Protection of High-Penetration Distributed PV

by

Dr. Thomas McDermott

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Thursday, Sept 24, 2020

Thomas E. McDermott received the B.S. and M.E. degrees in electric power from the Rensselaer Polytechnic Institute, and the Ph.D. degree in electrical engineering from Virginia Tech. He is currently a Chief Engineer in the Distributed Systems Group and Solar Sub-sector Lead at the Pacific Northwest National Laboratory, with 40 years of experience in consulting, software development, and research. His technical interests include simulation, transactive energy, and distribution system analysis. He is a Fellow of the IEEE (2014). Dr McDermott is also a licensed PE in Pennsylvania.

Protection of (Radial Circuits with) High Penetration Distributed Photovoltaics (PV)

U. S. Dept. of Energy Solar Energy Technologies Office

- Pacific Northwest National Laboratory
- Oak Ridge National Laboratory
- Georgia Tech
- Dominion Energy Virginia
- Chattanooga Electric Power Board

IEEE PSRC Meeting, September 24, 2020

Tom McDermott, FIEEE, Thomas.McDermott@pnnl.gov

IEEE PES PSRC Power & Energy Society®

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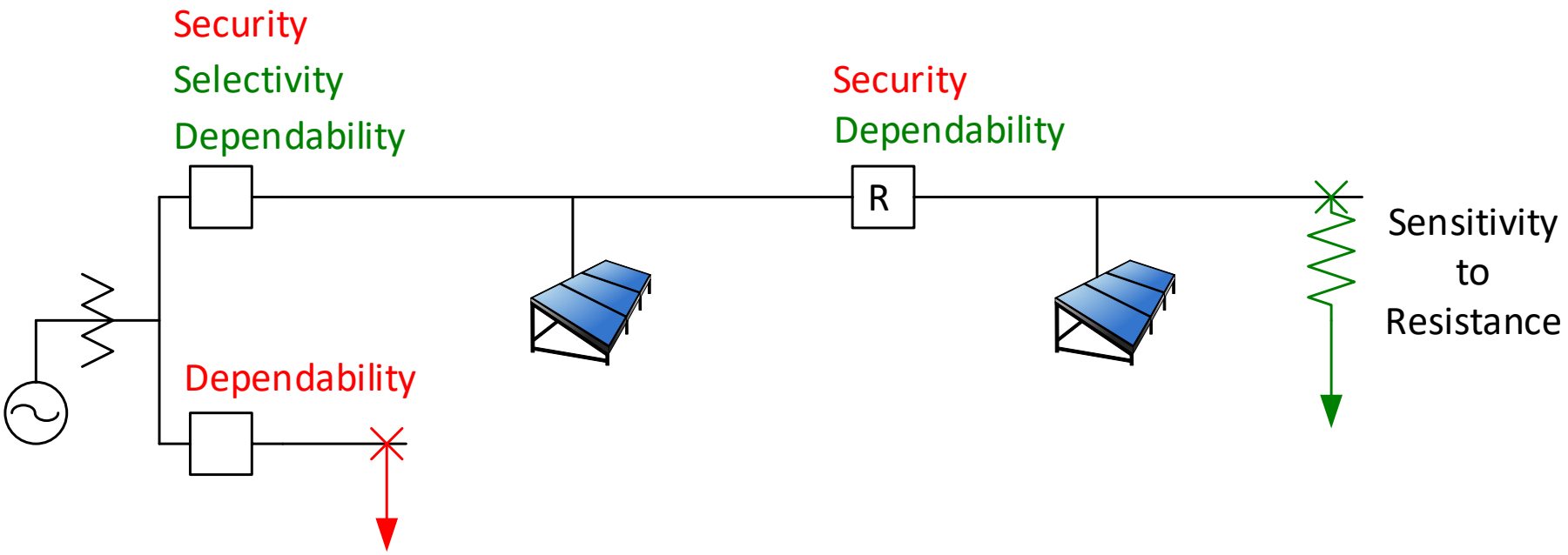
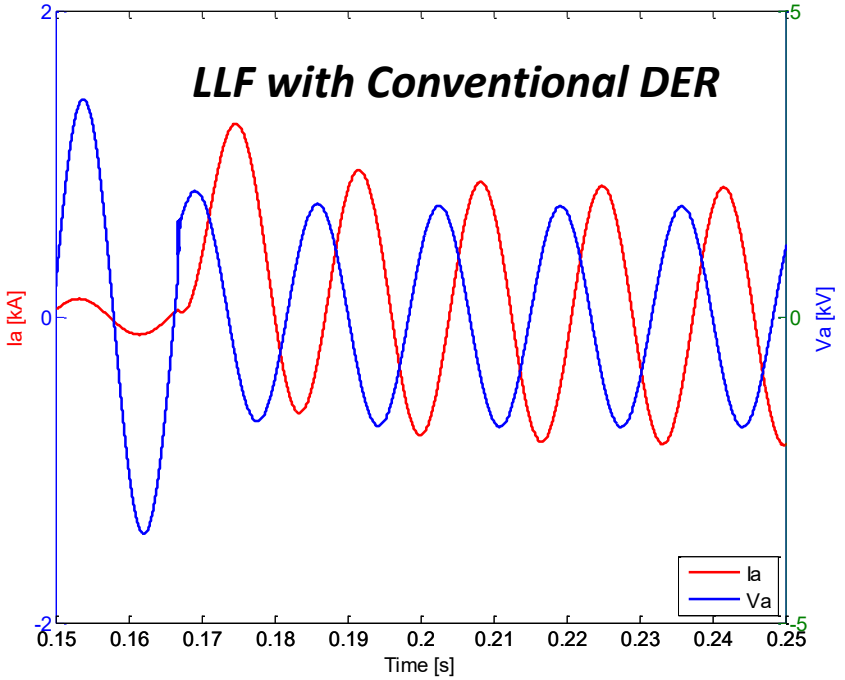
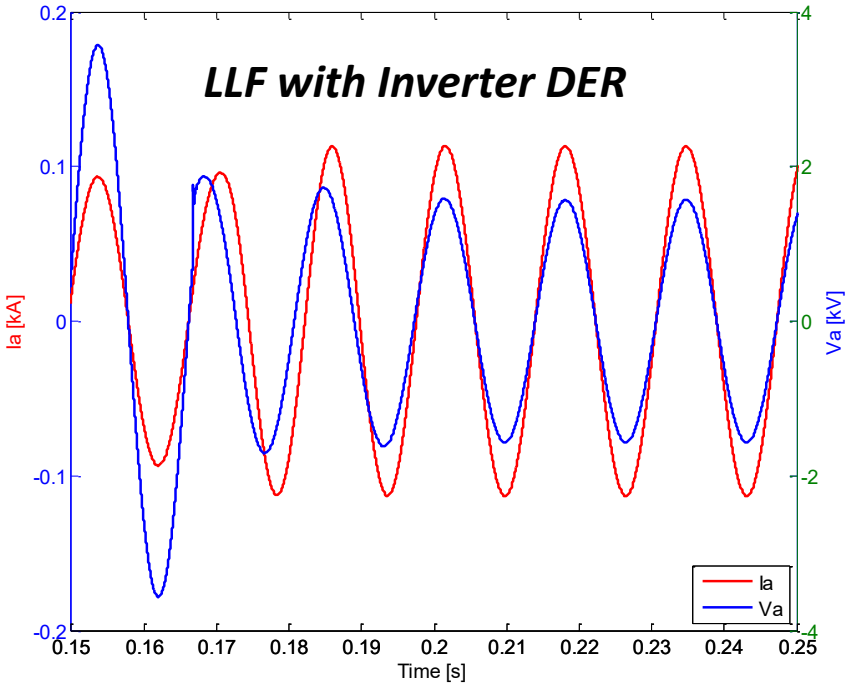
Objective is to protect radial circuits with large quantity of PV compliant to IEEE 1547-2018, without communication.

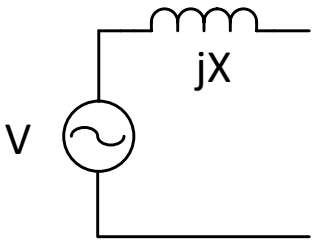


- *{PNNL, ORNL, LANL} Relaying for Distribution and Microgrids Evolving from Radial to Bidirectional Power Flow. 2019. doi:10.2172/1574999*
- *Wieserman et. al., "Test-Based Modeling of Photovoltaic Inverter Impact on Distribution Systems". IEEE PVSC. 2019. doi:10.1109/PVSC40753.2019.8980968*

Inverter-based resource (IBR) contributes lower magnitude but in-phase fault current, compared to rotating machines.







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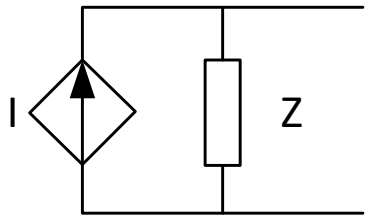
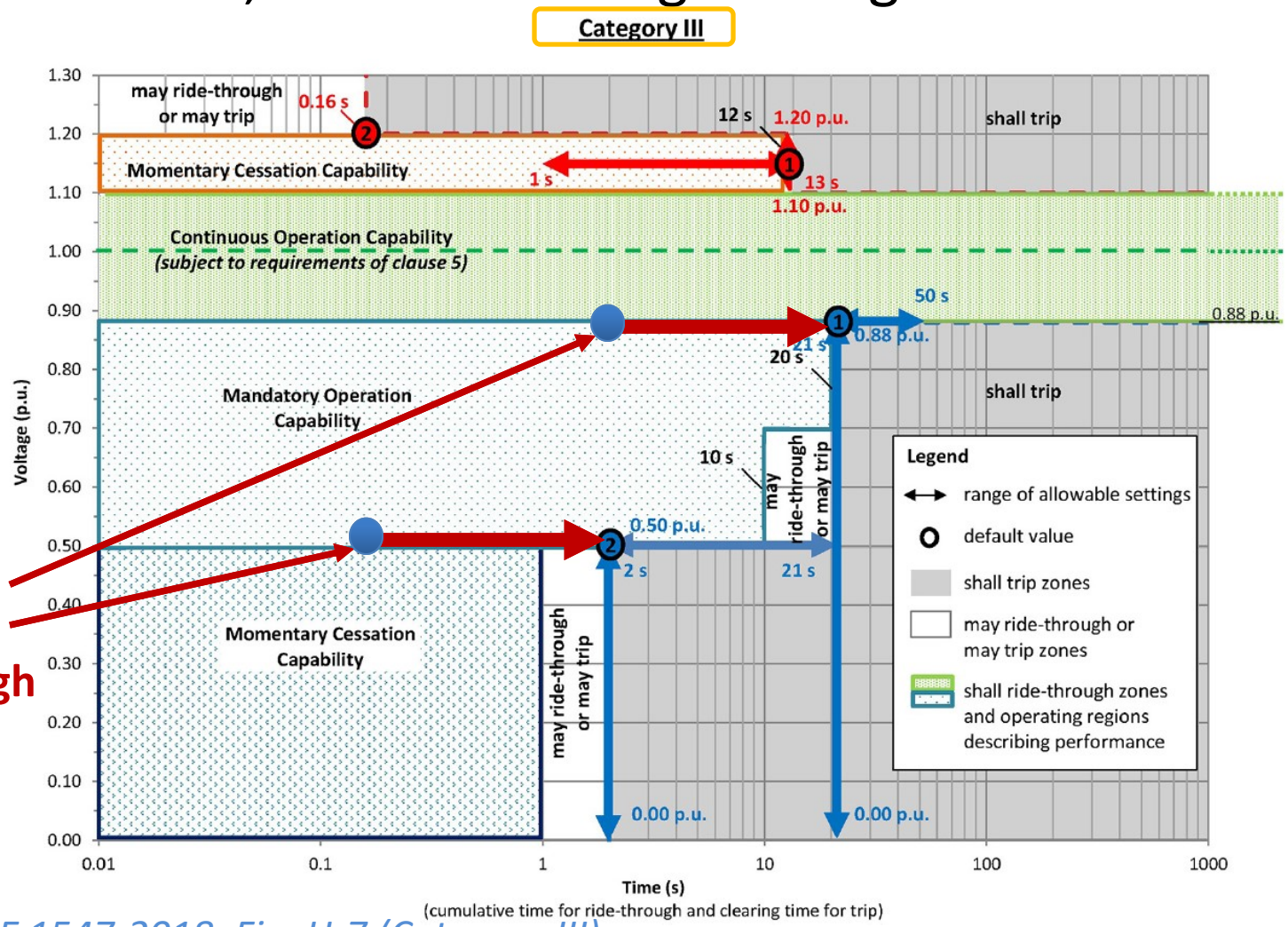


Norton source

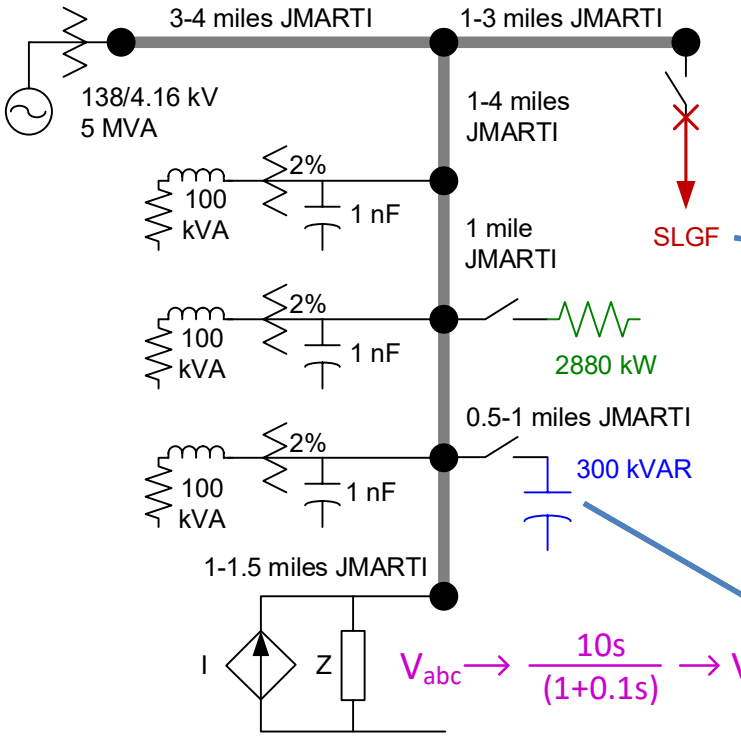
Much distributed PV relied on the undervoltage trip as de facto fault detection, but ride-through changes that.

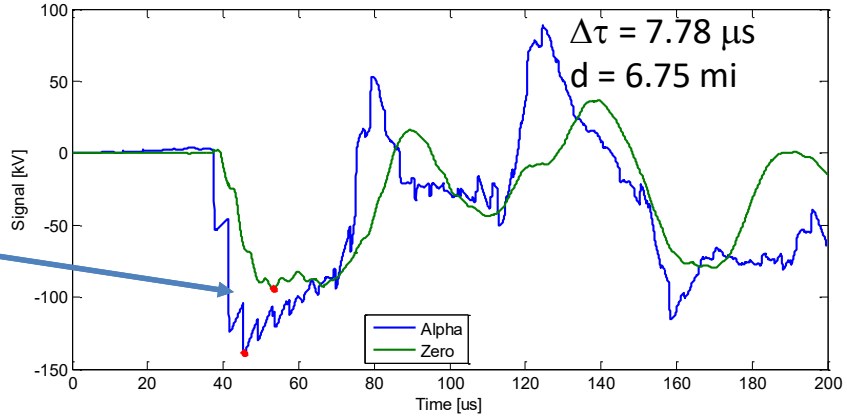
Existing IEEE 1547 Under-voltage Trip Points Were Shifted for Ride-through

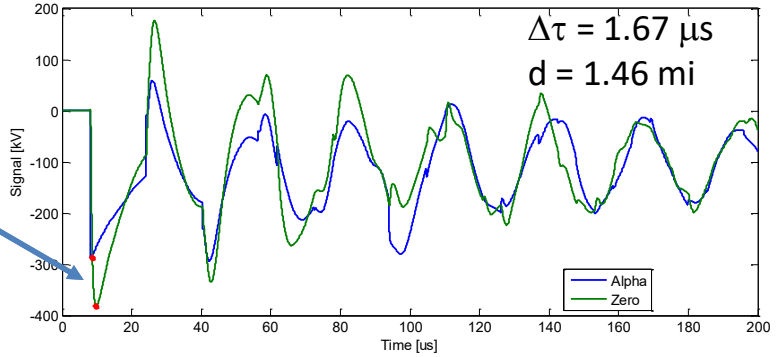


- *IEEE 1547-2018, Fig. H-7 (Category III)*

Traveling wave protection schemes would have to contend with forks, laterals, loads and multi-grounded neutrals.

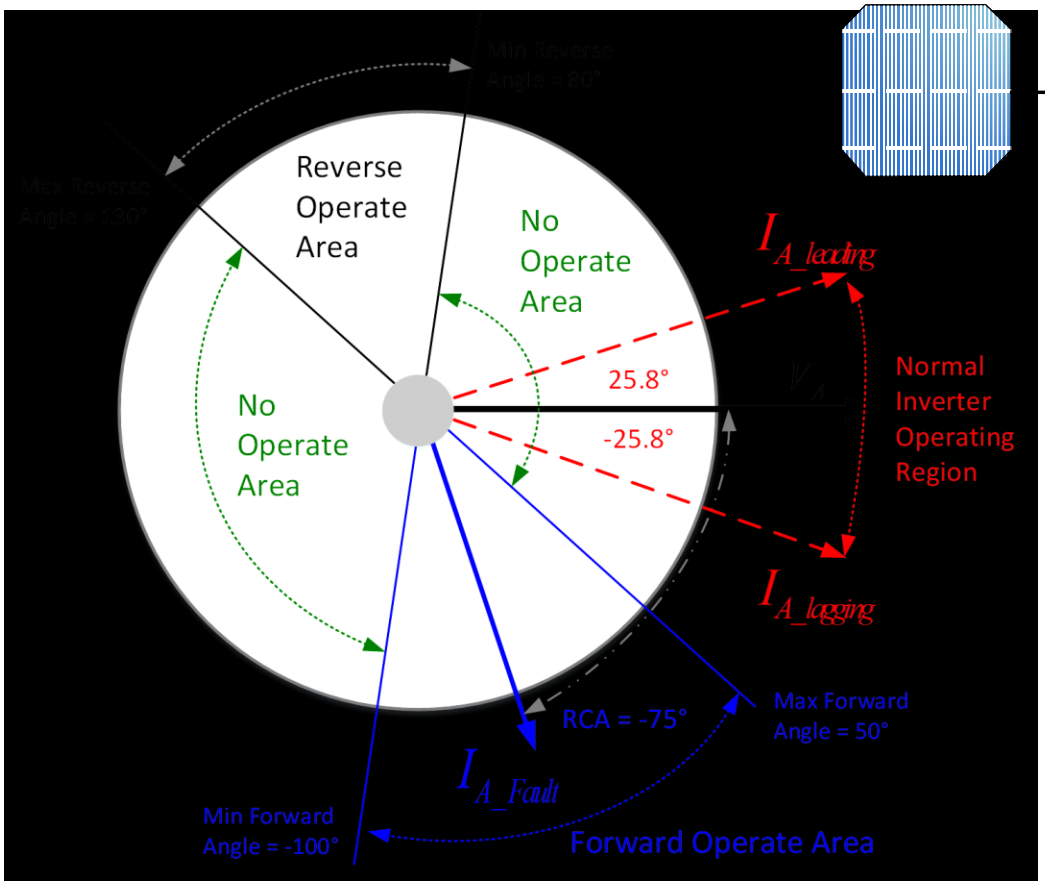


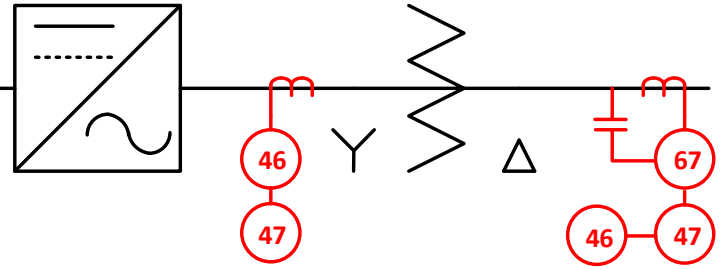


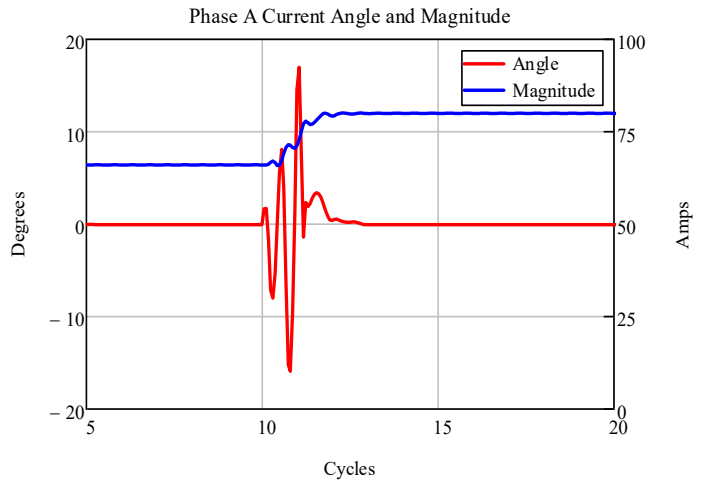


$$d = \Delta\tau / \left(1/v_0 - 1/v_1\right) = 0.8673\Delta\tau \qquad [\text{miles}, \mu\text{s}]$$

Focused directional (67) and negative sequence (46, 47) depend on the inverter and interconnection transformer.

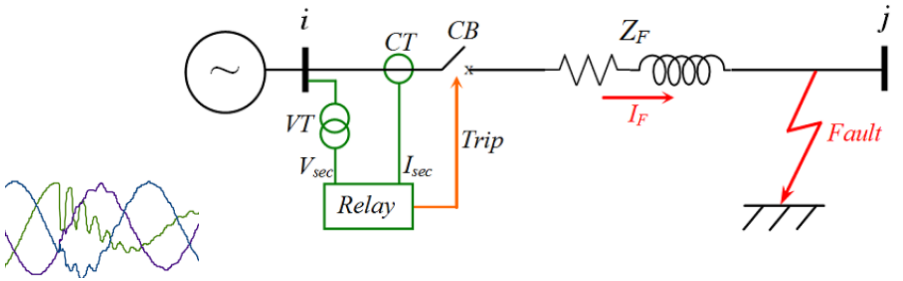


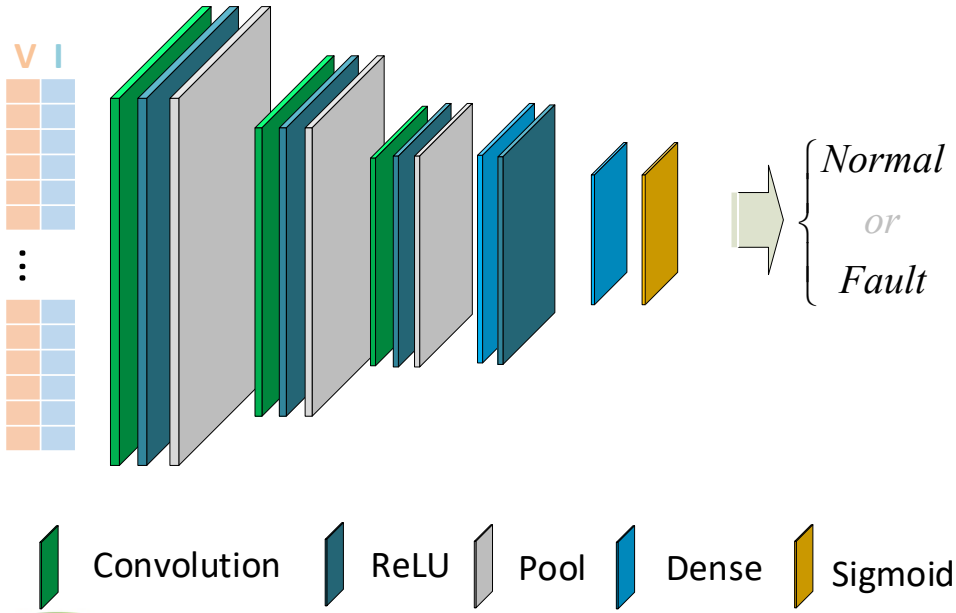


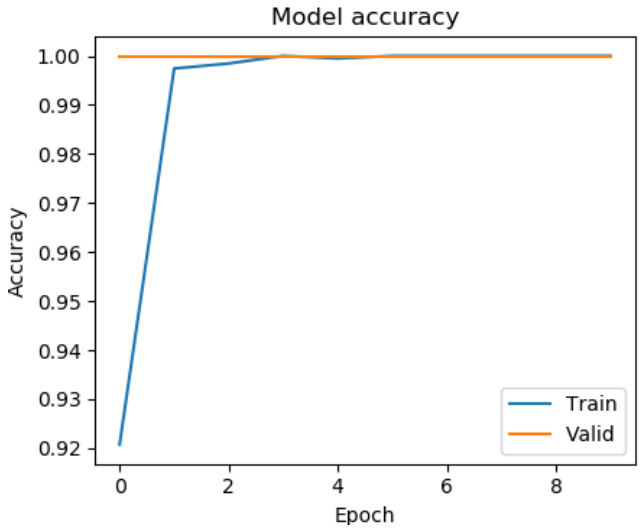


- *Hartmann, "Advanced feeder protection applications." IEEE PPFIC. 2017. doi: 10.1109/PPIC.2017.8003863*

Data-driven scheme uses voltage and current waveforms to recognize faults on IEEE 34-bus test system.





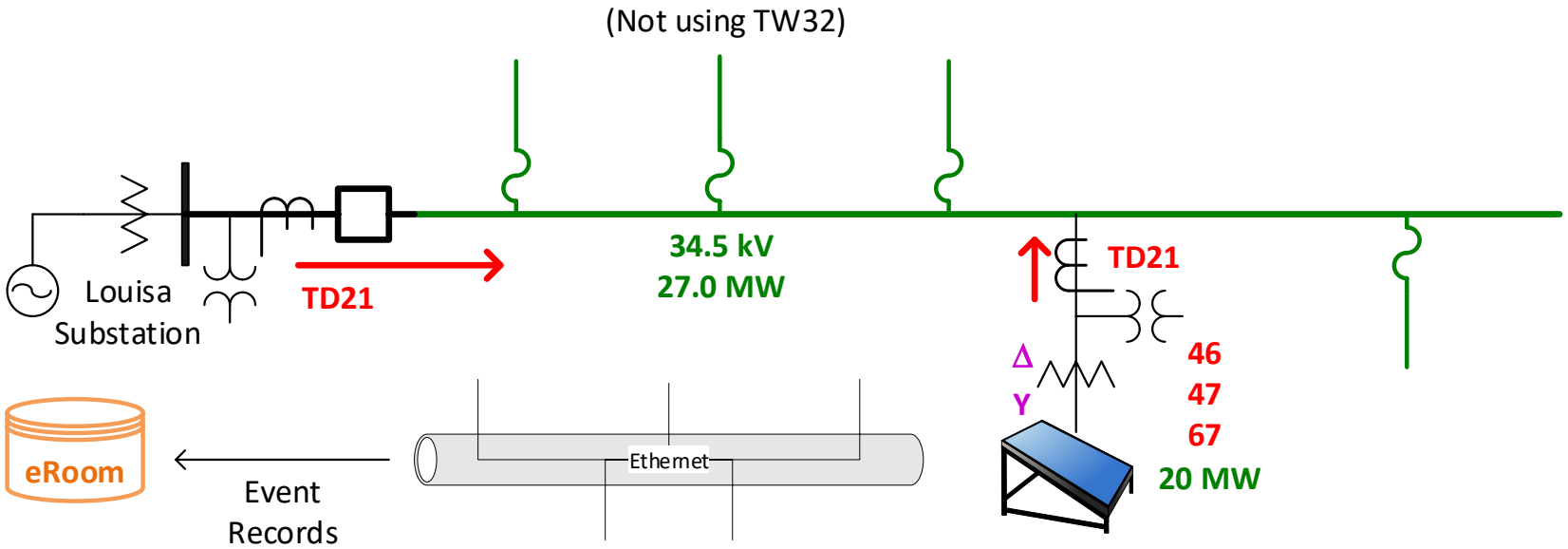


True-Positive is 2099 / 2105	False-Positive is 6 / 2105
False-Negative is 0 / 2935	True-Negative is 2935 / 2935

Test accuracy: 99.88%

- *Work by Rui Fan, now at University of Denver.*

Dominion Energy Virginia field trial of a 20-MW PV connected to a 34.5-kV circuit; 50% of peak load.

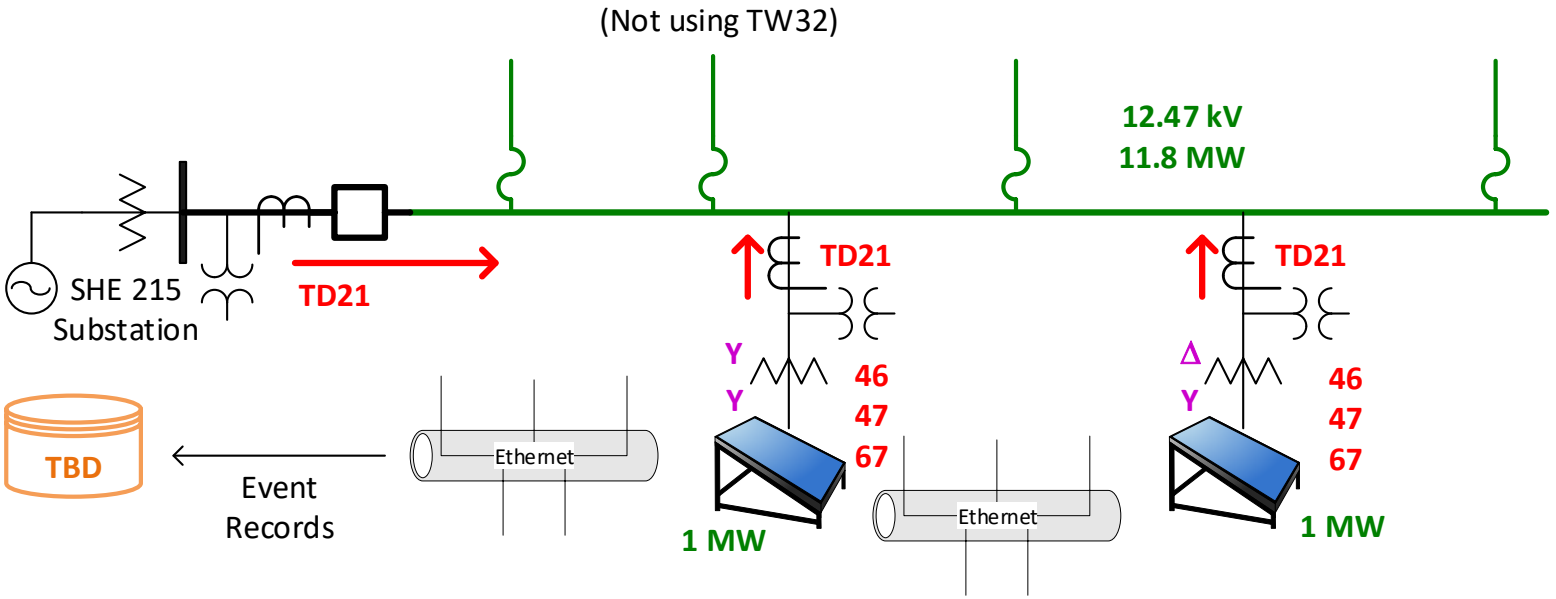


Source: Google Earth.

Some Relevant ANSI Device Numbers

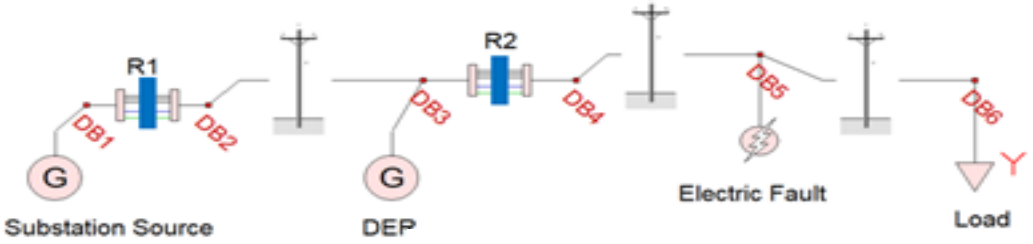
- 21 Line distance, i.e., impedance
- TD21 Time domain distance
- TW32 Traveling wave directional
- 46 Negative sequence current
- 47 Negative sequence voltage
- 67 Directional overcurrent

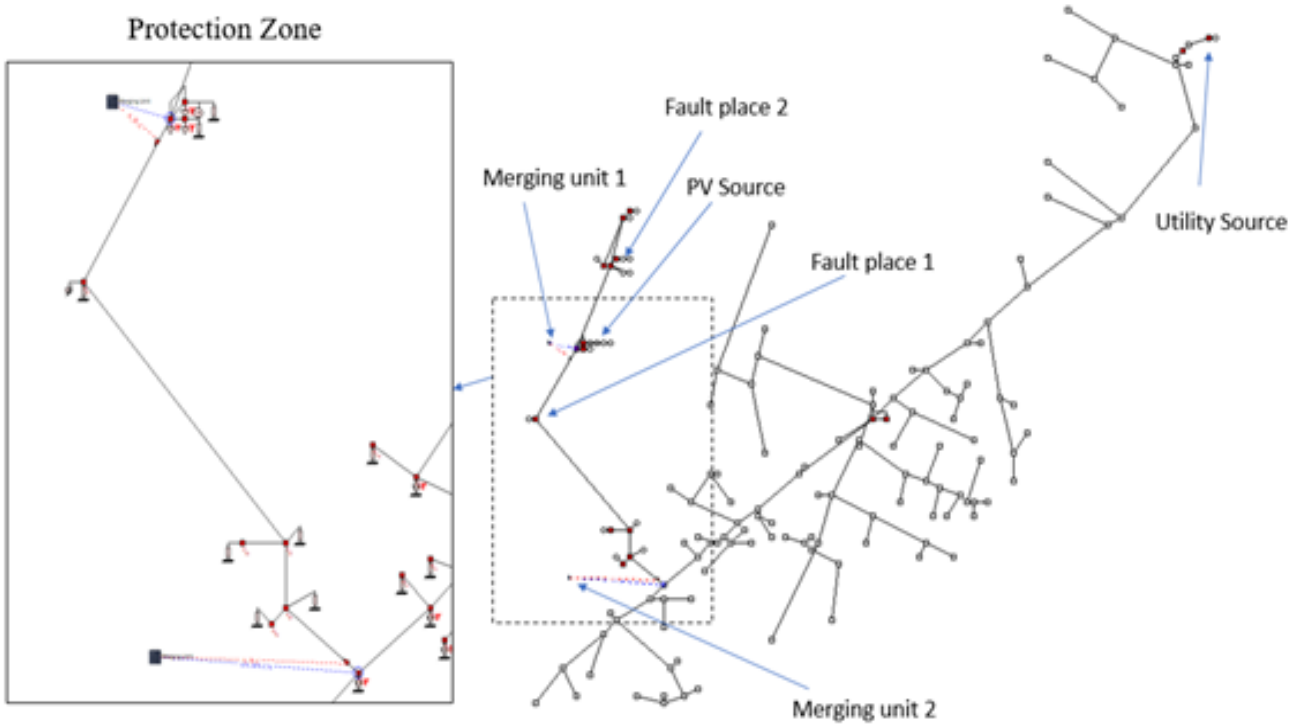
Chattanooga Electric Power Board trial of two 1-MW PV (different interconnect transformers) on 12.47-kV circuit.



Source: Google Earth.

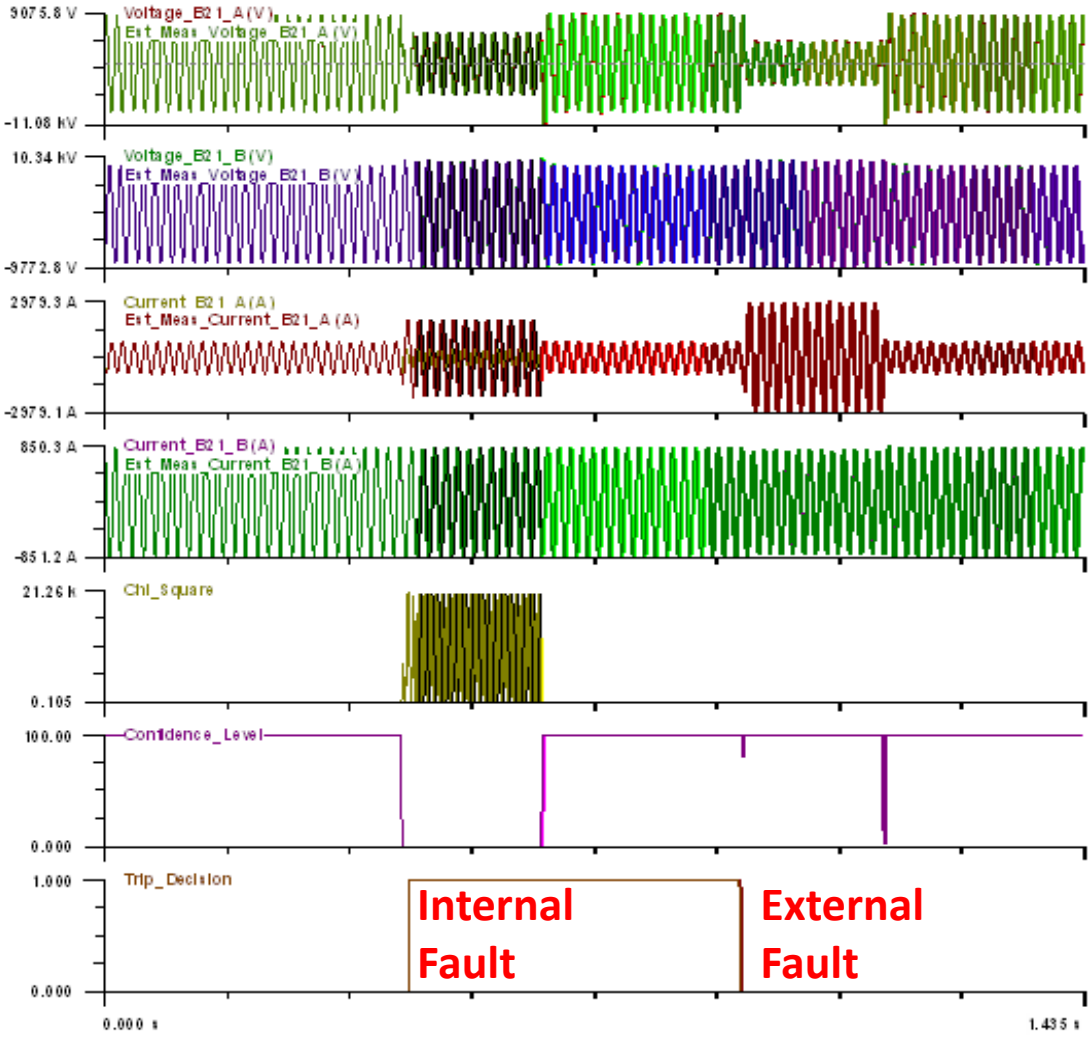
Georgia Tech segmented one of the Chattanooga EPB feeders to analyze estimation-based protection.



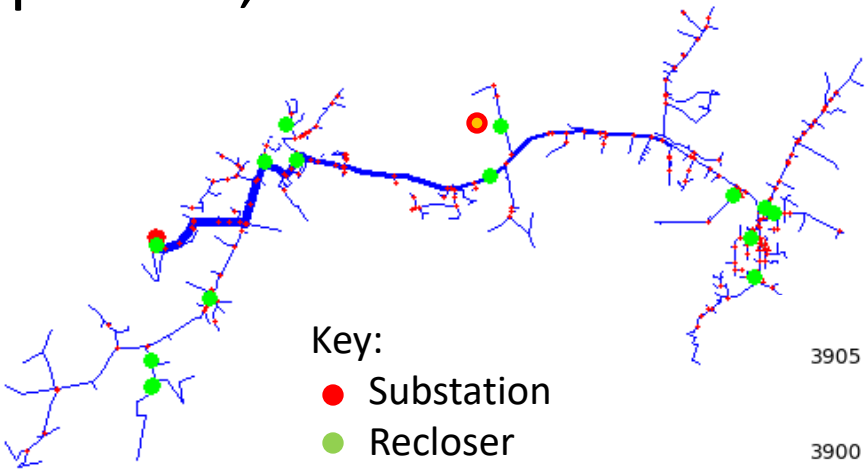


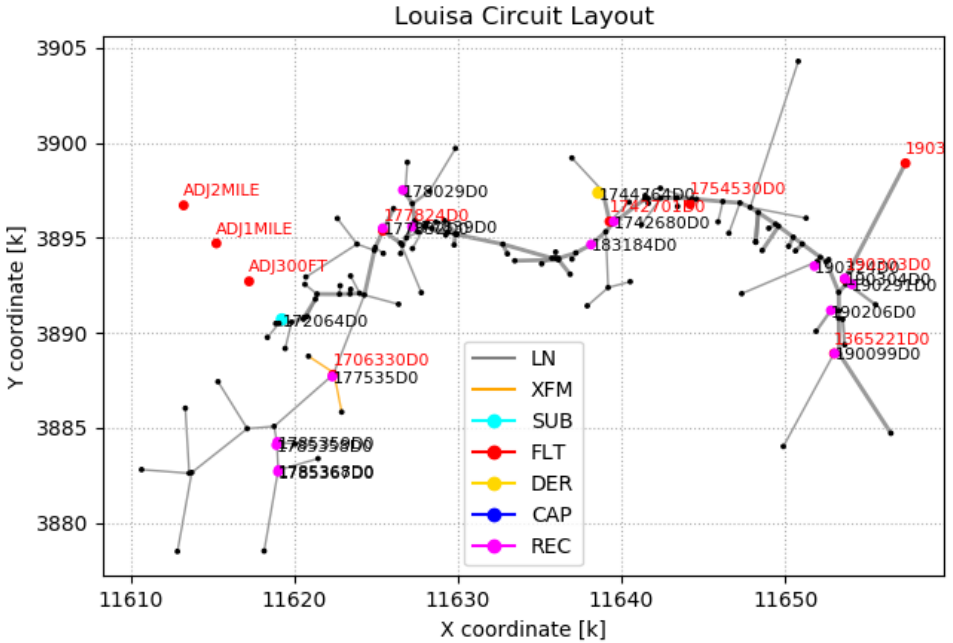
- *Meliopoulos et. al., "Dynamic State Estimation-Based Protection: Status and Promise." IEEE TPWRD. 2016. doi: 10.1109/TPWRD.2016.2613411*

Estimation-based protection discriminated internal and external faults even with incomplete measurements.



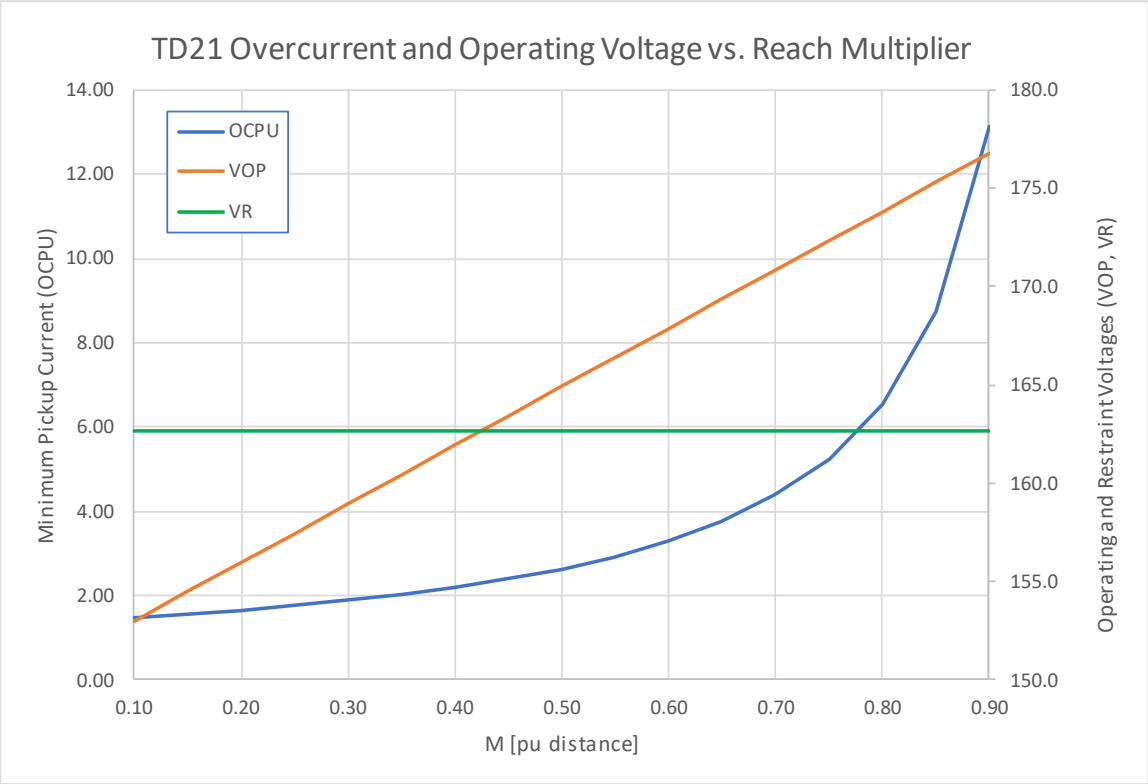
Converting feeder models from two different tools to OpenDSS, then to an electromagnetic transients program.





- *CIMHub, https://github.com/GRIDAPPSD/CIMHub (BSD License)*
- *OpenDSS, https://sourceforge.net/projects/electricdss/ (BSD License)*

With inverter-fed faults, there is a tradeoff between overcurrent supervision and reach of a distance scheme.



TD21 Operating Voltage:

$$V_{OP} = \Delta v - m\left|Z_1\right|\Delta i_z$$

OC21 Supervision:

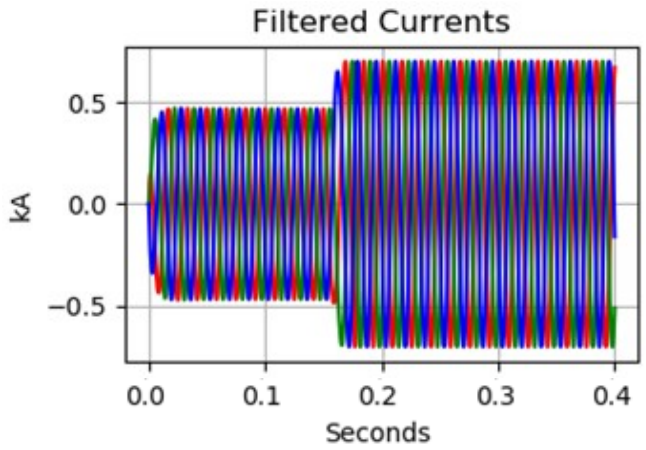
$$\left|\Delta i_z\right| > \frac{V_{\min}}{(1-m)\left|Z_1\right|}$$

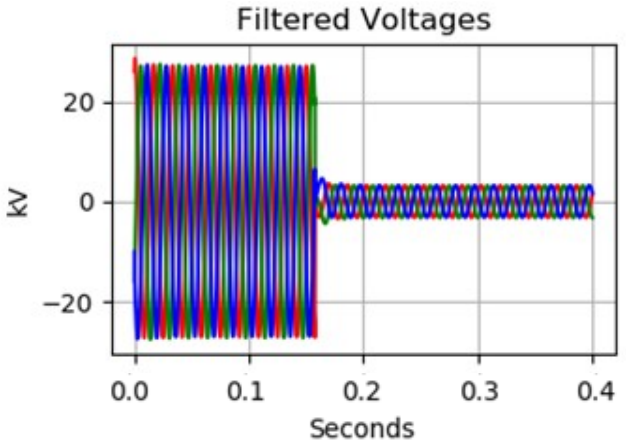
PV Setting Heuristic:

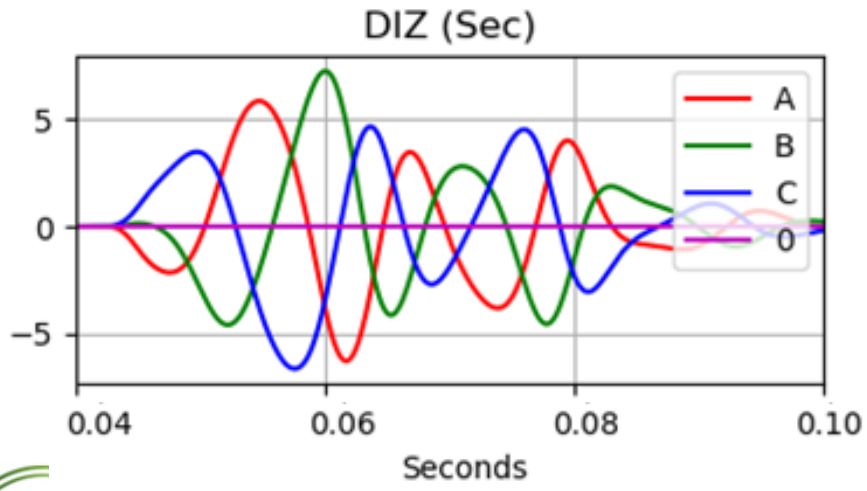
$$Z_1 = \frac{1}{m}(1-\Delta\bar{v})\frac{\sqrt{2}V_{nom}}{\Delta i_z}$$

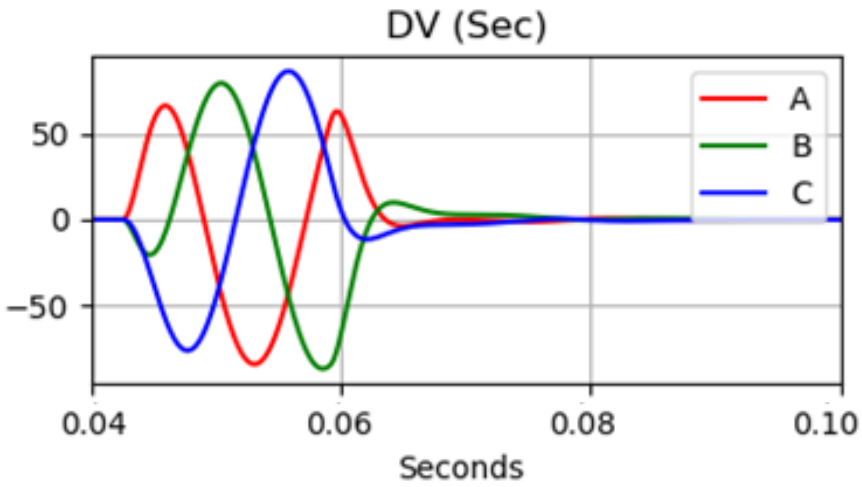
- *Schweitzer and Kasztenny, "Distance Protection: Why Have We Started with a Circle, Does it Matter, and What Else is Out There?" WPRC. 2018. doi: 10.1109/CPRE.2018.8349791*
- *Blumschein et. al., "Directional Comparison Based on High-Speed-Distance Protection using Delta Quantities." Western Protective Relay Conference (WPRC). 2014.*

Incremental voltages and currents based on a 1-cycle memory and with filtering.

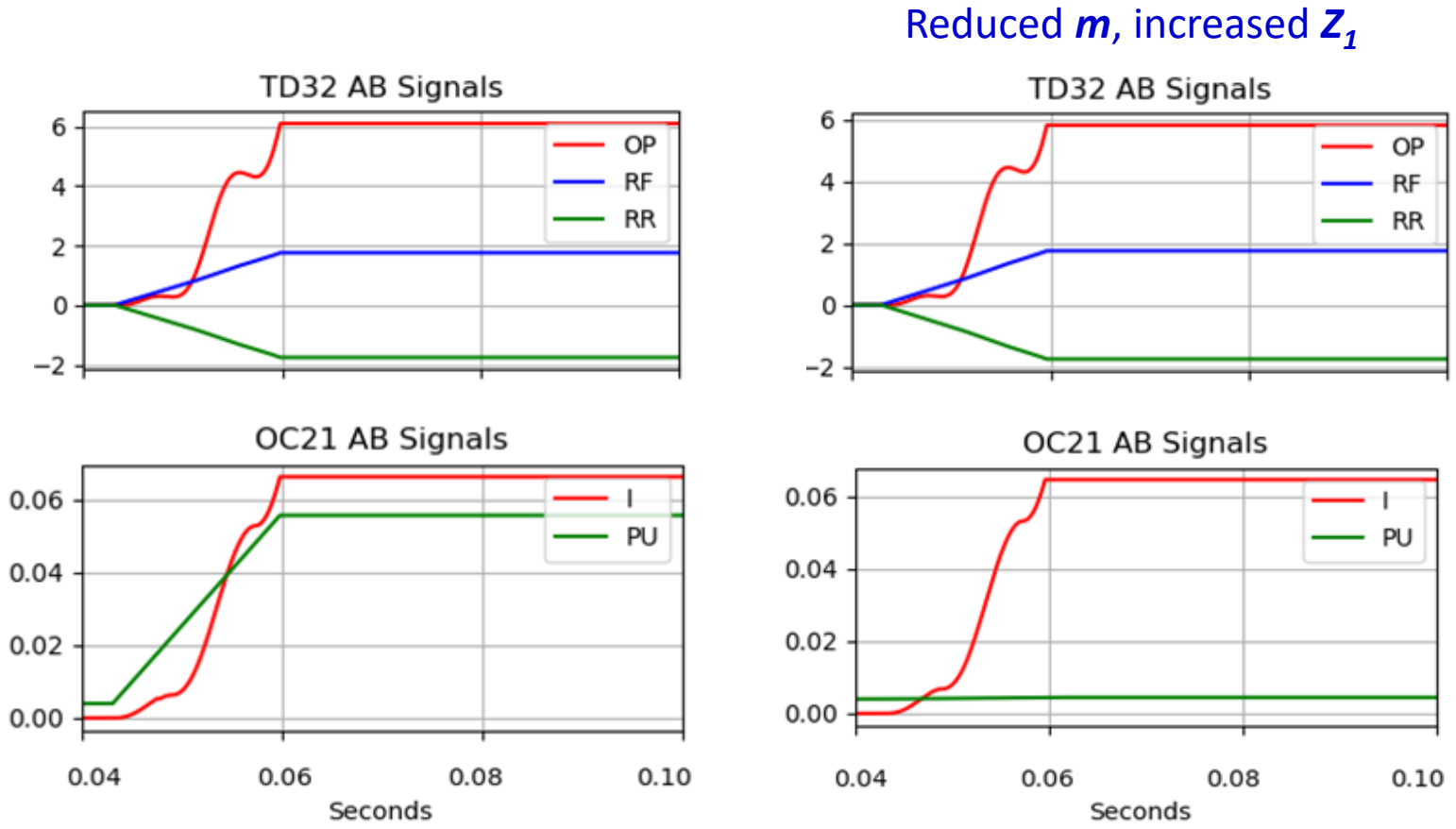






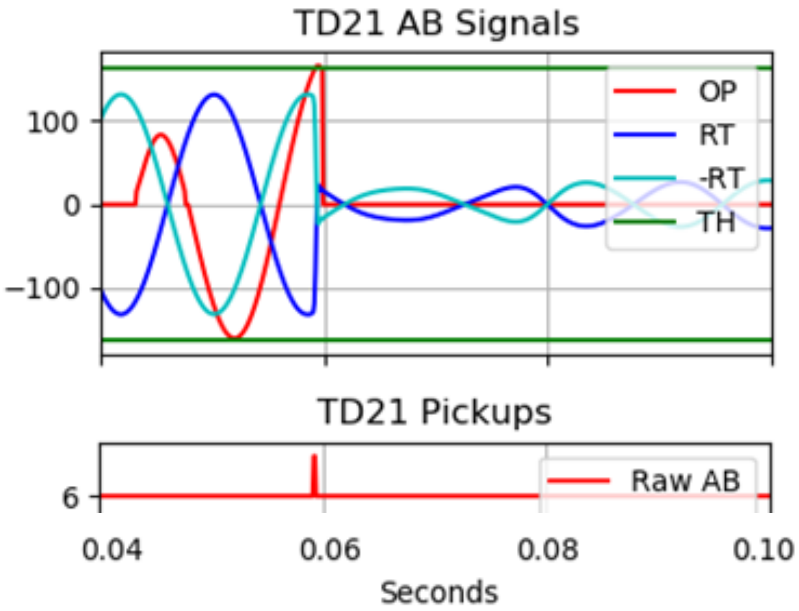


Altered settings to improve the overcurrent supervision, i.e., more sensitive, with same directional supervision.

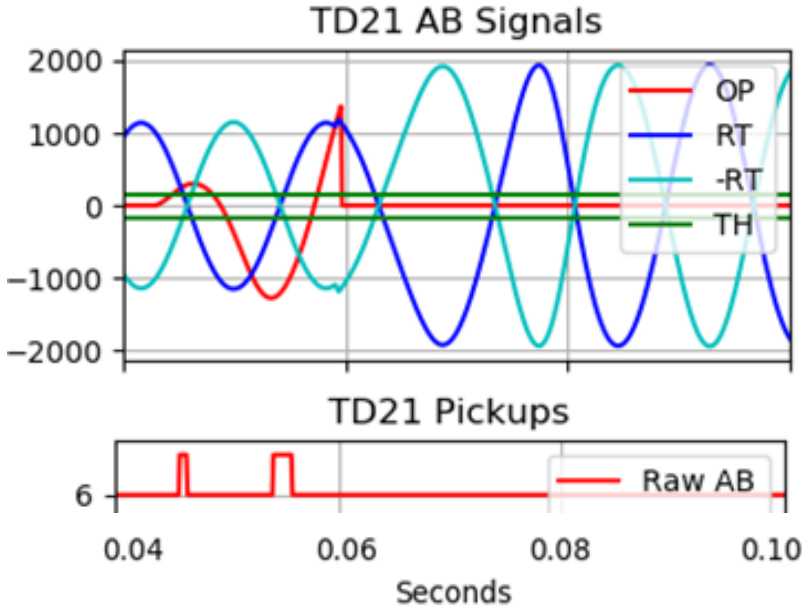


Reduced ***m***, increased Z_1

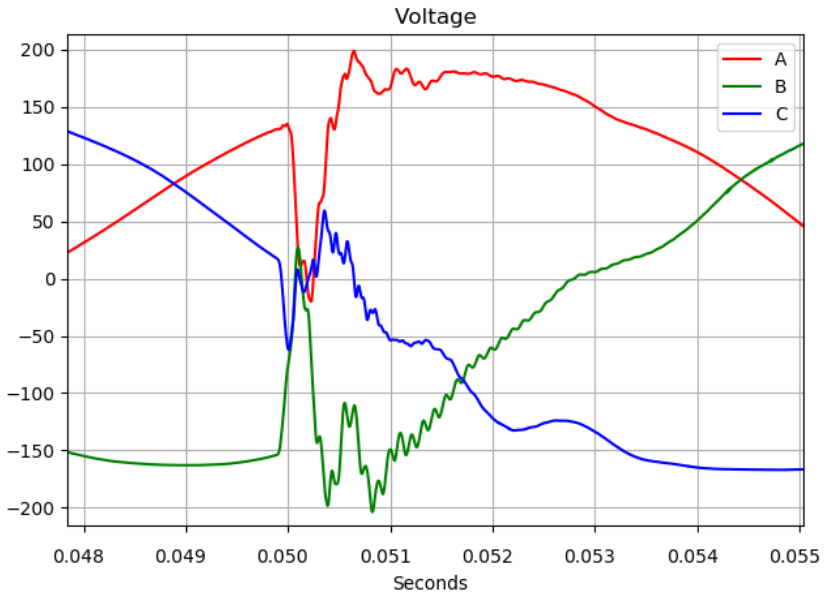
Altered settings to improve the distance pickup, i.e., more sensitive, and the supervised trip function.

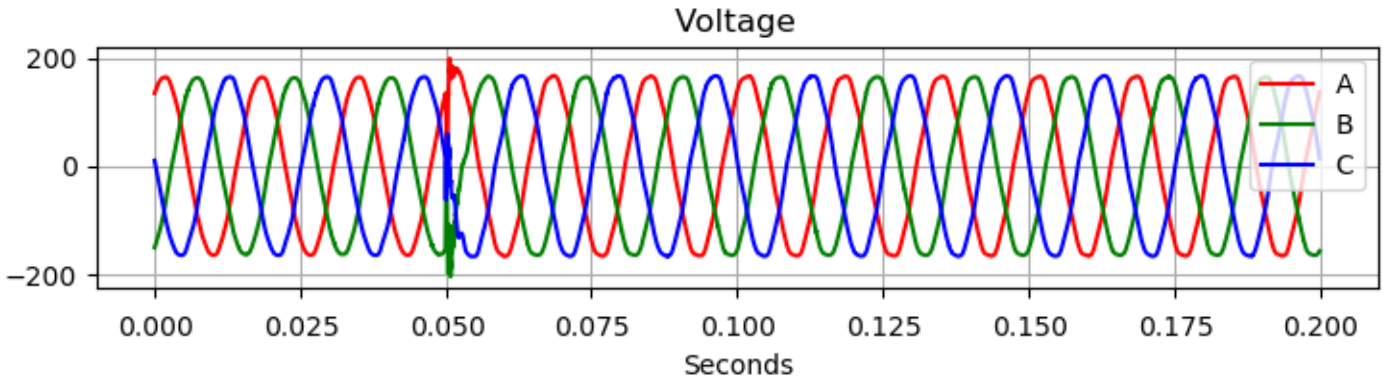


Reduced ***m***, increased Z_1



First record from Dominion PV site detected capacitor switching at the substation, 1 MHz sample rate, no trip.





The project is nearing a conclusion; we are still seeking industry guidance.

- Monitoring through December 31
  - What other use can be made of the high-resolution data?
  - Can we propose changes to IBR fault contributions?
- Industry engagement and technology transfer plans
  - Presentation to IEEE P1547.2; October 5-9
  - Report to be published on OSTI (January – February)
  - GA Protective Relay Conference; May 5-7, 2021
  - Publish new open-source relay models in OpenDSS
  - Can we publish the transient model converters?

QUESTIONS