High-Frequency Signature-Based Fault Detection for Future MV Distribution Grids

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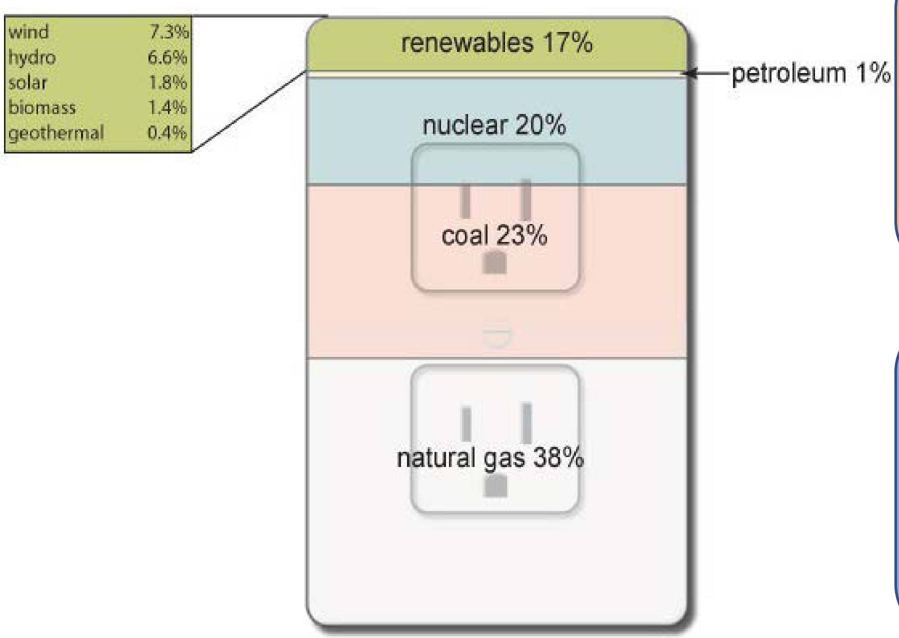
DER Impact on Protection and Challenges

US Generation Sources



Source: US, Energy Information Administration, Electricity in the United States

High Pen PV/DER
- Low fault current
- Reverse power flow
- Bottleneck for high penetration of ...
- Intermittent DER resourc...

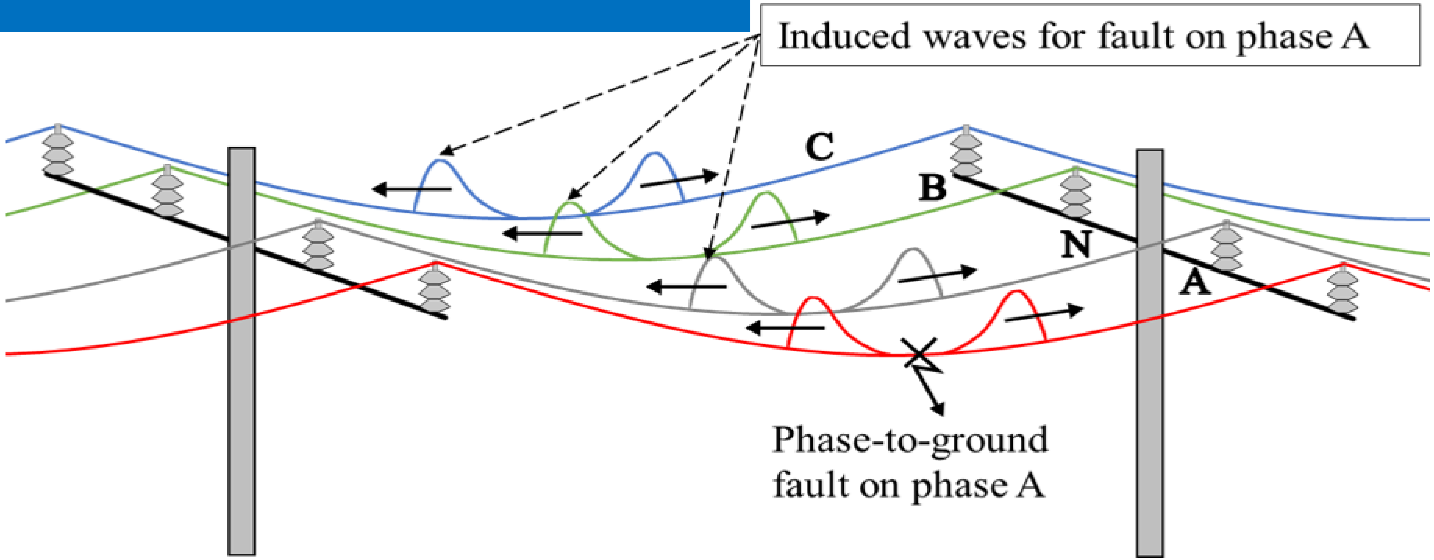
Resiliency
- High-impact, low-frequency events
- Damage prevention
- ...ecovery
- ...ity

Phasor based ...
- One full cycle observation window (slow)
- May need adaptive or multiple settings

- Future distribution network needs high speed fault detection and isolation

Traveling-wave based protection is applied to the future distribution grid

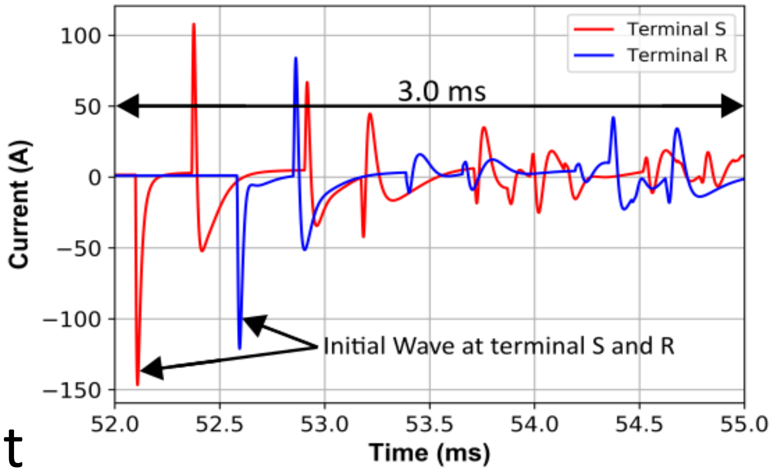
Traveling Waves in Power Systems

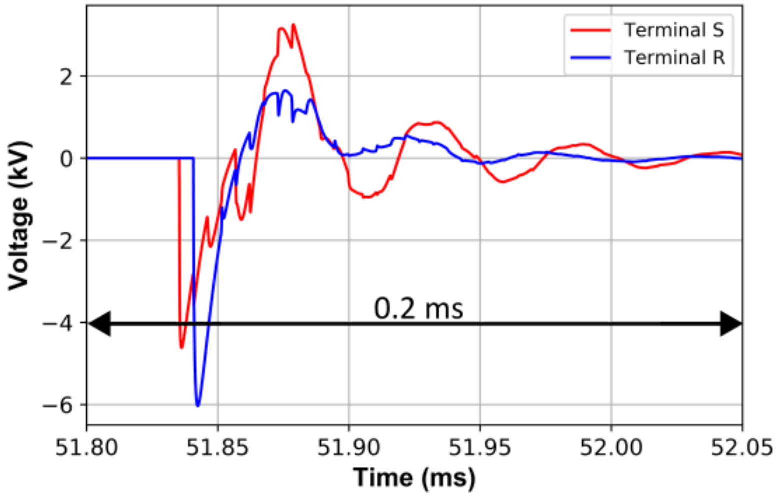


- Any disturbances in the circuit caused by fault, switching, lightning creates a traveling-wave (TW) transient.
- Waves travel at close to the speed of light (186,282 mi/s).
- Used in insulation failure and surge protection design.

Traveling-Waves in Transmission & Distribution

- Transients generated by a fault lasts typically 3 ms (< 1/4th cycle) in transmission.
- In distribution, short lines and frequent taps produces multiple reflections from terminals
- Switching events in distribution produce similar traveling waves.
- Different methods are required to analyze the traveling wave in distribution.





Traveling-Waves in Distribution

Advantages

- Independent of fault currents
- Not affected by CT saturation, power swings, line compensation
- Application to single and two phases
- Faster fault detection

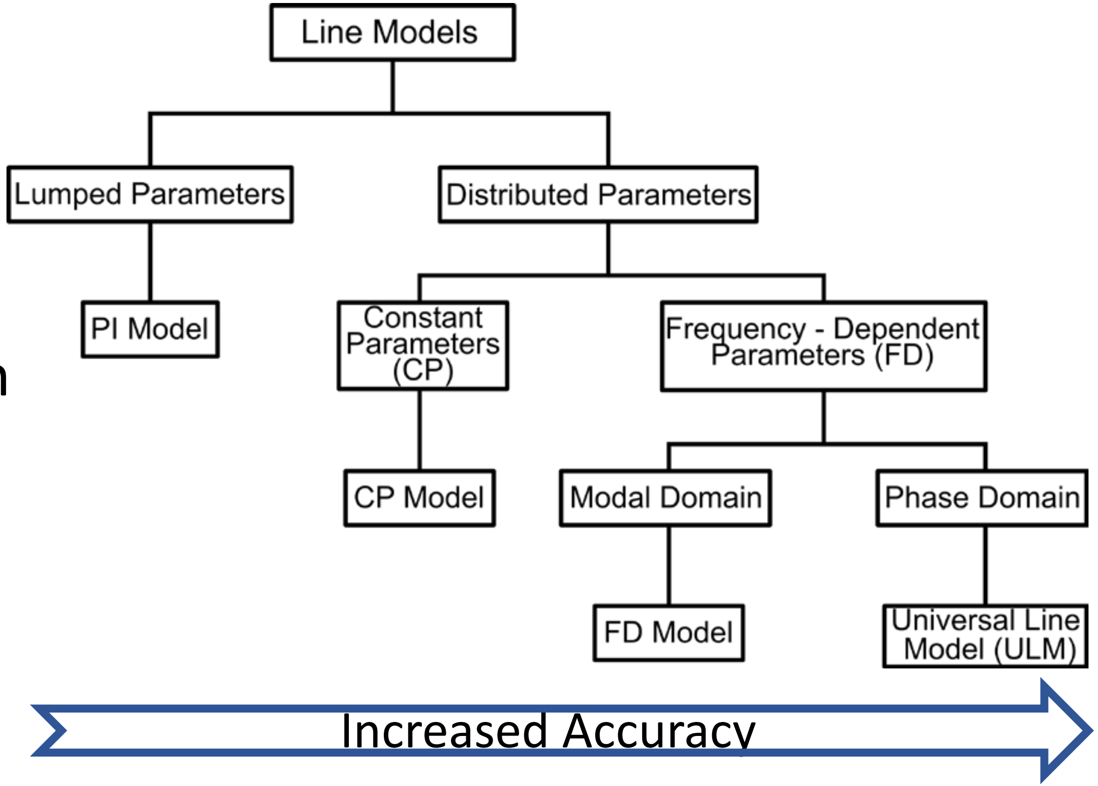
Challenges

- Frequent taps
- High attenuation
- Presence of transformers, capacitors
- Requirements for CT and PT are high

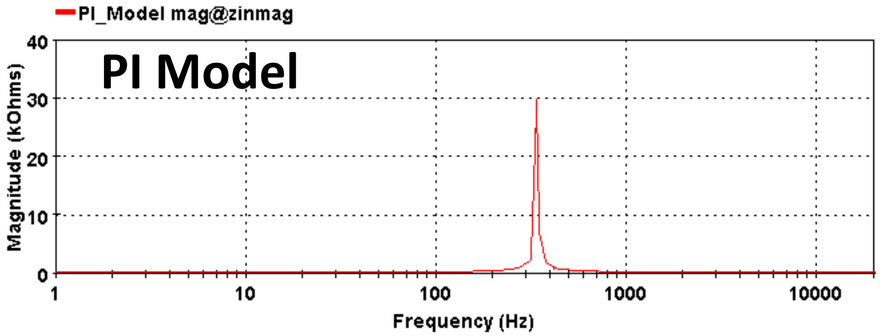
High-frequency signatures generated as a result of TW are used to detect and locate a fault

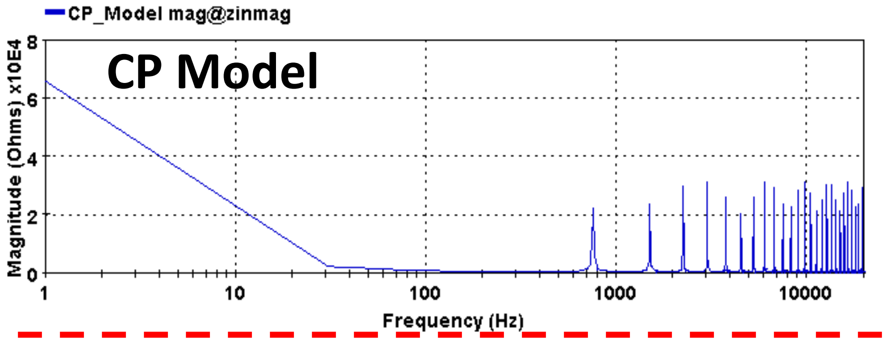
Line Models for EMTP

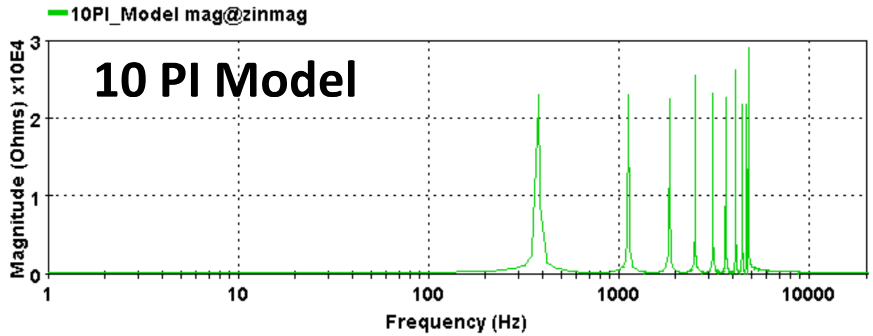
- Frequency-dependent (FD) model is the most accurate line model to study the high frequency transients.

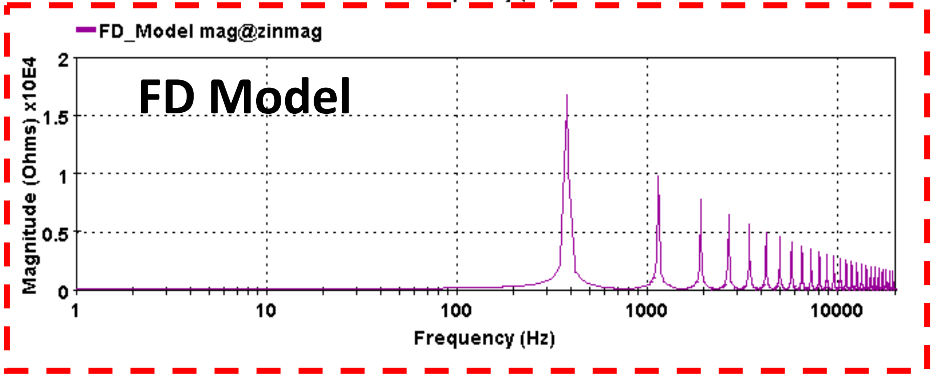


Line Models Frequency Response



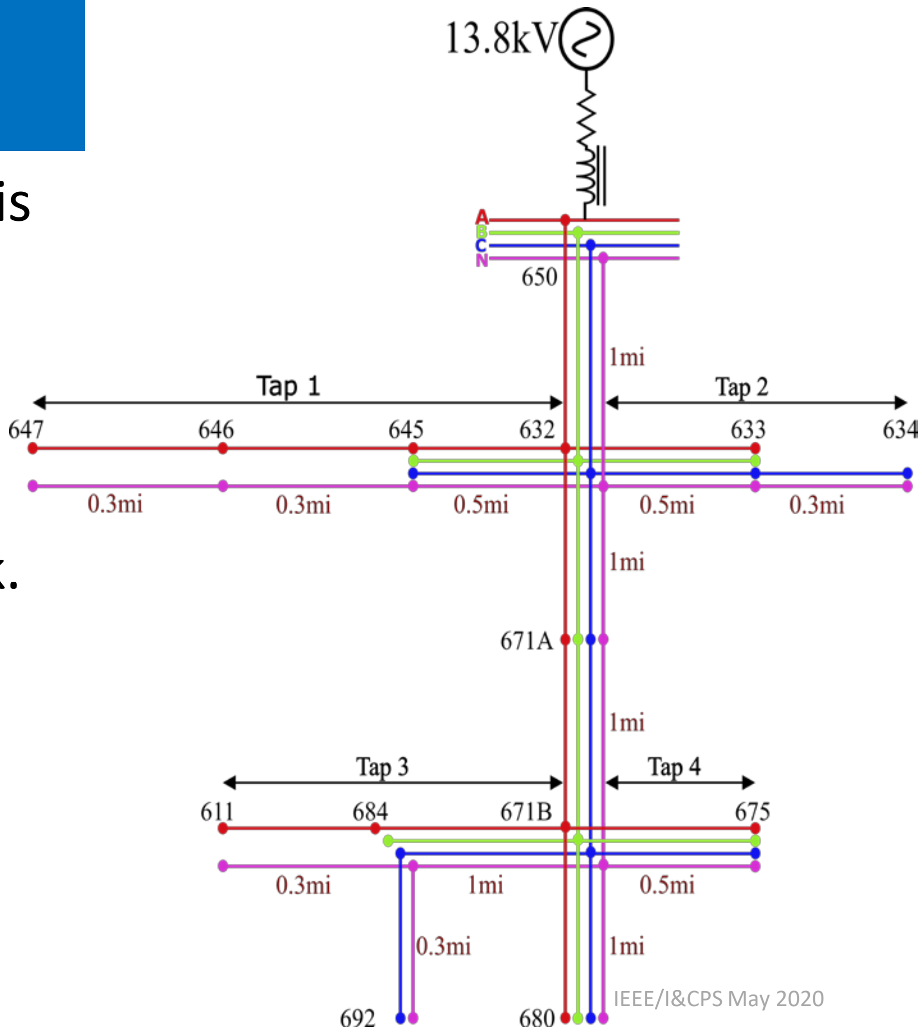






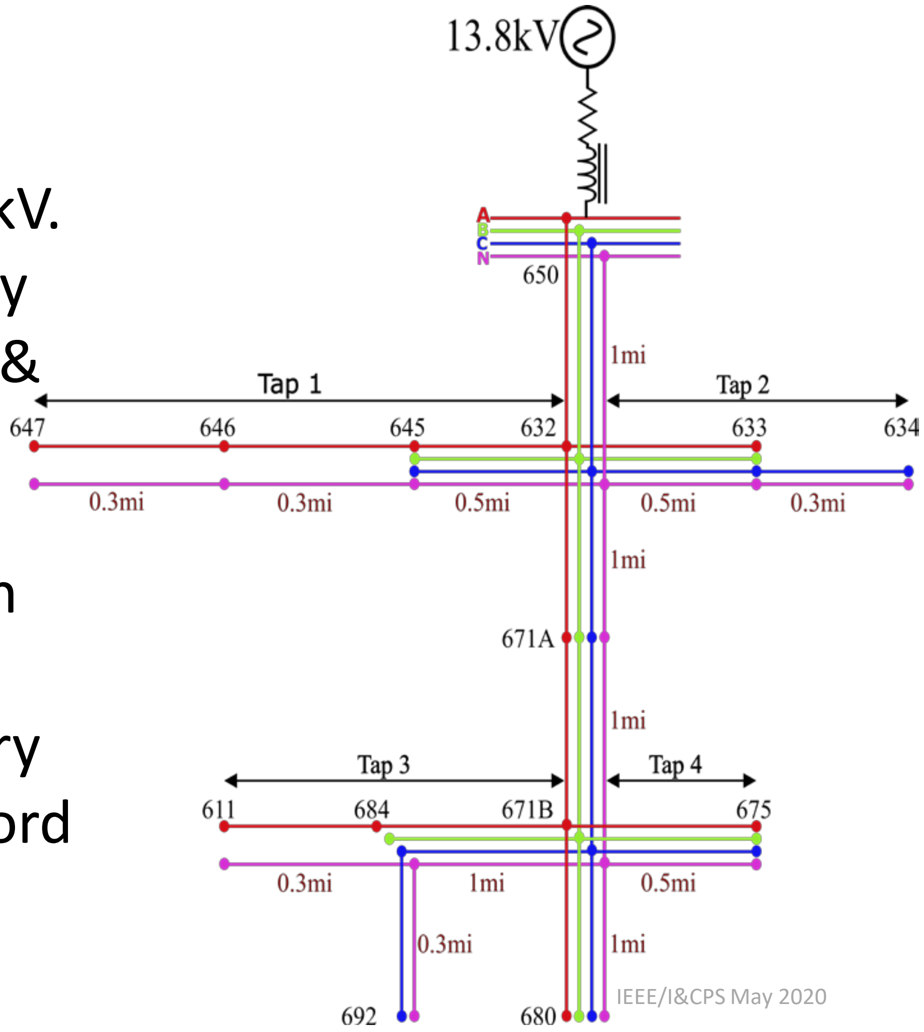
Traveling-Waves Simulation

- Modified IEEE 13-bus test system is developed as 13.8 kV. medium voltage (MV) distribution network in EMTP-RV
- Understand the signature of the transients in the complex network.
- Ideal CT and PT characteristics are assumed.
- Frequency dependent (FD) line model is crucial for EMTP simulations.



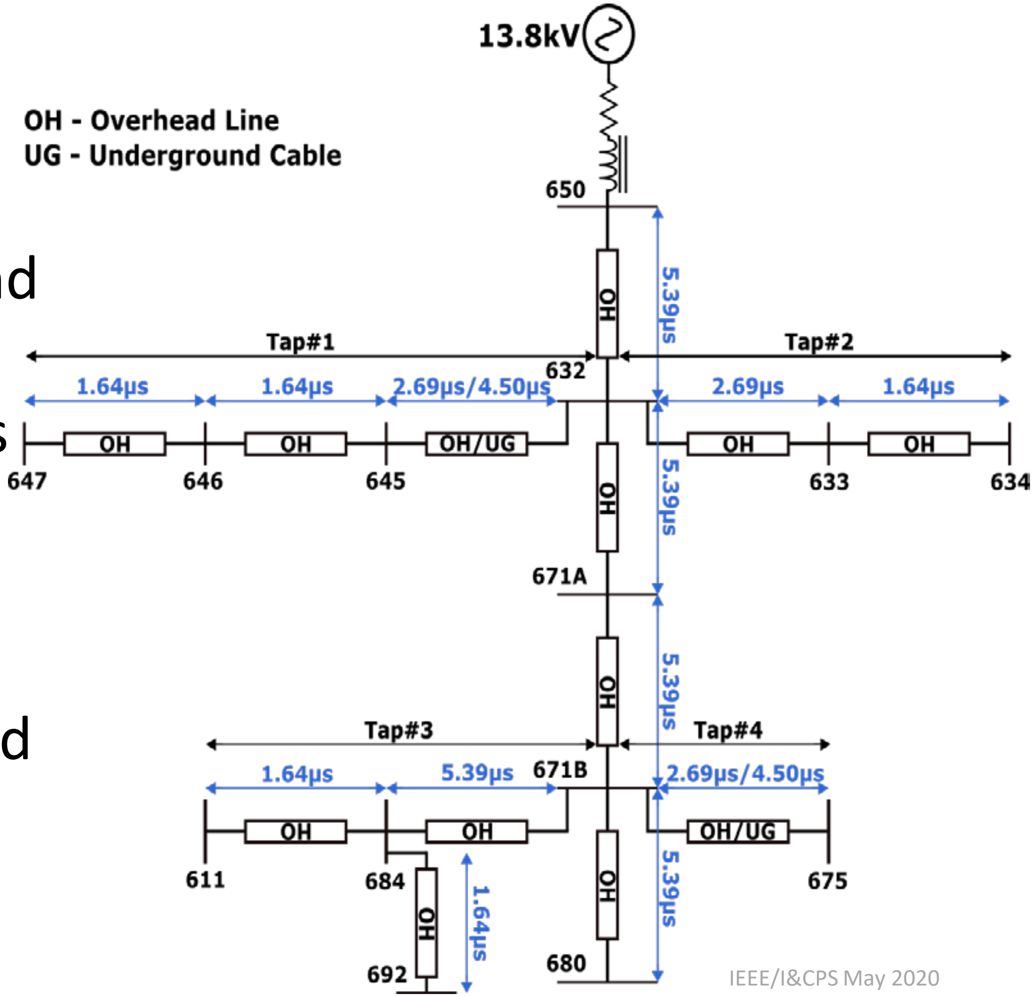
MV Distribution Test Case

- Modified IEEE test system at 13.8 kV.
- Two overhead lines are replaced by underground cables between 645 & 632, 671B & 675.
- Simulation timestep off 100 ns is used to study the different cases in test system.
- Voltage and current probes at every bus are sampled at 10 MHZ to record high frequency waves.

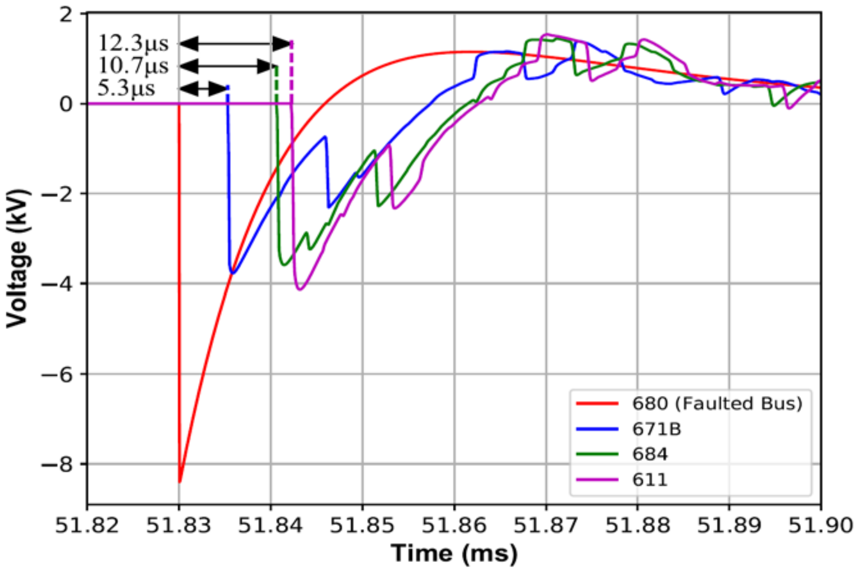


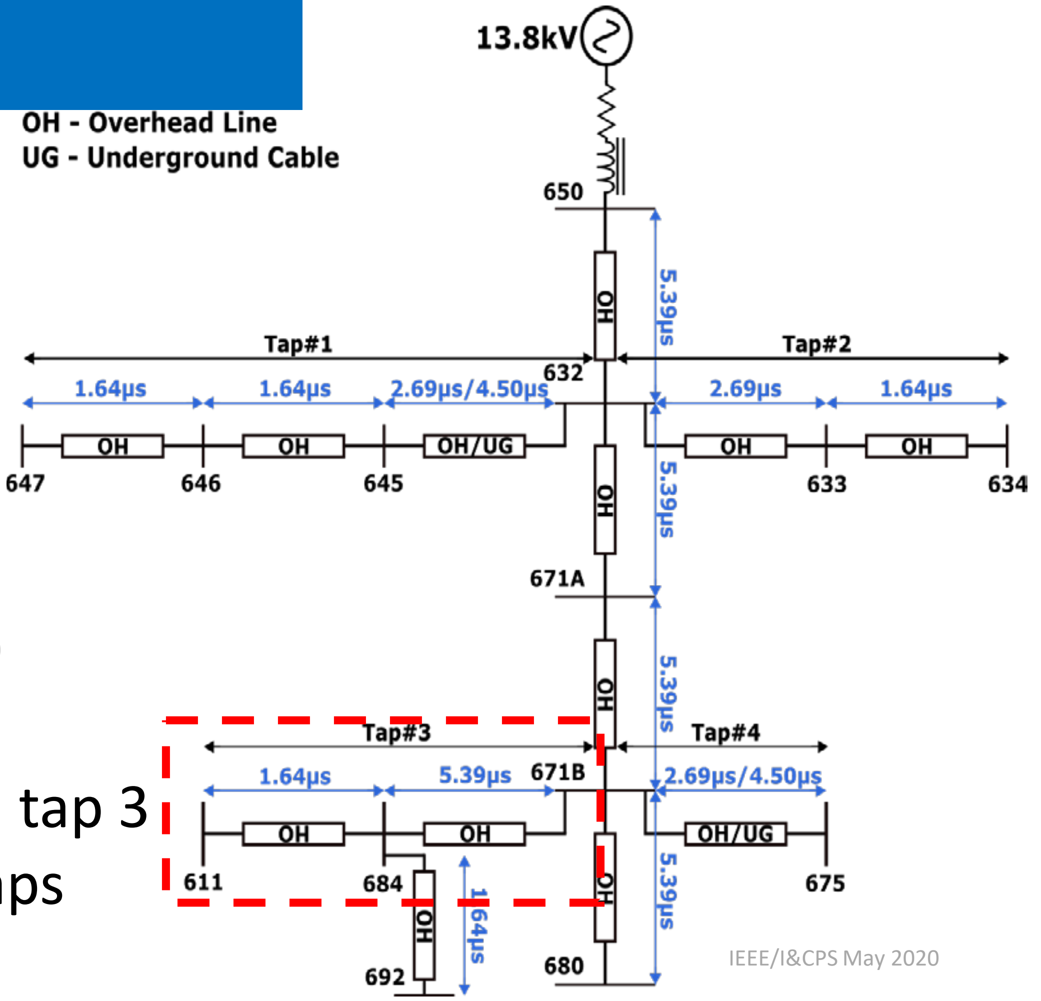
Traveling-Wave Timing Diagram

- Indicated times are the wave propagation time from one end to other end of line.
- To estimate arrival wave times at buses, add the times in the path between fault and selected bus.
- Alpha mode velocities are used to calculate the propagation time.



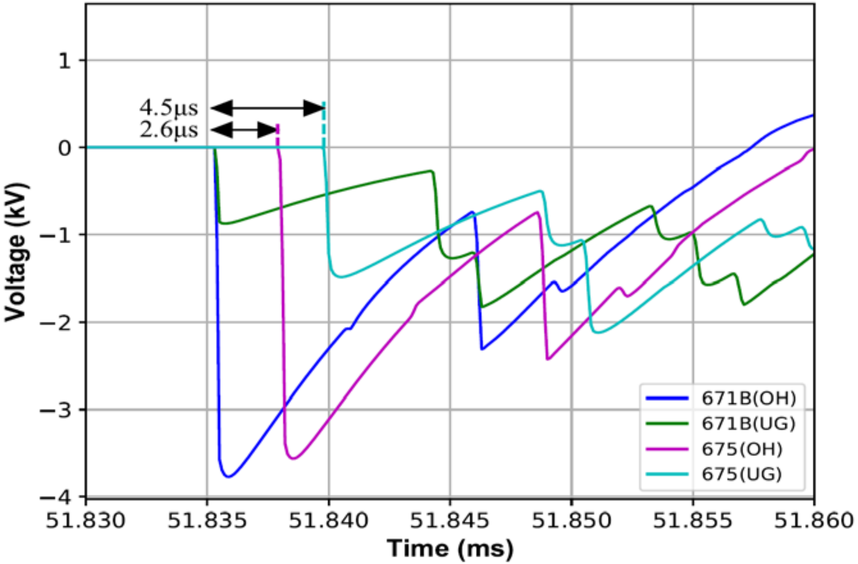
Overhead Lines with SLG Fault on Bus 680

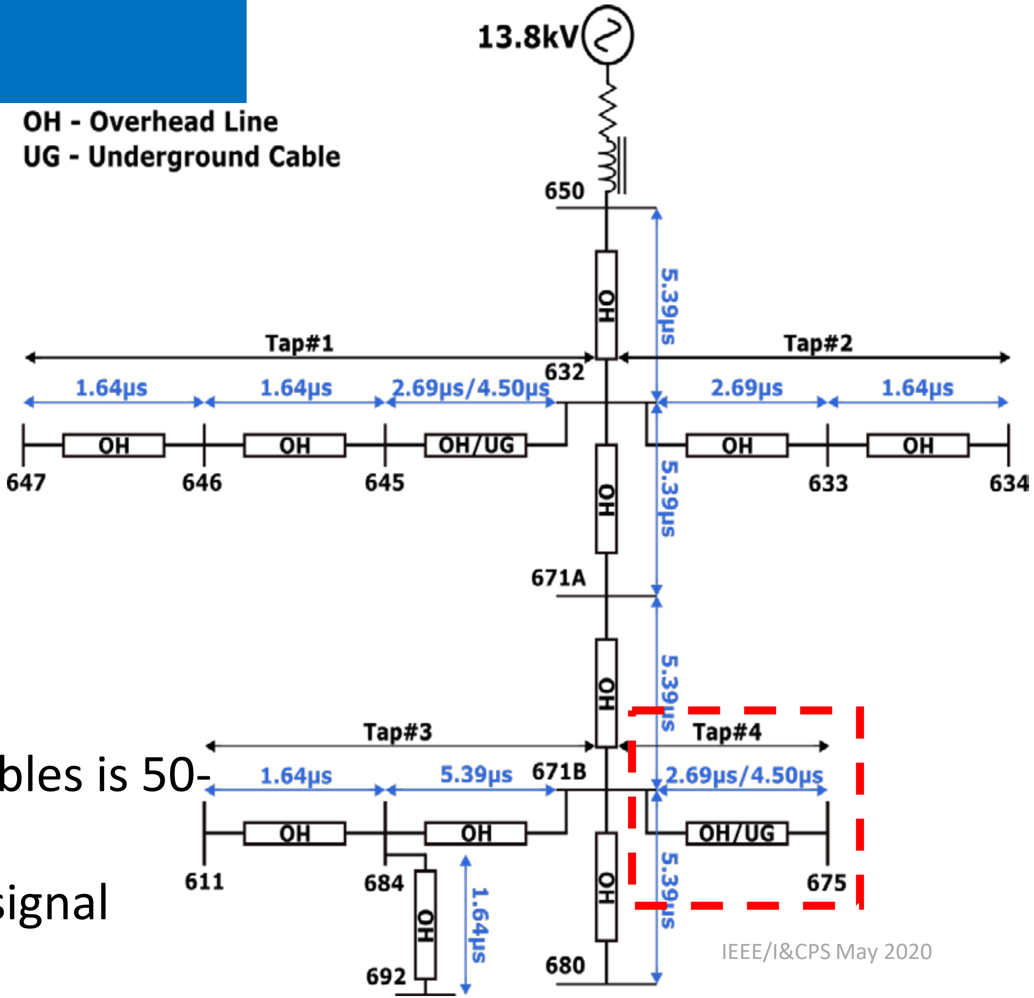




- ➢ Estimated wave arrival times match the simulated times in tap 3
- ➢ Multiple reflections due to taps

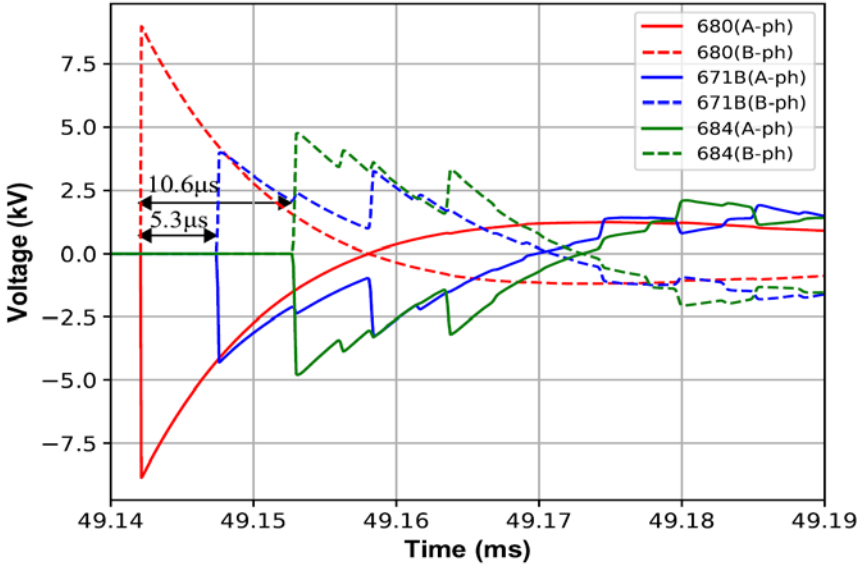
Overhead and Underground Lines with SLG Fault on Bus 680

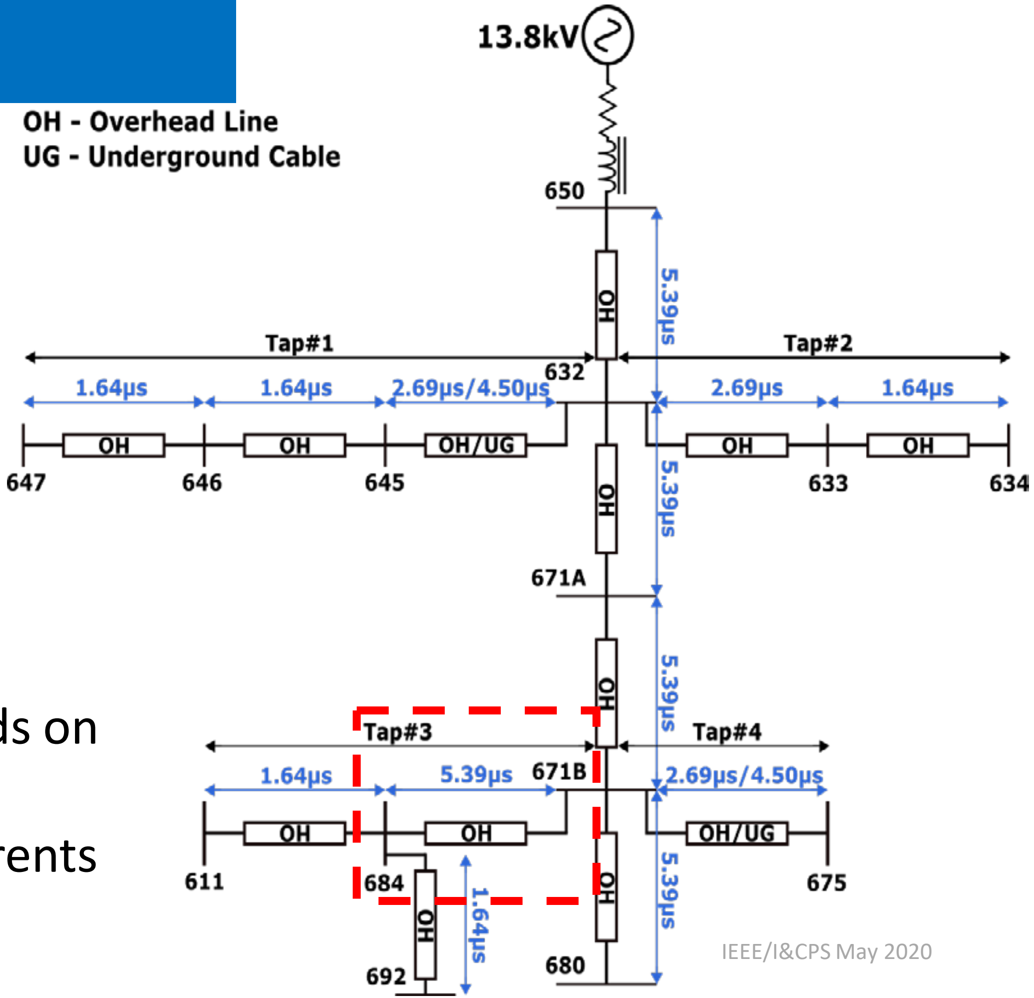




- ➢ Wave propagation velocity in UG cables is 50-60% of OH
- ➢ Superimposed on 8 kHz oscillatory signal

OH Lines with Line-to-Line Fault on Bus 680





- ➢ Waves launched at the fault depends on voltage difference
- ➢ Similar characteristic to LL fault currents

Future Work

- Different fault types such as high impedance, arcing fault will be studied using the test system.
- Frequency signatures will be developed using advanced signal processing techniques.
- High frequency models of transformer and DER will be developed and validated through testing.
- Results will be validated through field data.

Thank you

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