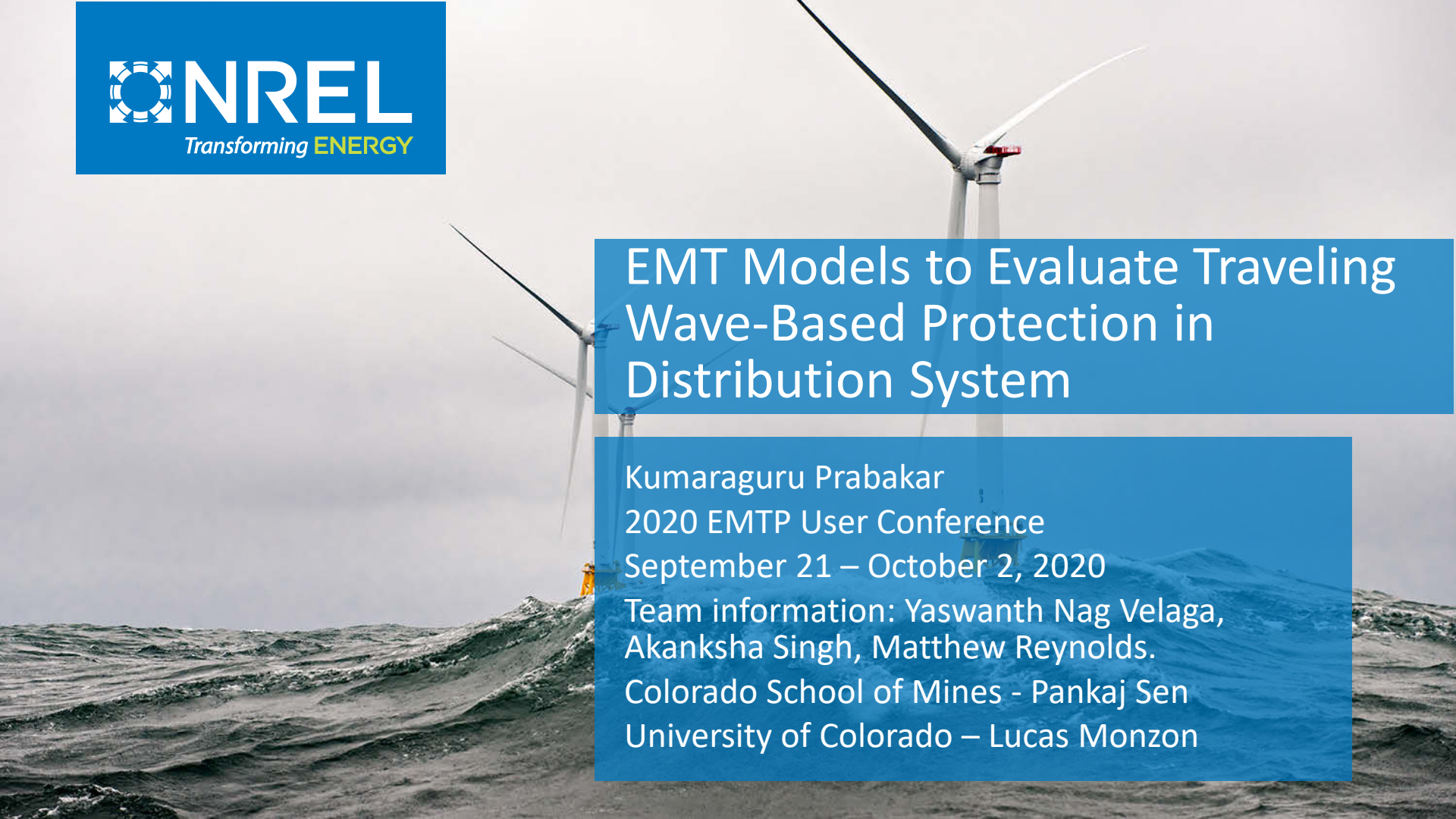


EMT Models to Evaluate Traveling Wave-Based Protection in Distribution System

Kumaraguru Prabakar

2020 EMTP User Conference

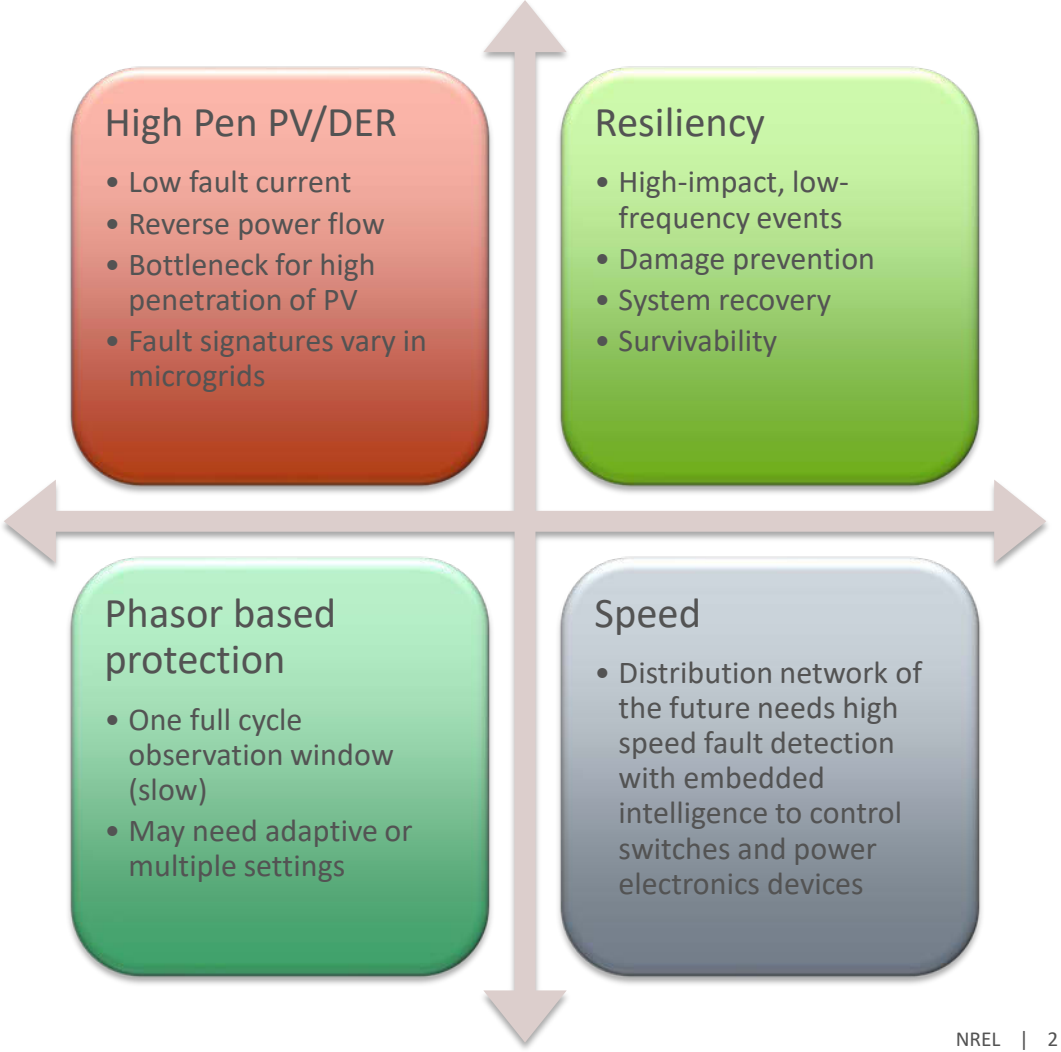
September 21 – October 2, 2020

Team information: Yaswanth Nag Velaga, Akanksha Singh, Matthew Reynolds.

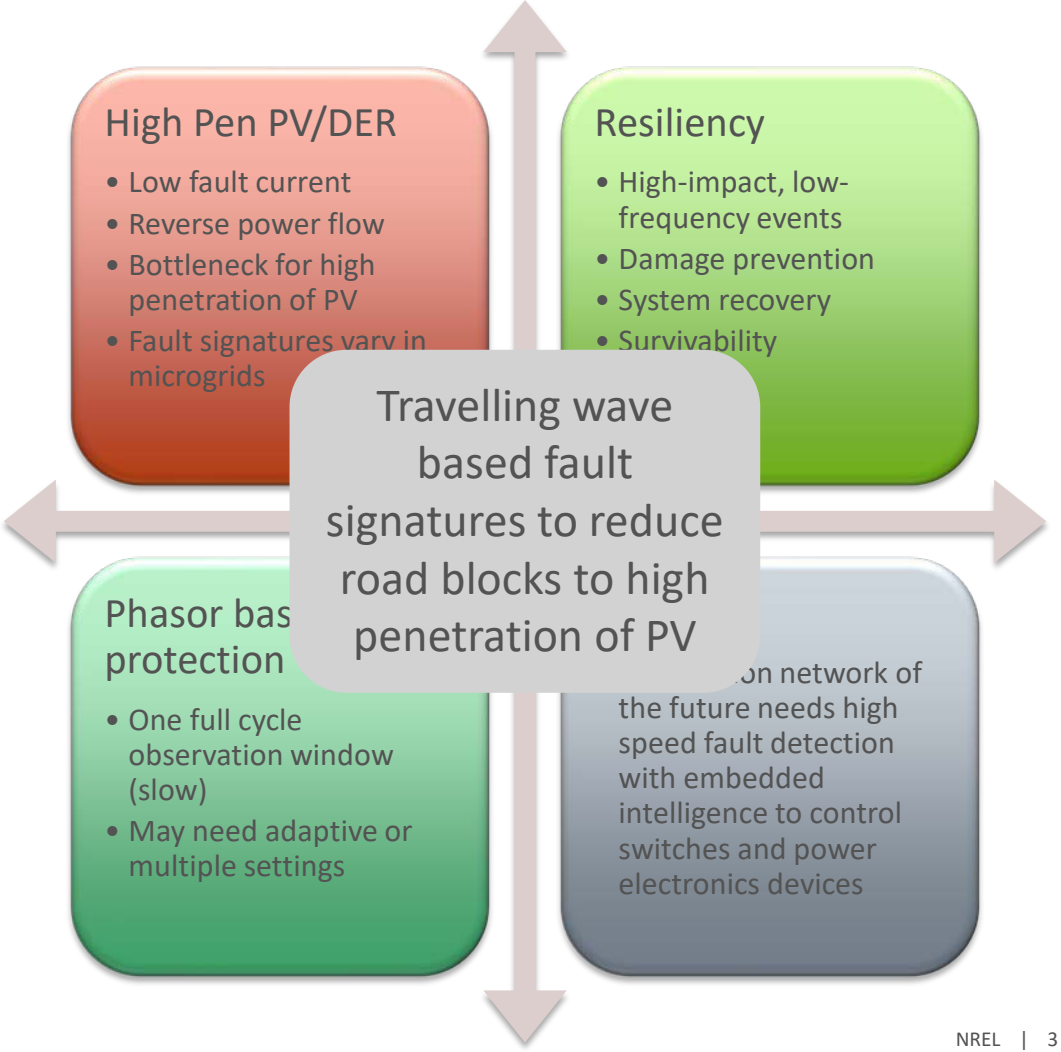
Colorado School of Mines - Pankaj Sen

University of Colorado – Lucas Monzon

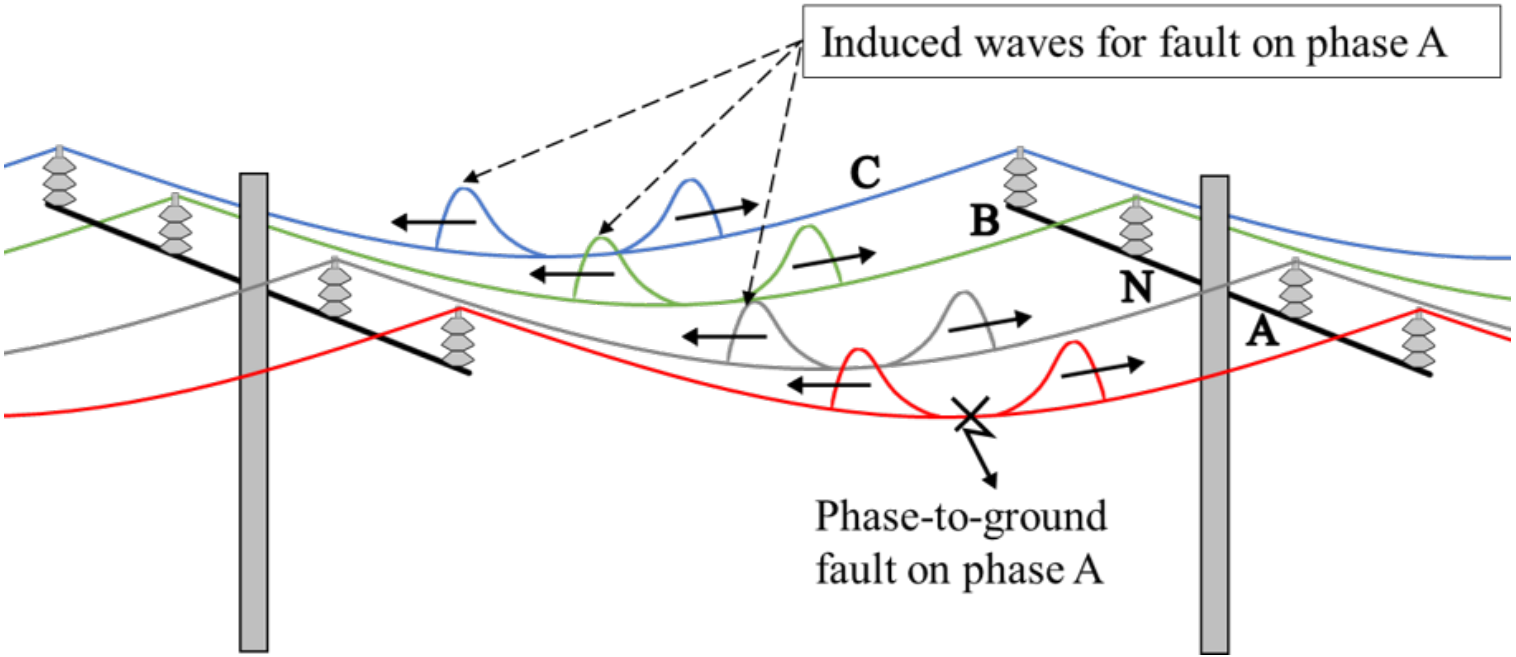
The Challenge



The Challenge



Traveling waves in multiconductor line during phase-to-ground fault



Incorporating frequency dependence into line models

- Frequency dependent transmission line and underground cable models implements in EMTP:
  - Frequency-Dependent Line (FDLINE)
  - LMARTI
  - Universal Line Model (ULM)
- These methods approximate the frequency dependence with rational functions (e.g. via Bode's Asymptotic fitting (BAF) and vector-fitting).
- Fitted functions are then converted to the time domain and used in time-domain algorithms. Delicate numerical aspects of this step can have adverse affects on the simulation results.

Frequency dependent line model

FDLINE by J. Marti

- Introduced in 1981-82
- Accuracy limited for underground cables
- complex frequency dependent transformation matrices are approximated for the whole frequency range by selecting a single representative frequency.
- only the real part of the constructed transformation matrix is used.

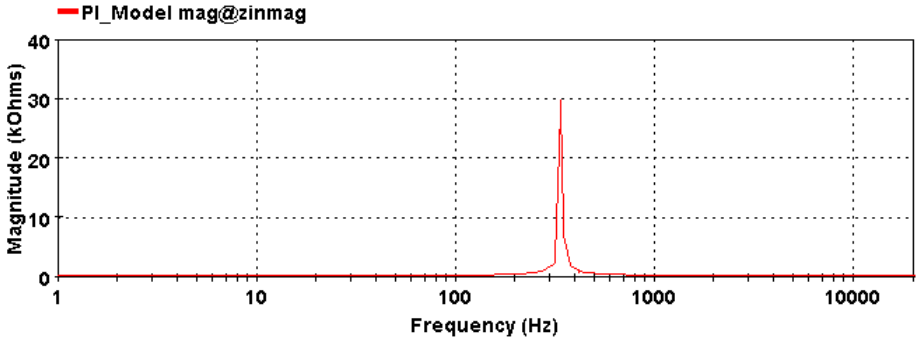
LMARTI Line Model by L. Marti

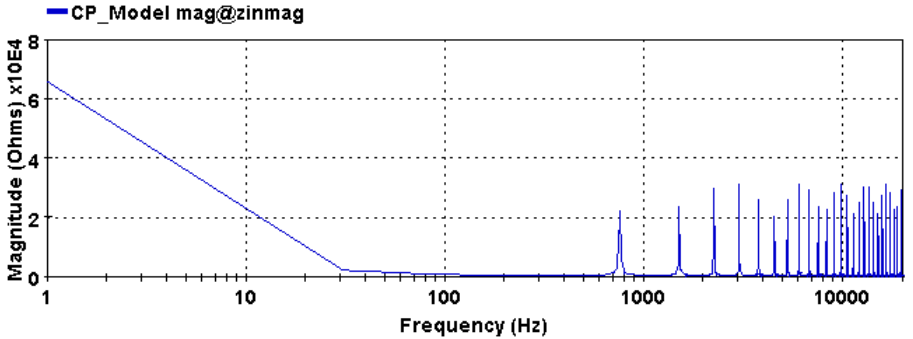
- Introduced in 1988
- Address the frequency dependence of cable parameters and modal transformation matrices.
- Transformation matrices were synthesized with BAF rational function approximations with real negative poles.
- Fitting the transformation matrices with minimum-phase rational functions proved difficult

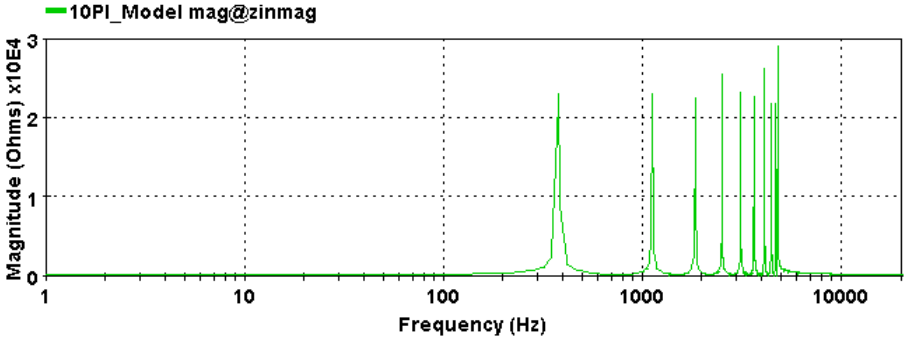
Universal line model

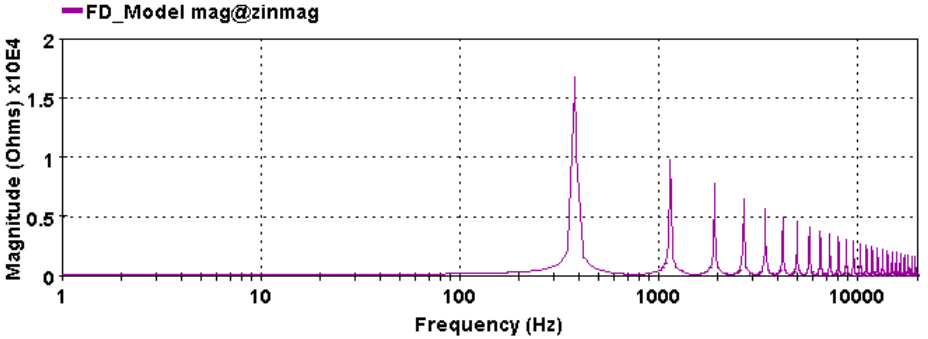
- Introduced in 1999
- Vector fitting algorithm based rational function approximation
- Computationally expensive
- Difficulties involved in the modal domain line models led to the development of this alternative model that avoids transformation matrices by working directly in phase instead of modal coordinates.

Frequency response of different line models



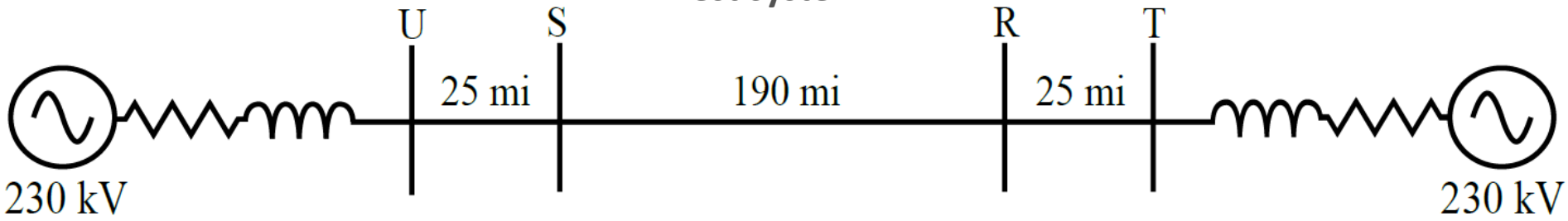




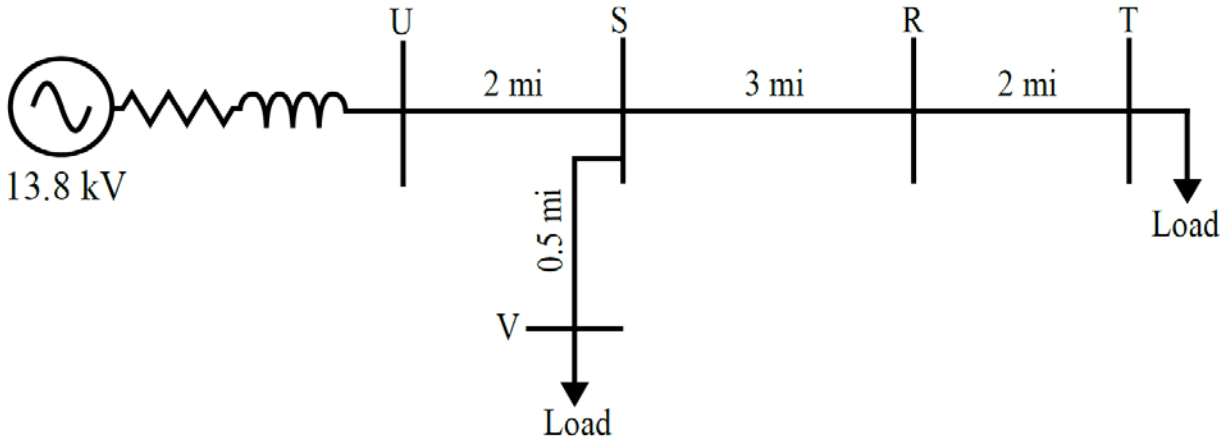


Test systems modeled in EMT to compare TW in transmission and distribution system

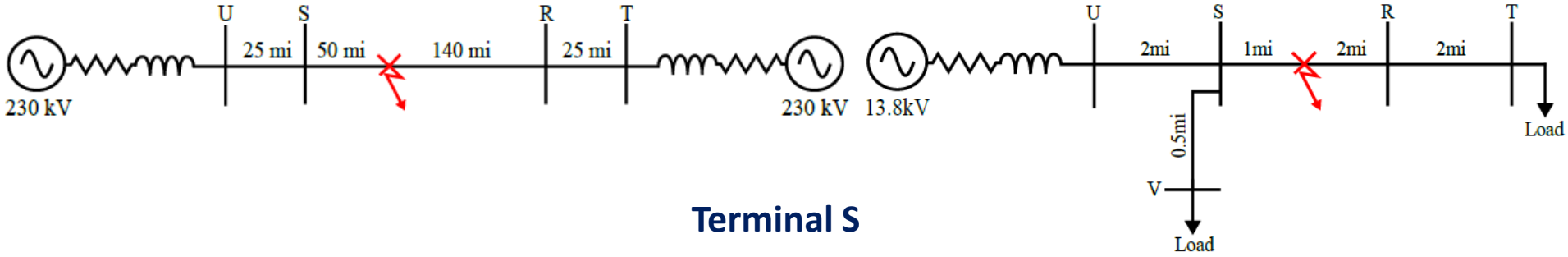
Test system 1



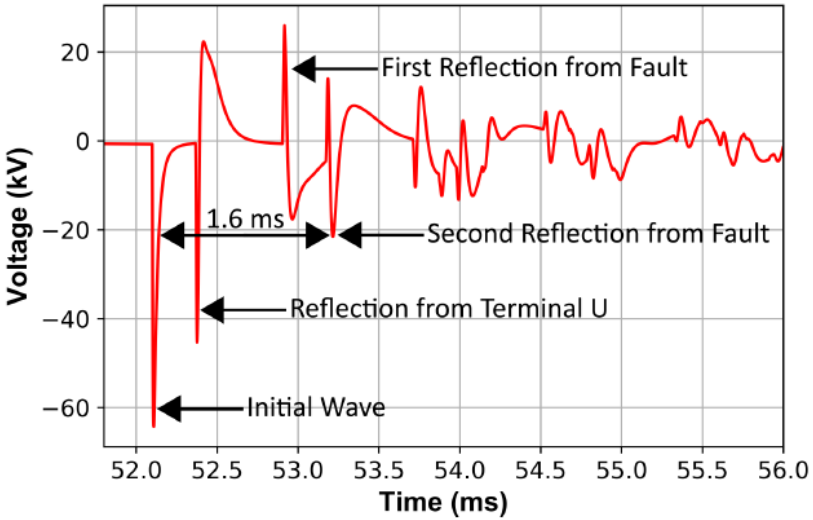
Test System 2

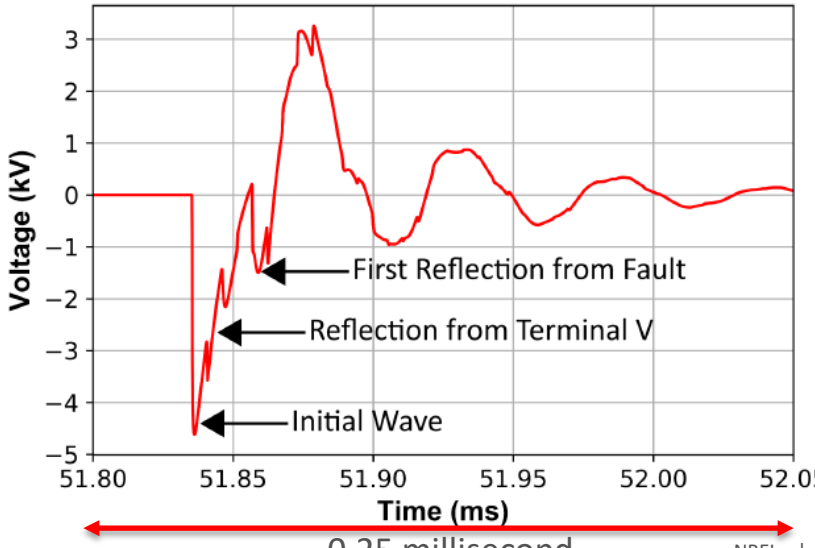


Comparison between scenario 1 and 2

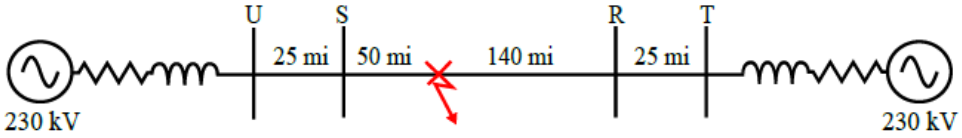


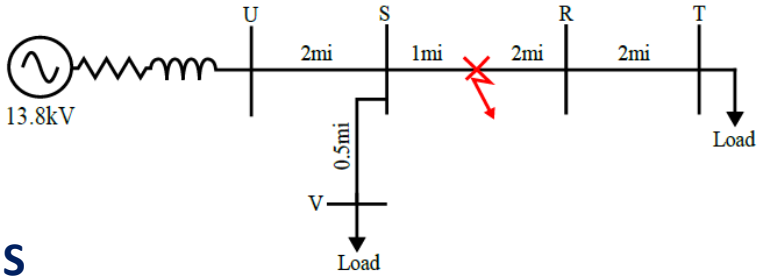
Terminal S



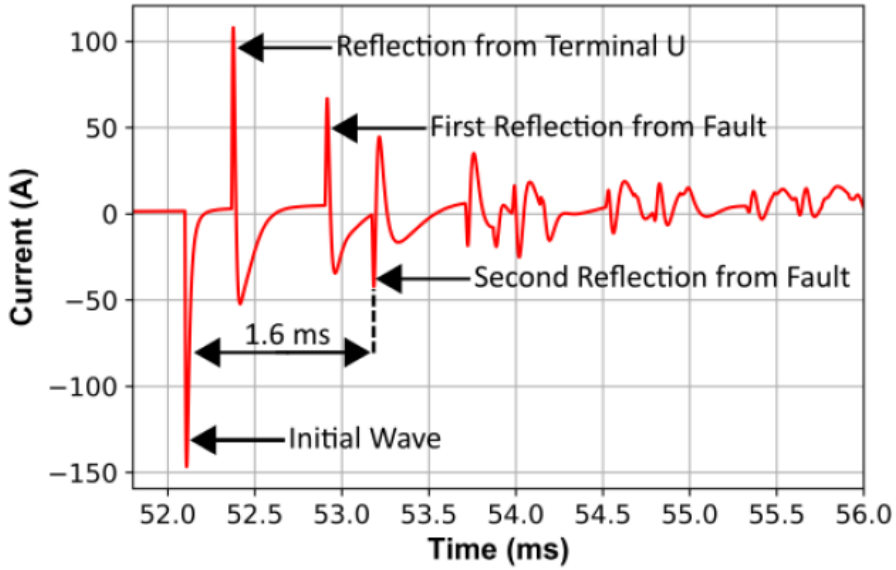


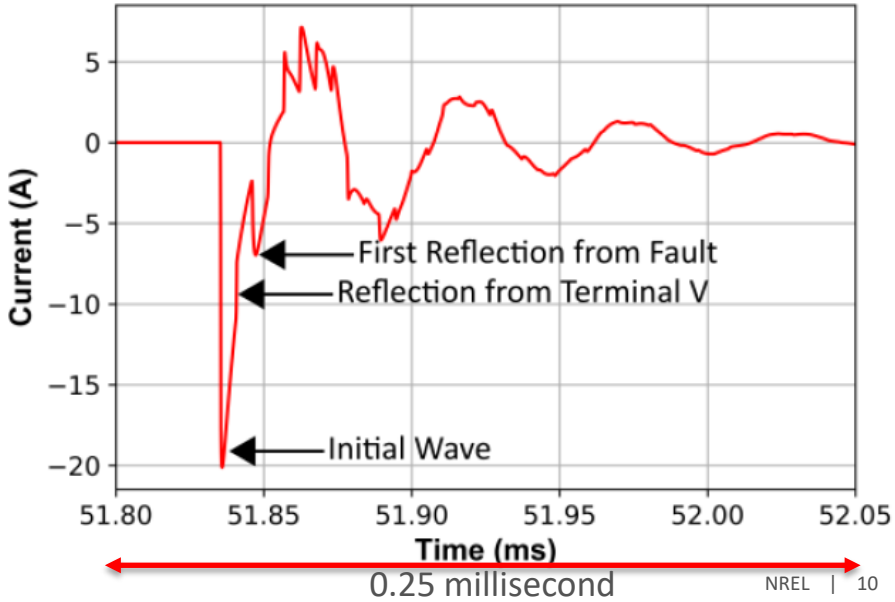
Comparison between scenario 1 and 2



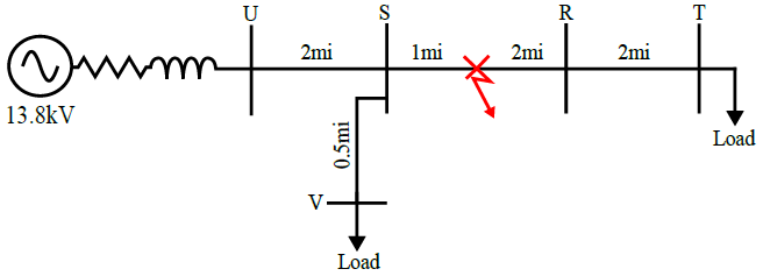


Terminal S

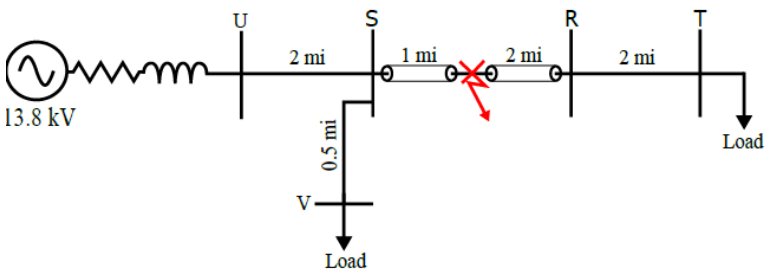




Comparison between scenario 2 and 3

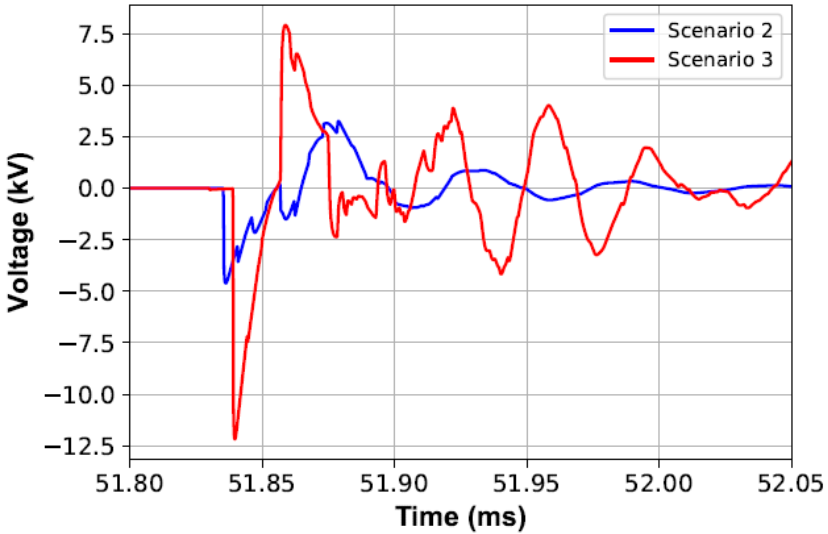


Scenario 2

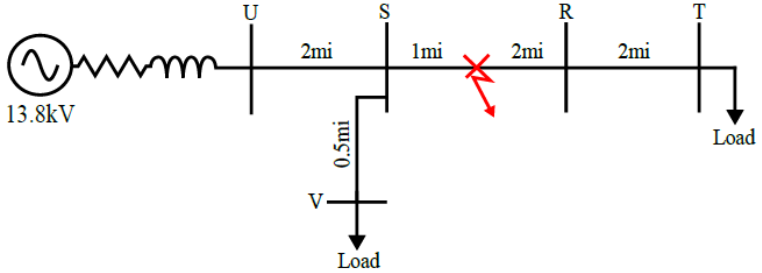


Scenario 3

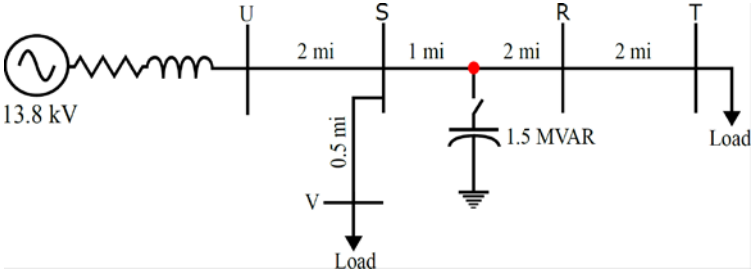
Terminal S



Comparison between scenario 2 and 4

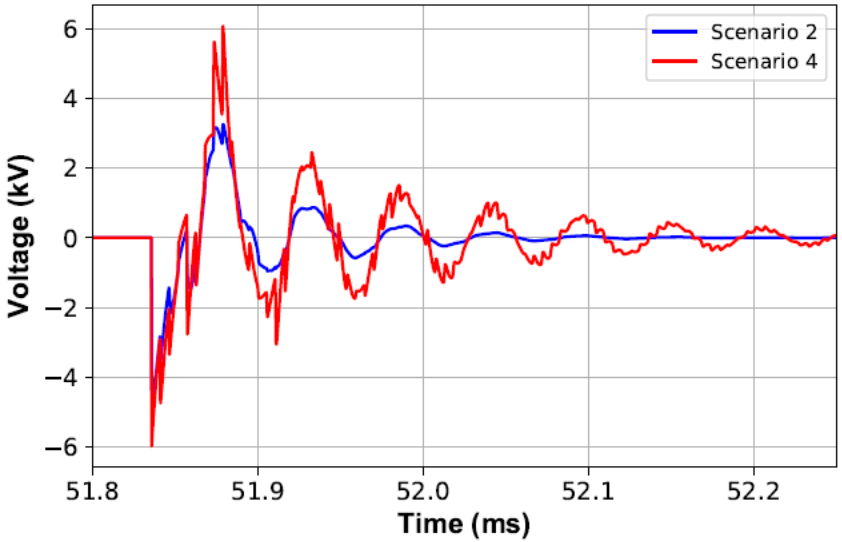


Scenario 2

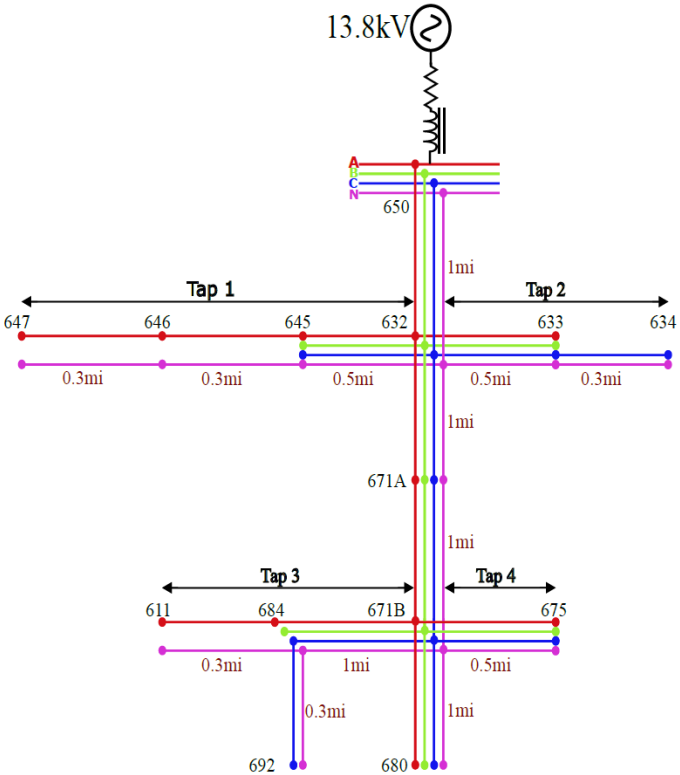


Scenario 4

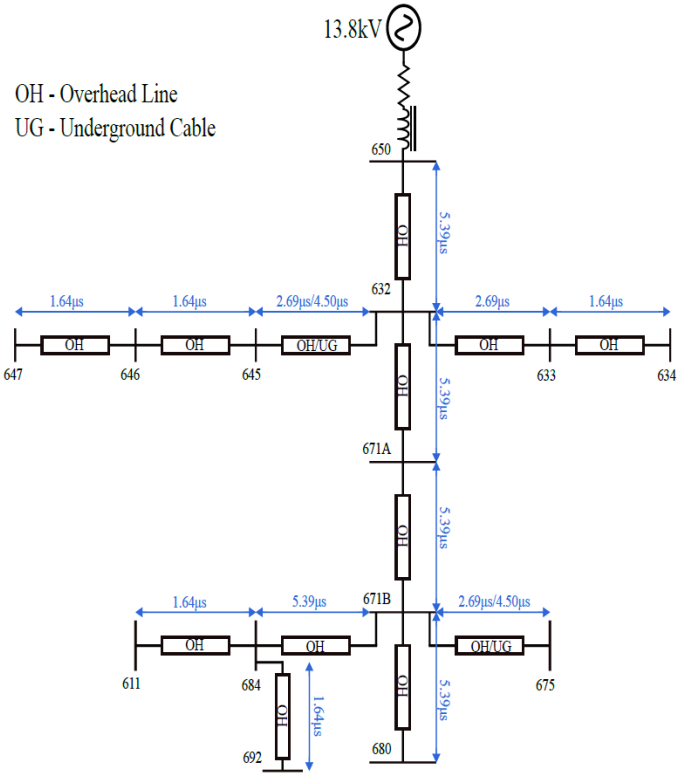
Terminal S



Modified IEEE 13 bus system

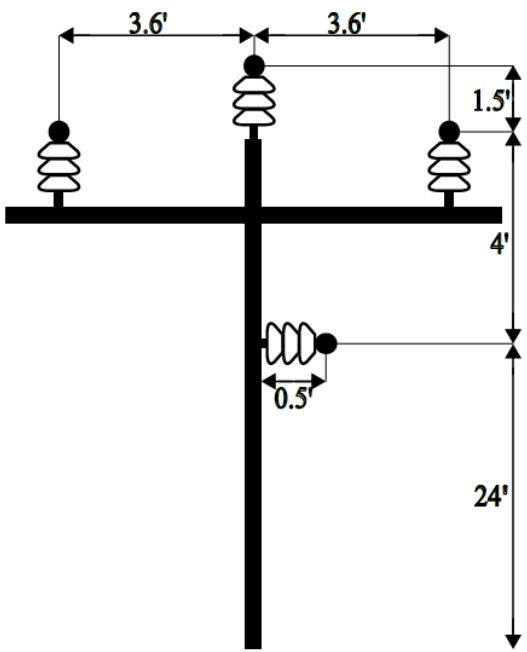


(a) Distribution 13-bus test system

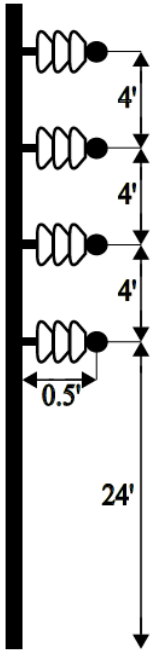


(b) Distribution 13-bus wave travel time

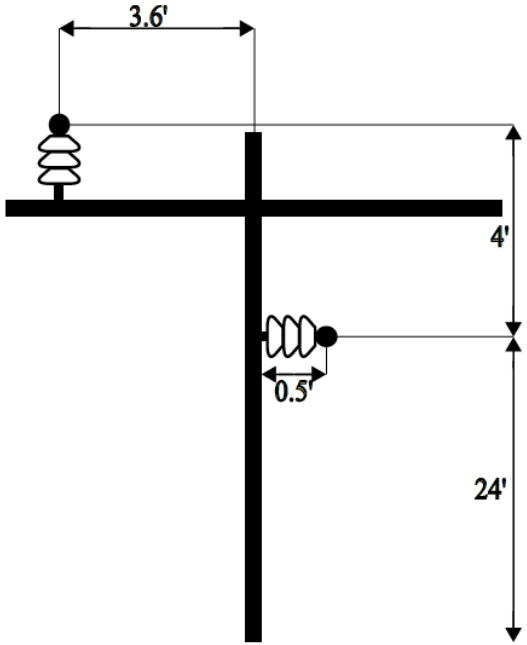
Tower configuration and cable configuration



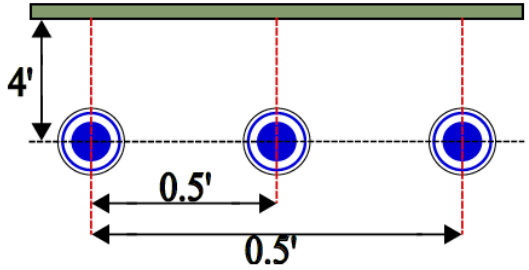
(a) ID-500



(b) ID-505



(c) ID-510



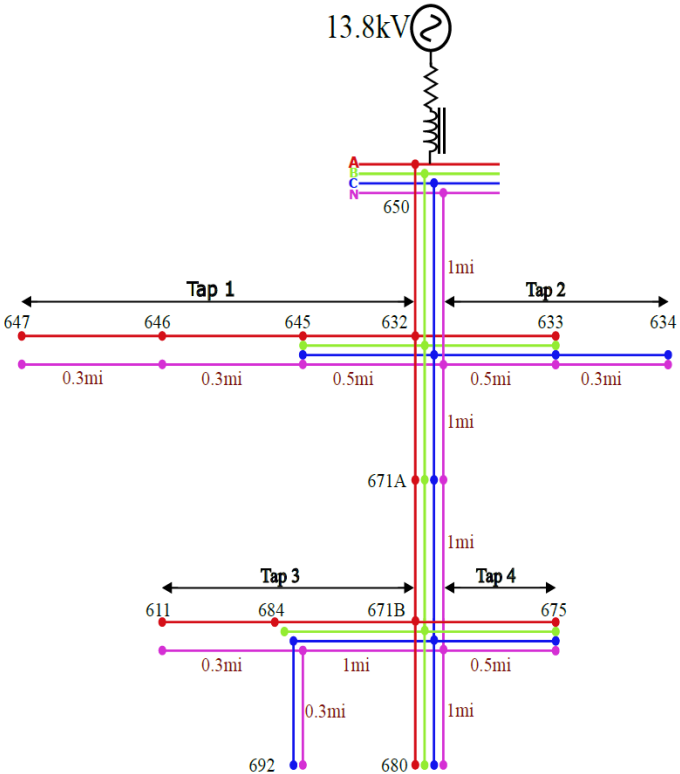
(d) ID-515

Line configuration and cable configuration

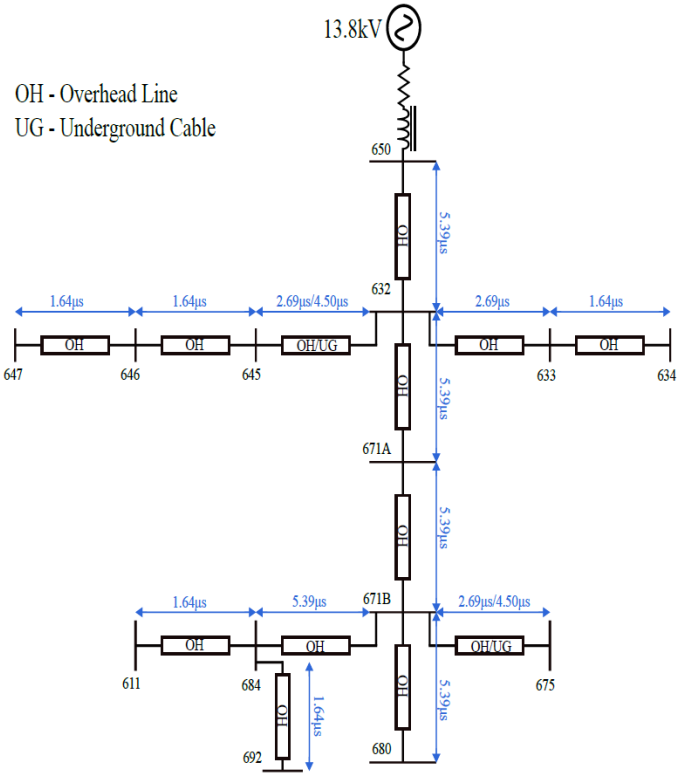
TABLE I. OVERHEAD LINE DATA

Node A	Node B	Length(mi)	Phase	Neutral	Spacing ID
			AWG	ACSR	
650	632	1	4/0	1	500
632	633	0.5	1/0	2	505
633	634	0.3	4/0	1	510
632	645	0.5	1/0	2	505
645	646	0.3	4/0	1	510
646	647	0.3	4/0	1	510
632	671A	1	4/0	1	500
671A	671B	1	4/0	1	500
671B	680	1	4/0	1	500
671B	675	0.5	1/0	2	505
671B	684	1	4/0	1	500
684	611	0.3	4/0	1	510
684	692	0.3	4/0	1	510

Modified IEEE 13 bus system



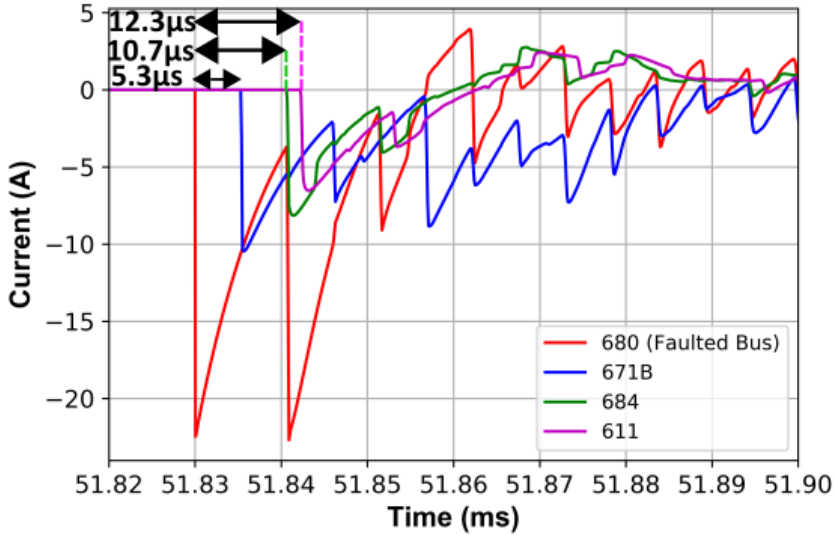
(a) Distribution 13-bus test system

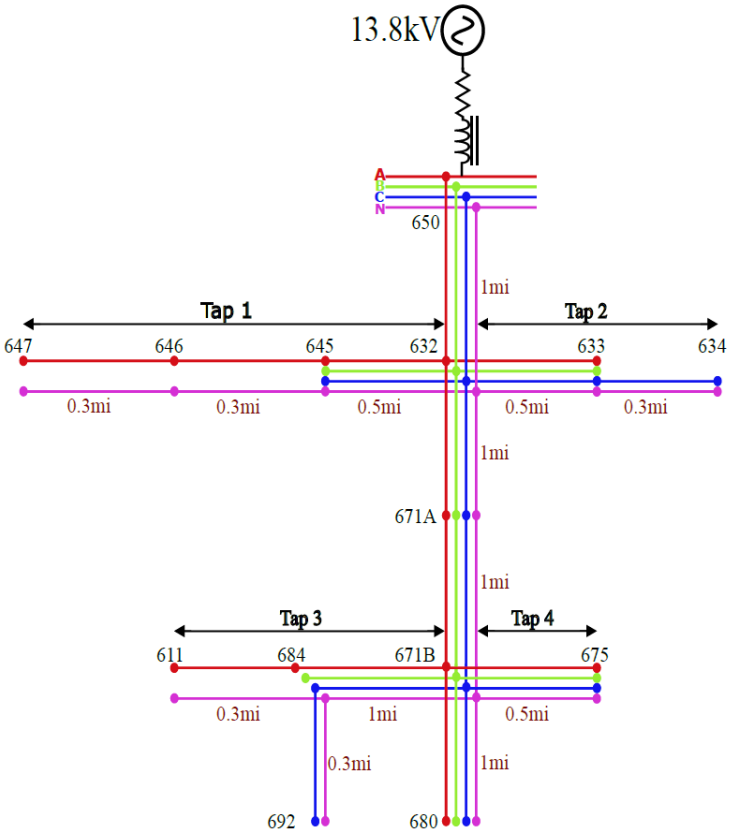


(b) Distribution 13-bus wave travel time

Test Case SLG : Overhead Lines with Fault on Bus#680

- Initial wave times estimated at 671B, 684, 611 are 5.39µs, 10.78µs, 12.42µs respectively.
- In the simulations, they arrive at 5.3µs, 10.7µs, 12.3µs.

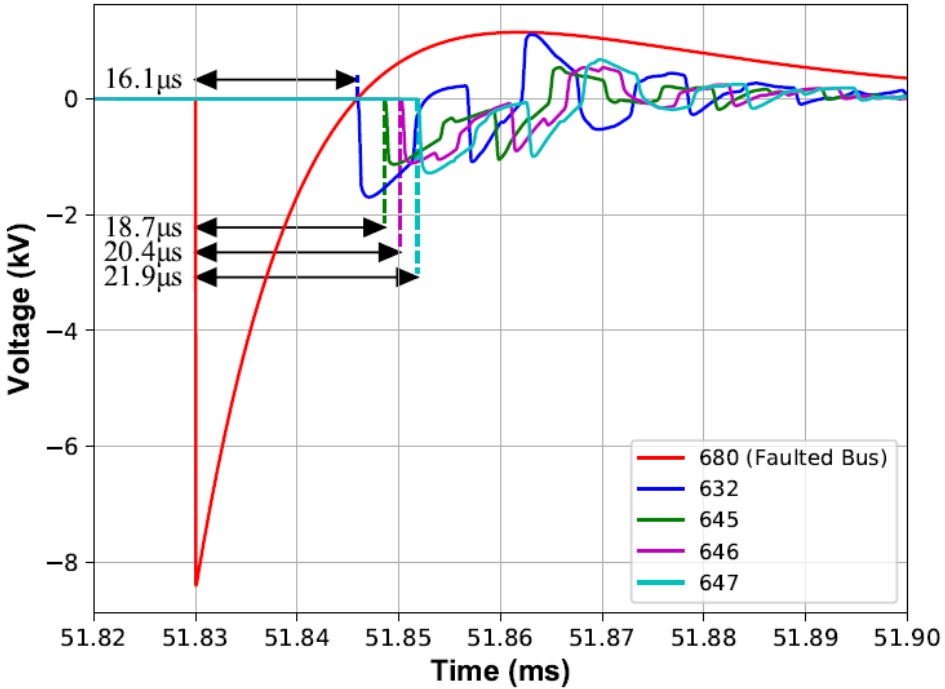


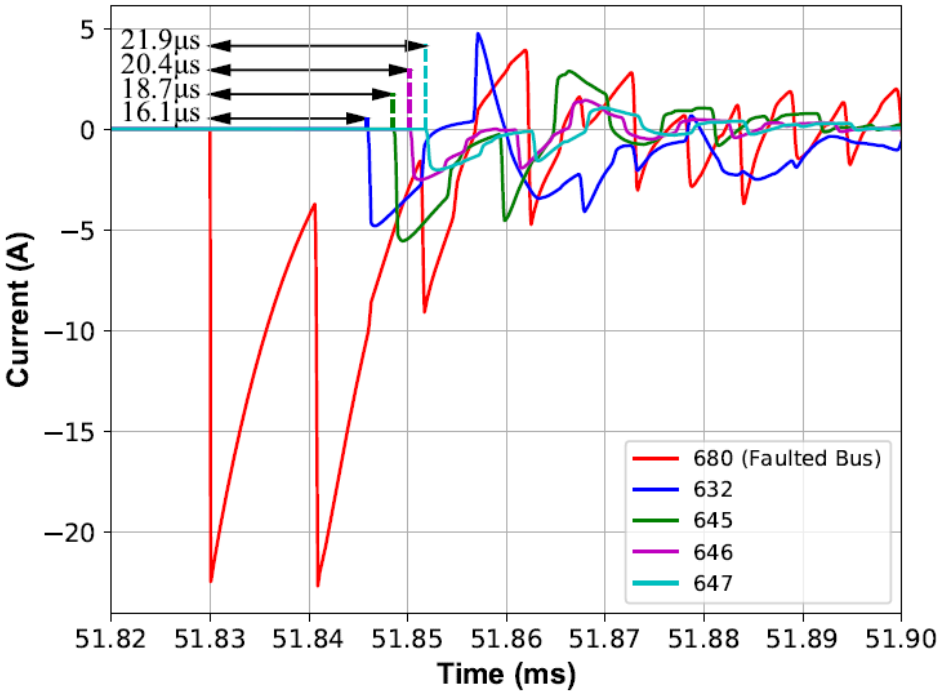


(a) Distribution 13-bus test system

Test Case SLG: Overhead Lines with Fault on Bus#680

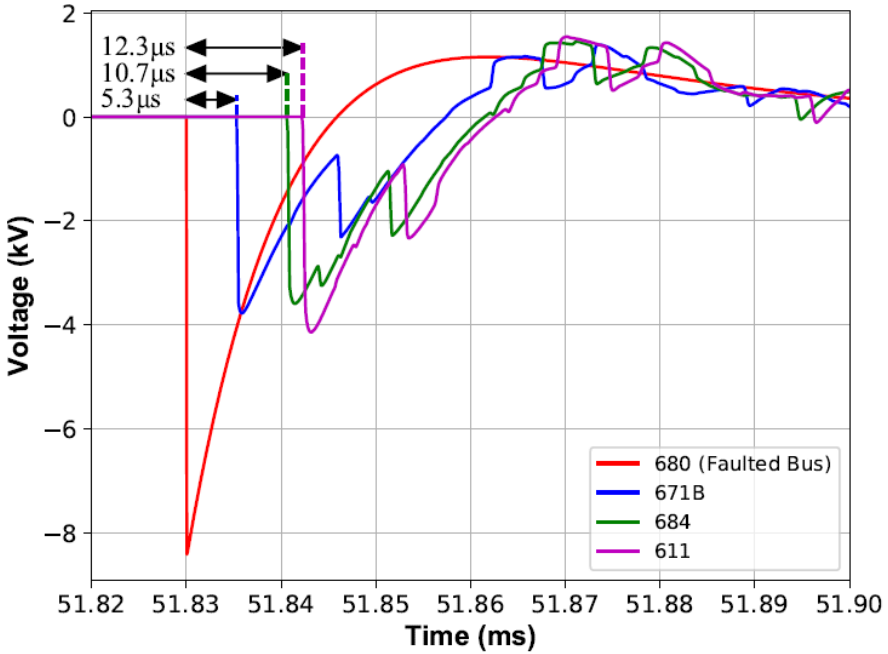
Tap 1

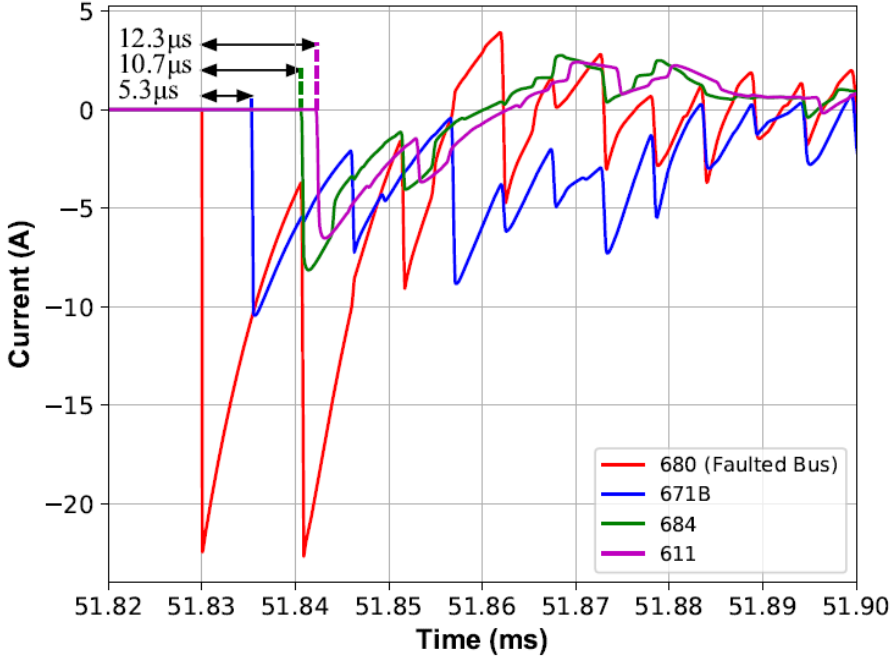




Test Case SLG: Overhead Lines with Fault on Bus#680

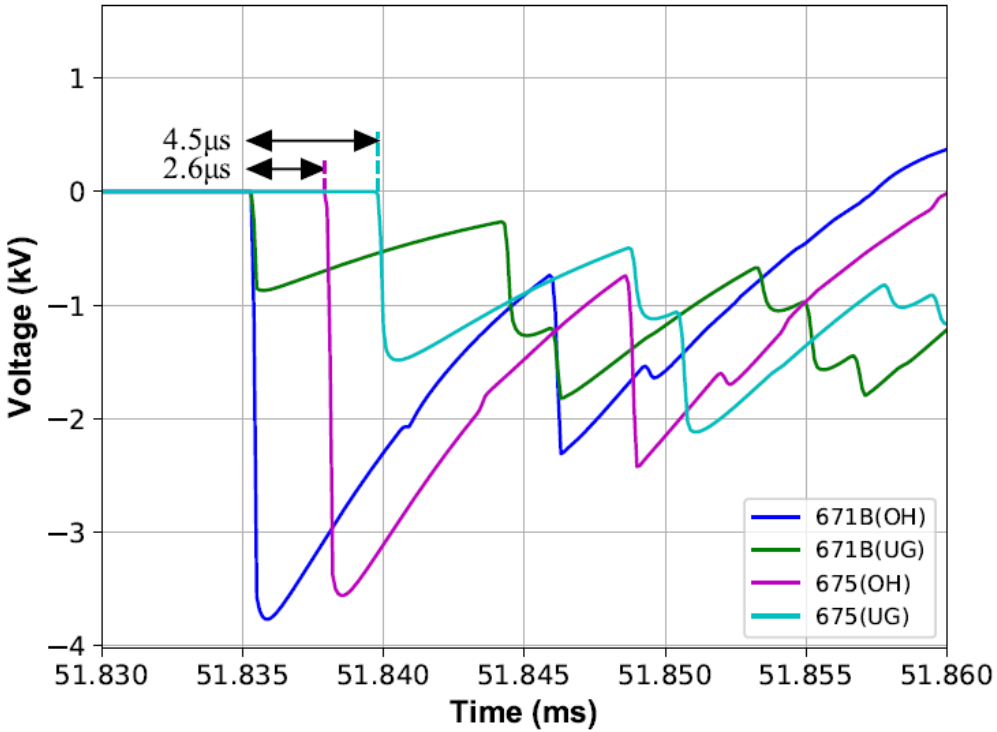
Tap 3





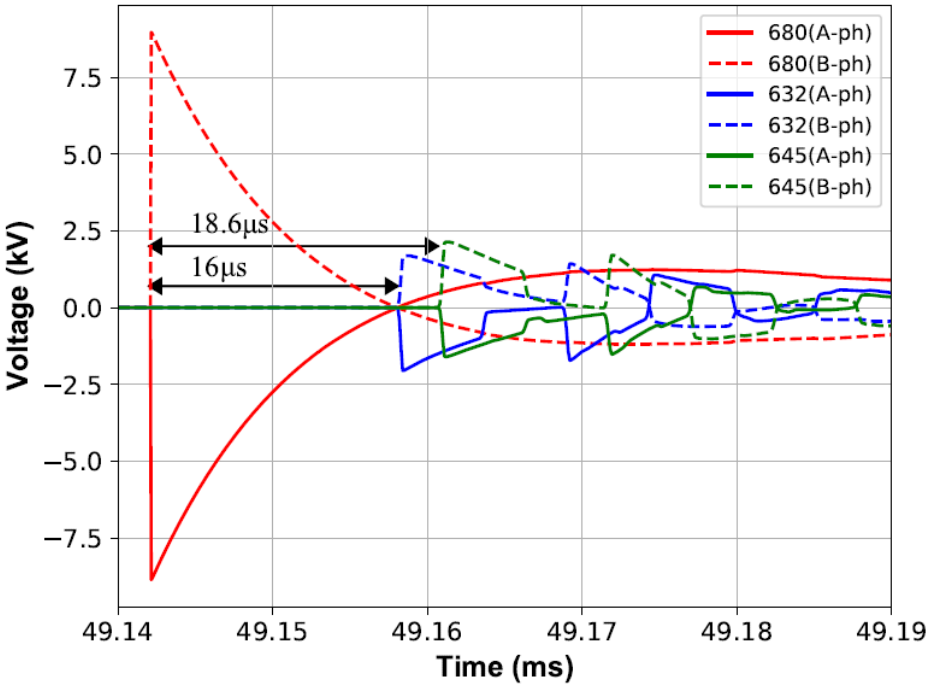
Test Case SLG: Overhead Lines with Fault on Bus#680

Traveling Wave in underground cable section

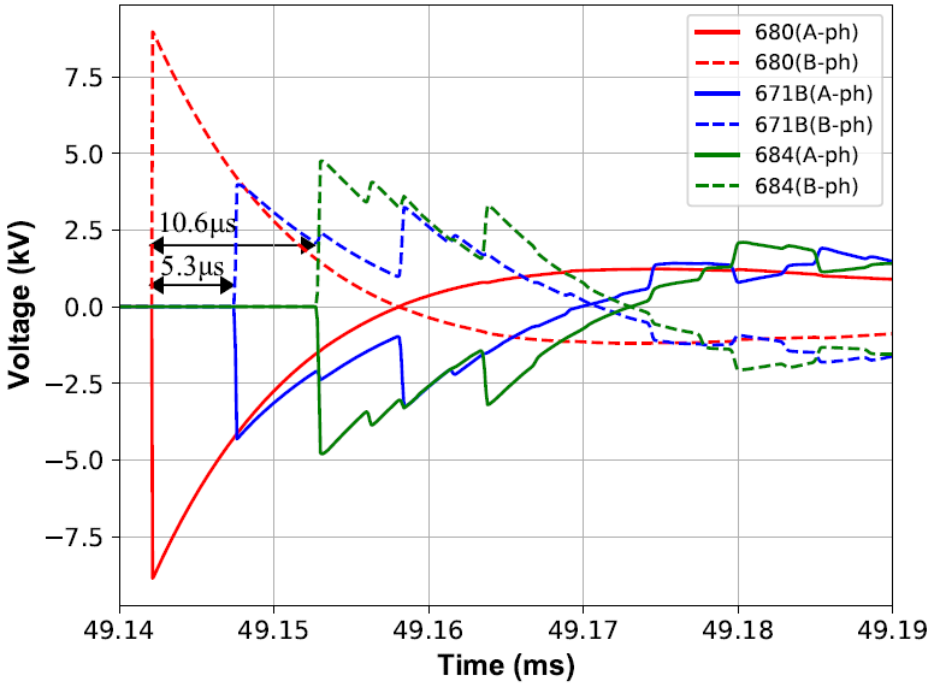


Test Case LL: Overhead Lines with Fault on Bus#680

LL Fault

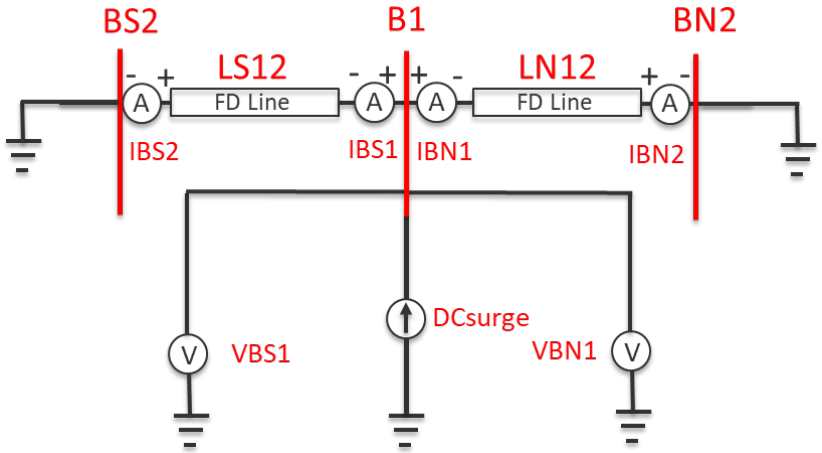


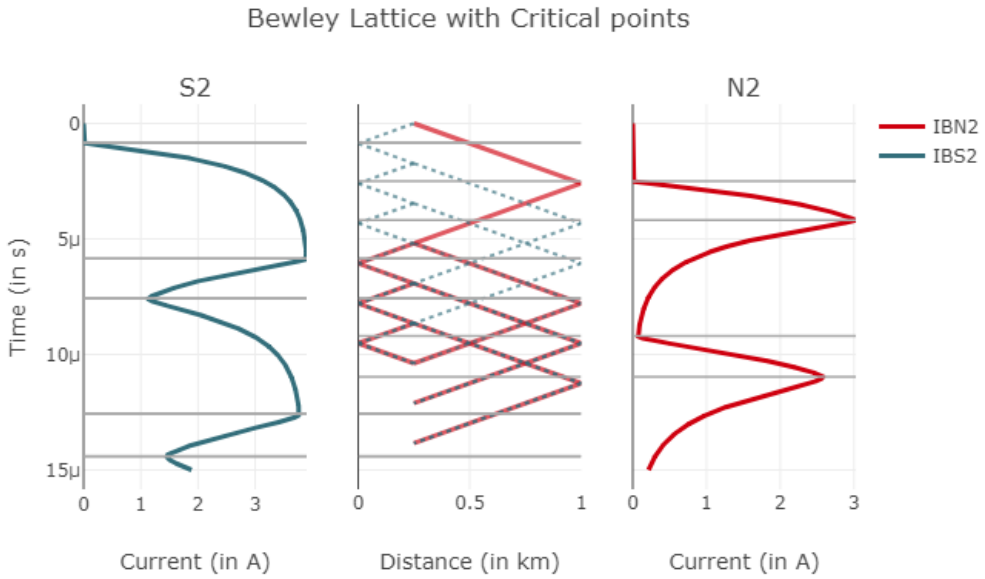
Tap 1



Tap 3

Simulation of faults in overhead lines





Publications

- Y. N. Velaga, K. Prabakar, A. Singh, P. Sen, and B. D. Kroposki, “Advanced Distribution Protection for High Penetration of Distributed Energy Resources (DER)”. United States: N. p., 2019. Web.
- L. Monzón, W. Johns, D. Iyengar, M. Reynolds, J. Maack, and K. Prabakar, “A Multi-Function AAA Algorithm Applied to Frequency-Dependent Line Modeling,” 2020 IEEE Power & Energy Society General Meeting (PESGM), 2020, pp. 1-5.
- Y. N. Velaga, K. Prabakar, A. Singh, and P. Sen, “Traveling Wave Relays for Distribution Feeder Protection with High Penetrations of Distributed Energy Resources,” Accepted for 2021 IEEE Rural Electric Power Conference (REPC) 2021.

Intellectual property developed

- Open source software tool titled “SWR-19-17 Bewley Lattice Visualization” available at NREL’s github repository.

www.nrel.gov

NREL/PR-5D00-77754

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 34237. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.