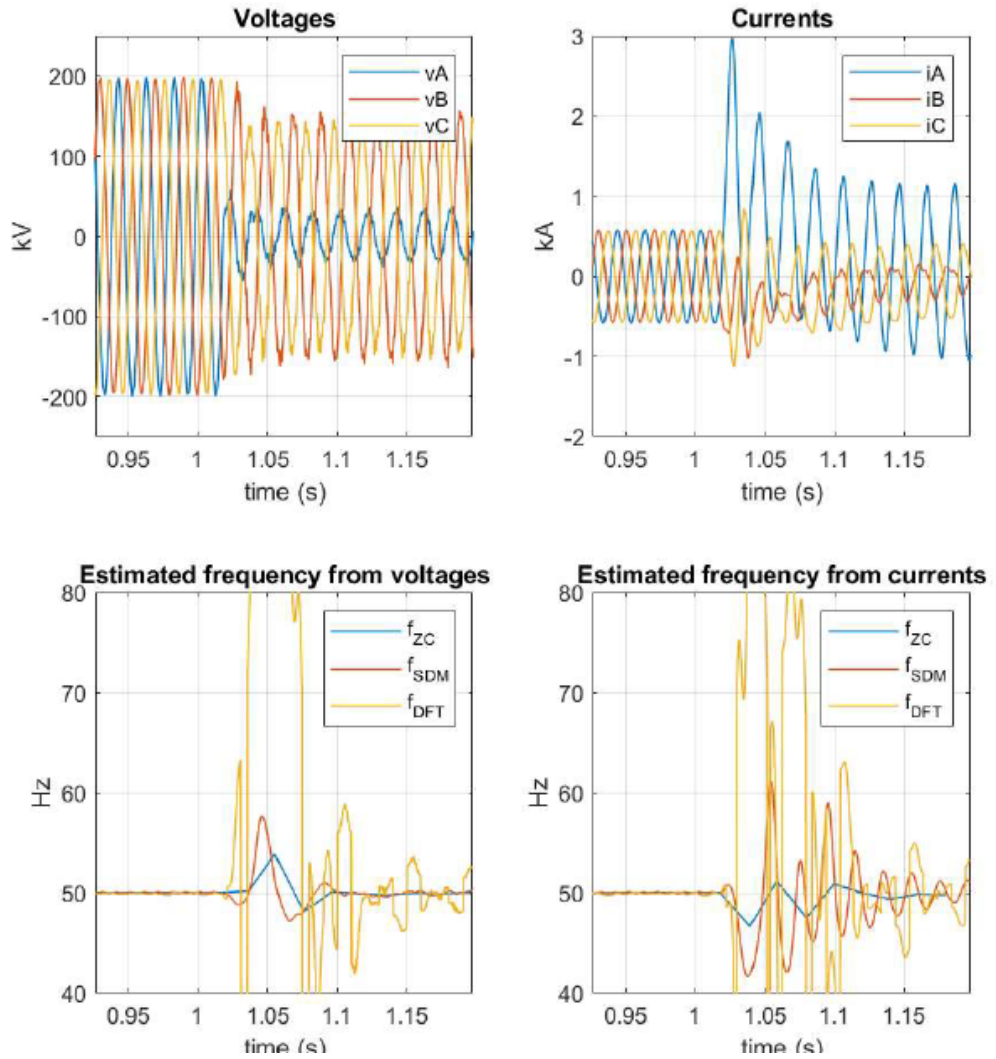
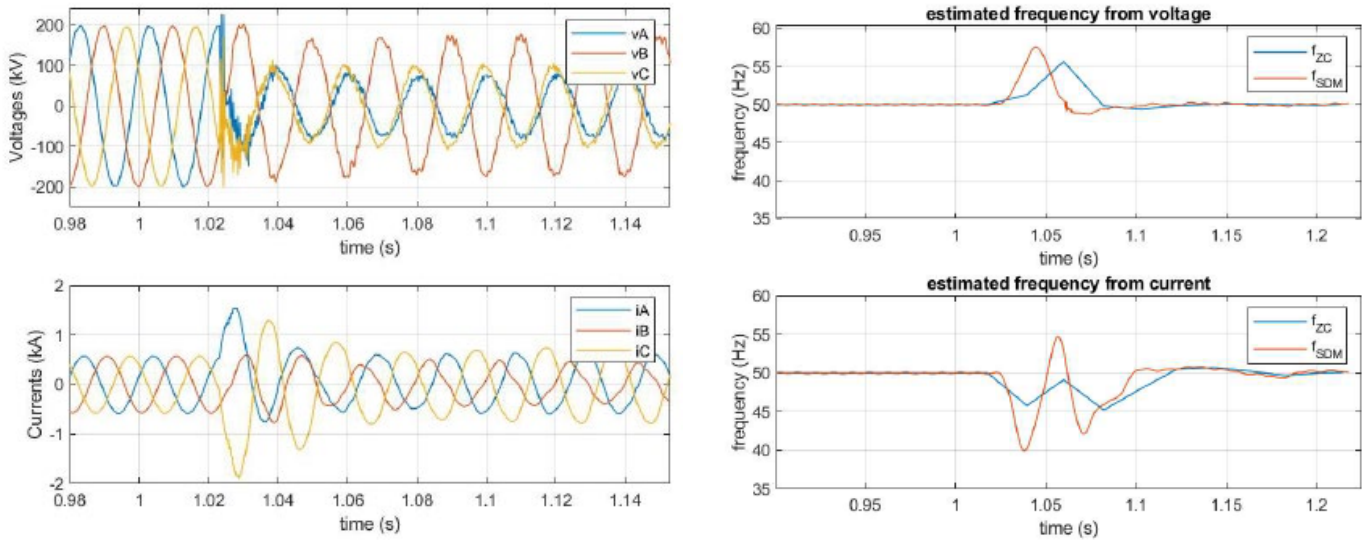
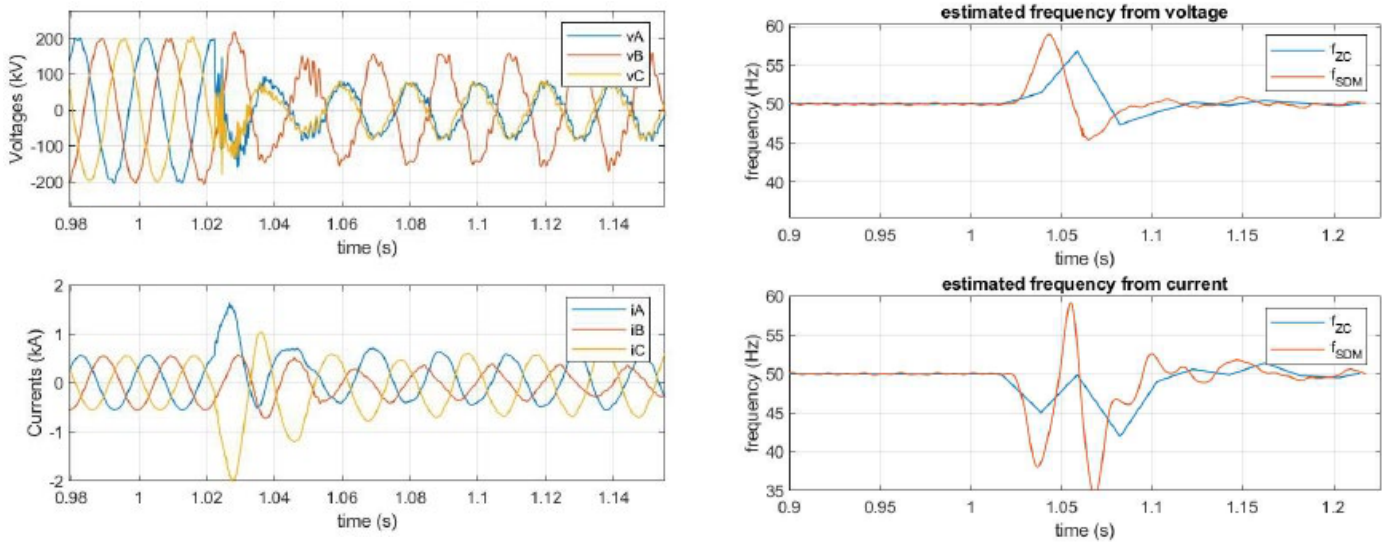


Figure 9: Voltage and current waveforms for a solid phase-A to ground fault and estimated frequency from voltages and currents.

Frequency and IBRs: System Strength



Frequency measured in stronger system (SIR =1)



Frequency measured in stronger system (SIR =5)

- Estimated frequency in the weaker system shows excursions that are larger and last relatively longer as compared to those in stronger systems.
- The frequency estimated usingvoltages is relatively less affected.
- Voltage at IBR terminal mainly governed by grid, but current governed by control system.
- Voltage waveforms are a better choice for frequency estimation in grids dominated by IBRs.

Frequency and IBRs: IBR Type and Current F

- Current frequency becomes crucial when voltages are not available for frequency estimation such as in line and bus differential relays.
- Wide divergence in frequency immediately following the disturbance. Eventually the measurements converge.
- Therefore, the delayed frequency measurements would be more accurate for frequency relaying.

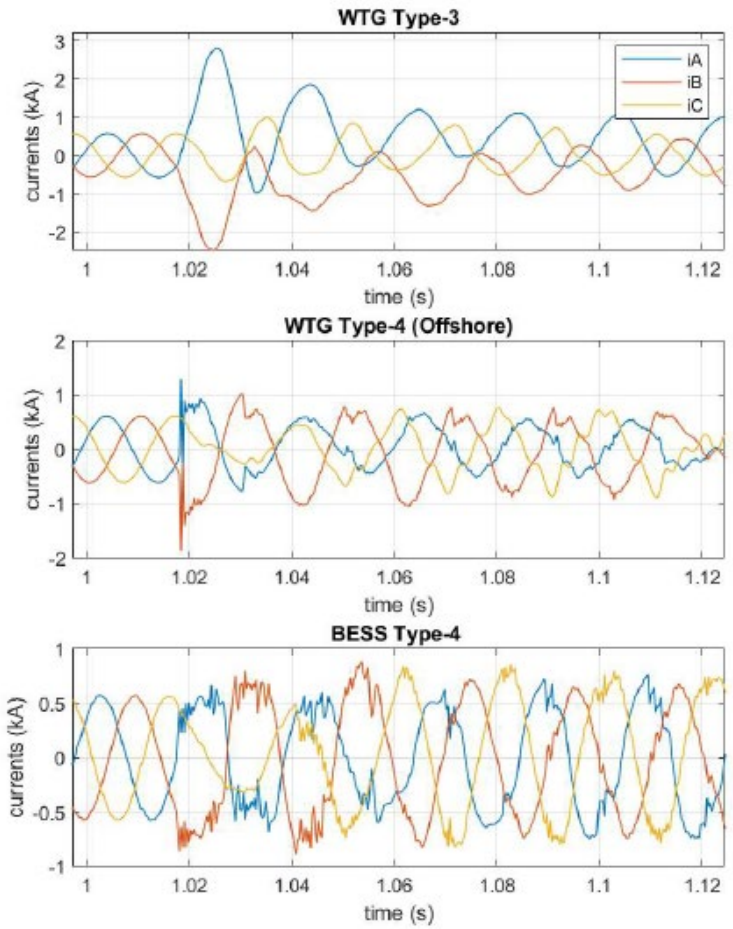


Figure 14: The recorded phase current waveforms for a solid phase A to phase-C, close-in forward fault at the IBR terminal of the transmission line for different types of IBRs.

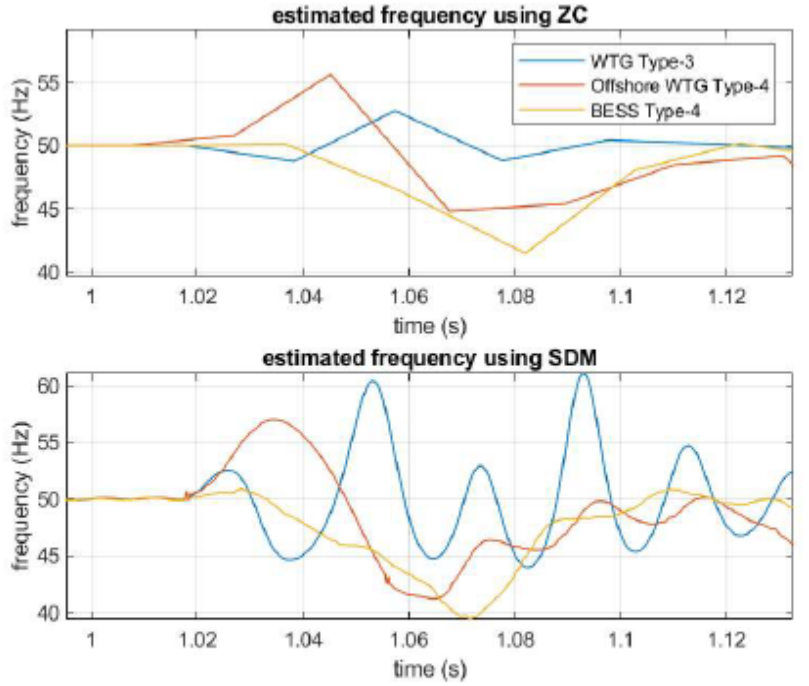
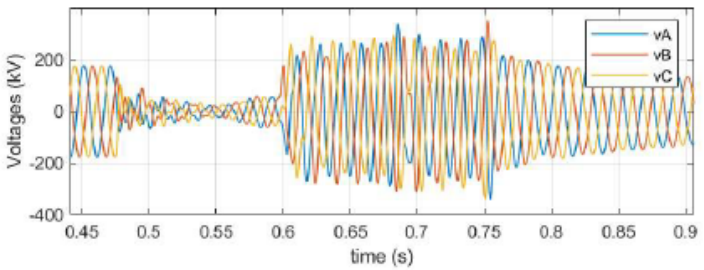
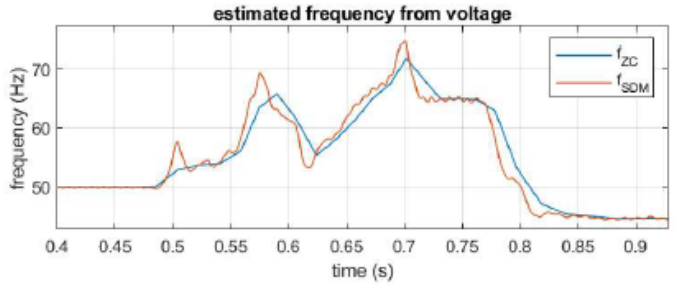


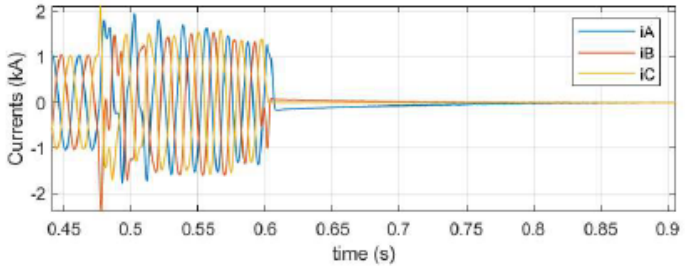
Figure 15: The estimated frequency following a solid phase A to phase-C, close-in forward fault at the IBR terminal of the transmission line for different types of IBRs.

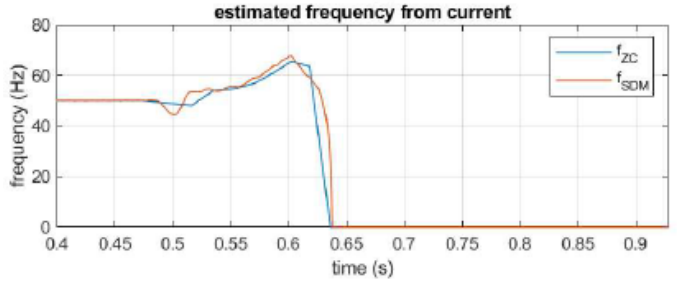
Frequency and IBRs: Real Field Case

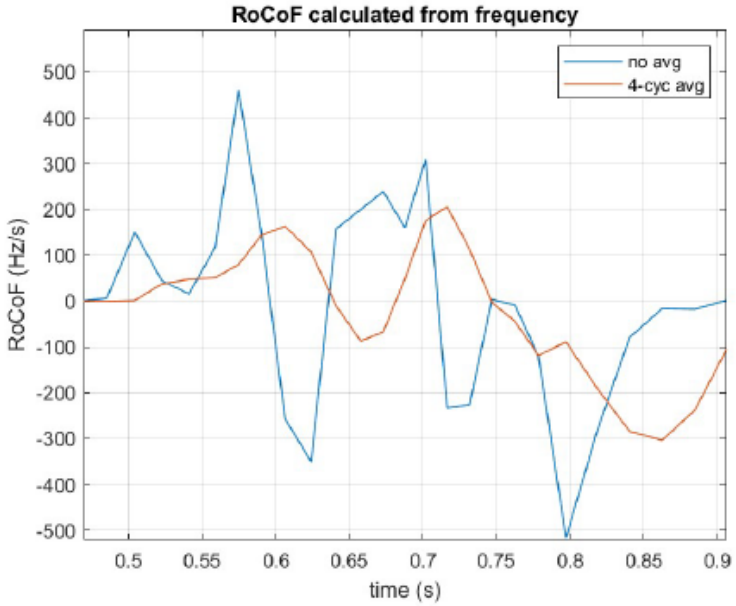
- System frequencychanged from its nominal value of 50Hz to about 70Hz and then finally settling at 45Hz, with-in a span of 300ms.
- RoCoF values calculated from frequency lie in the range of 100-300Hz/s.
- This highlights the ‘double-duty’ that is required of sanity check for frequency measurements, i.e., to reject uncredible measurement while dealing with the wide frequency excursions observed in IBR dominated systems.











Conclusions

1. Low pass or low band pass filtering is strongly recommended/critical .
2. The frequency estimation techniques that are aimed at providing instantaneous value of the frequency are likely to produce larger frequency excursions
3. Larger frequency excursions are expected in a weaker system as compared to the stronger system. Voltages are relatively less affected than current .
4. The type of the IBR used could affect the accuracy of the frequency measurement from the current waveforms immediately following the inception of a fault . This is due to the different transient behavior of the control systems. The delayed frequency measurement is recommended for use.
5. Very high RoCoF values can be encountered in IBR-dominated systems.
6. Sanity check of frequency measurements has to perform 'double-duty' of discarding erroneous measurements while accommodating wider frequency excursions.

Thank You

Questions?