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Impact of Modeling Assumptions on Traveling Wave Protective Relays in Hardware in the Loop

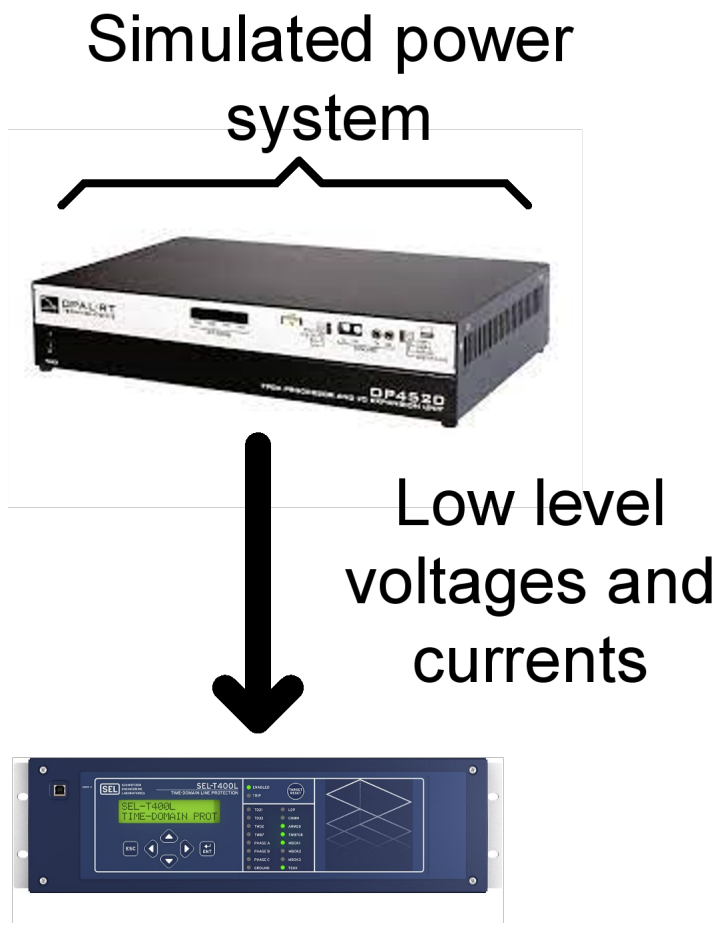
Javier Hernandez-Alvidrez

Sandia National Laboratories

jherna4@sandia.gov

Introduction

- **Legacy distance protection schemes are starting to transition from impedance-based to time-based using traveling wave (TW) detections.**
  - Control Hardware in the Loop (CHIL) simulations have become a common practice before commissioning a device into a power grid.
  - We incorporated a commercially-available TW relay into a CHIL for transmission-level simulations to illustrate some limitations when combining different types of transmission lines models.
  - Under specific simulation conditions, the TW relay was not able to give an accurate fault location.



Brief Analytical Background

- Traveling wave phenomena in transmission lines is described by:

$$\frac{\partial^2 V}{\partial x^2} = LC\frac{\partial^2 V}{\partial t^2}$$

$$\frac{\partial^2 I}{\partial x^2} = LC\frac{\partial^2 I}{\partial t^2}$$

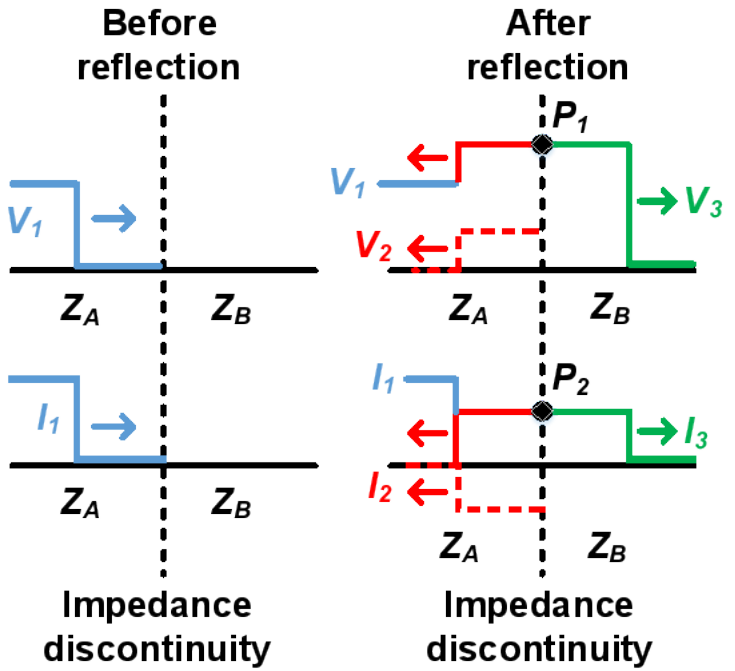
- Whose solution is given by the classical D'Alembert formulas:

$$I(x,t) = f_1(x - vt) + f_2(x + vt)$$

$$V(x,t) = Z_0 f_1(x - vt) - Z_0 f_2(x + vt)$$

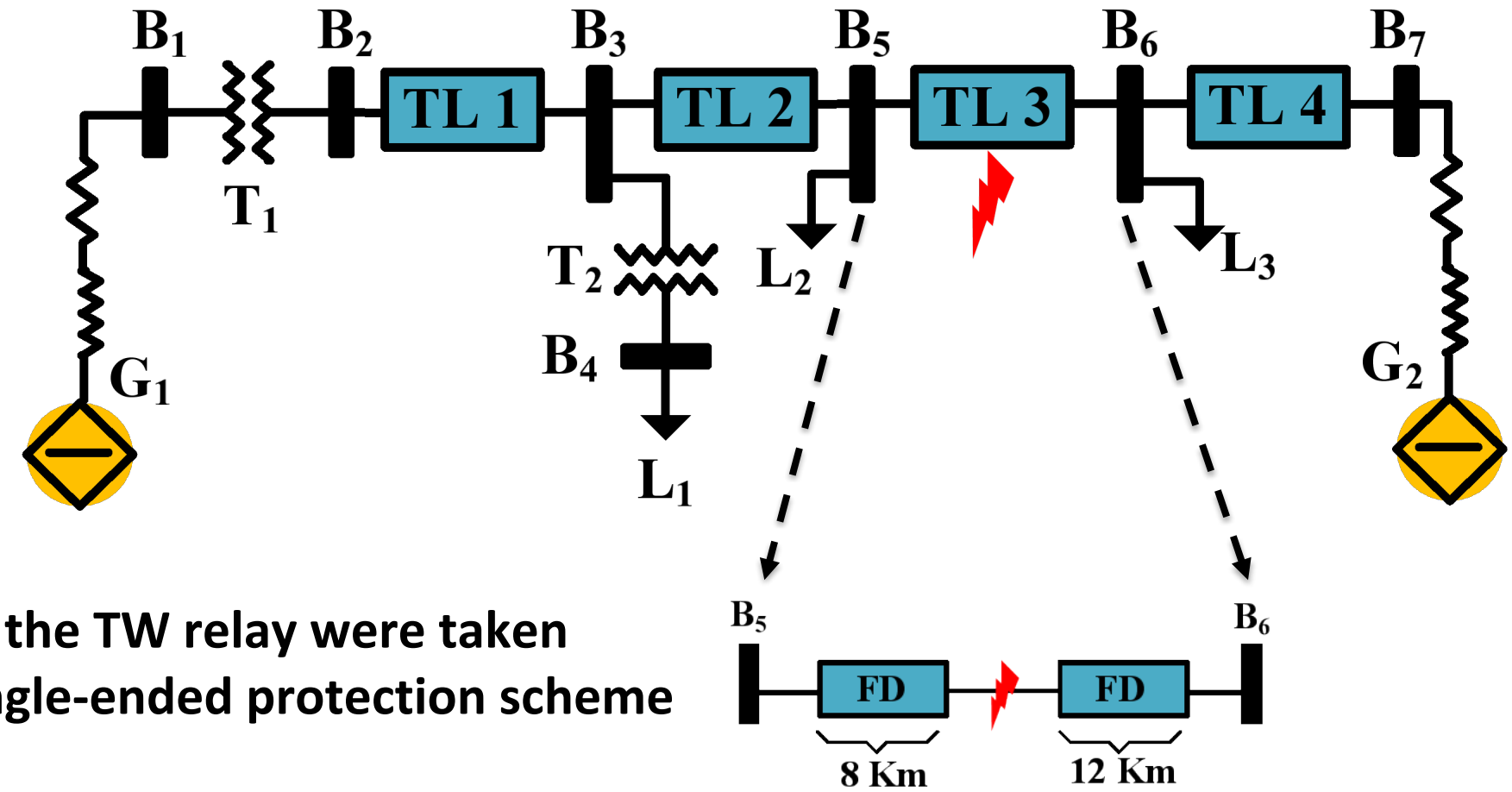
- Where $\boldsymbol{v}$ is the propagation speed of the TW, and $\boldsymbol{Z_0}$ is the characteristic impedance.

- If a TW encounters an impedance discontinuity, it experiences a change in amplitude, followed by the initiation of a reflected and refracted TW.



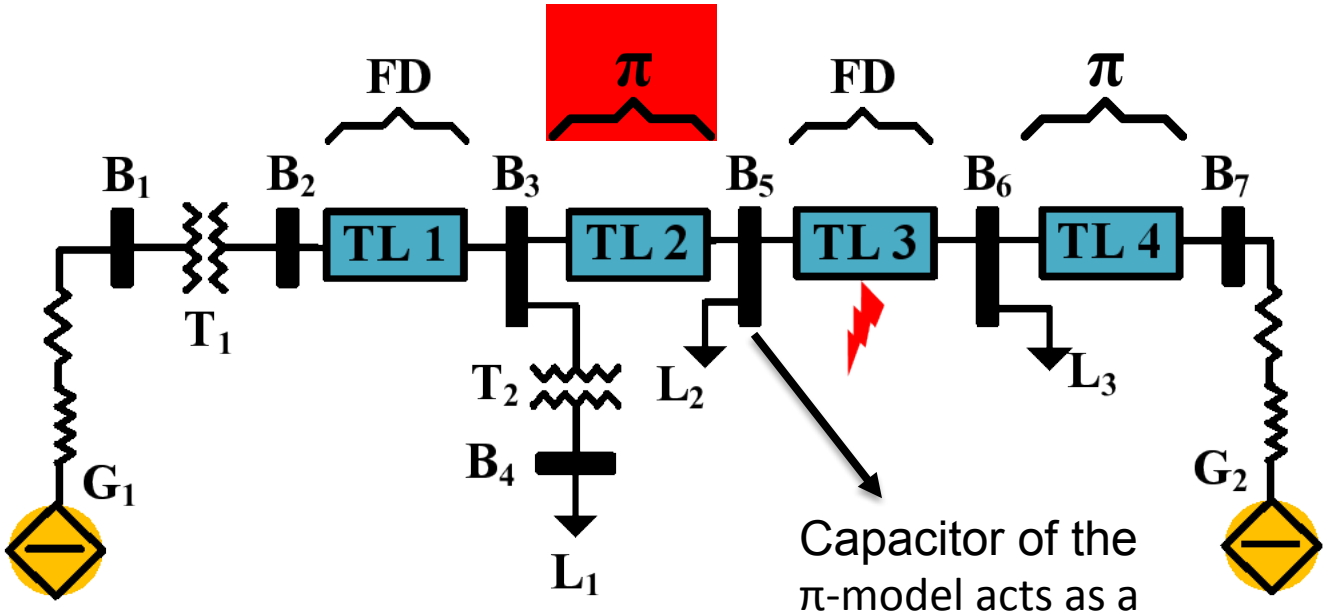
Simulated Power System

- The following power system was simulated in: Simulink (HIL setup), ATP, and PSCAD.



Measurements for the TW relay were taken at Bus B5, using single-ended protection scheme

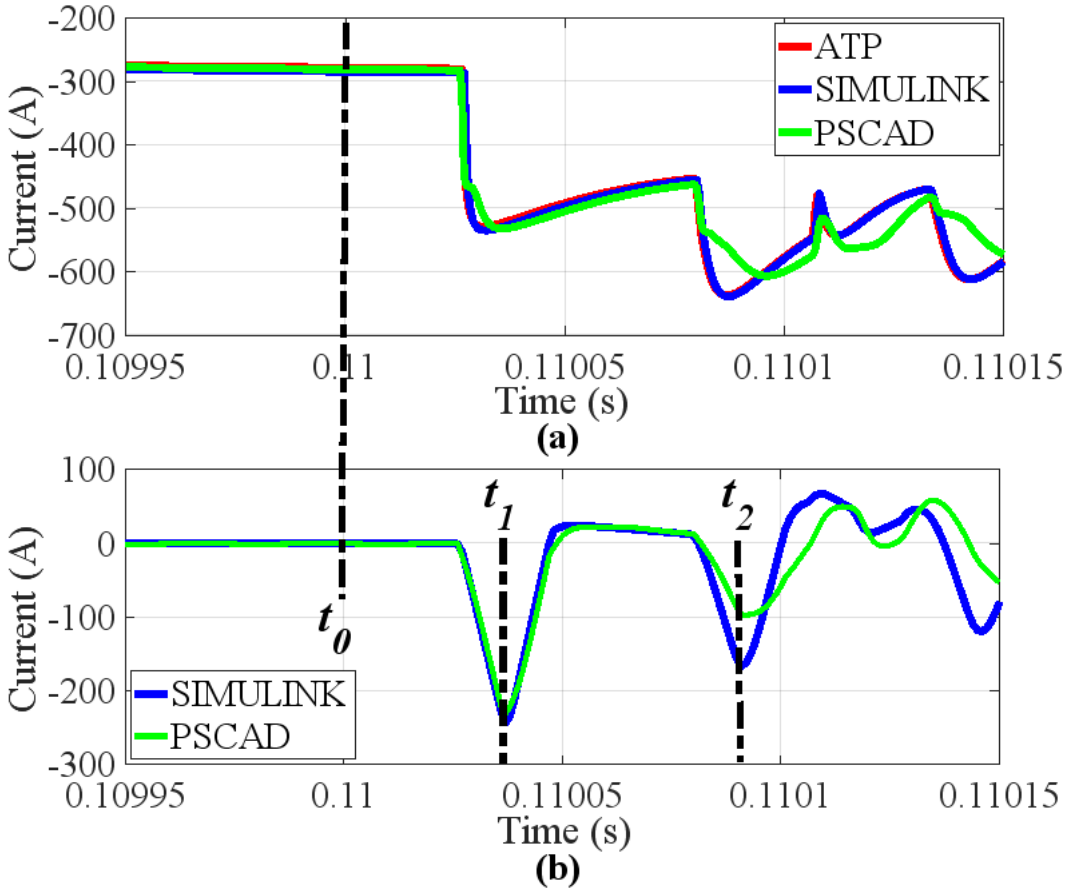
Results (Simulation Case #1). Correct Fault Location.



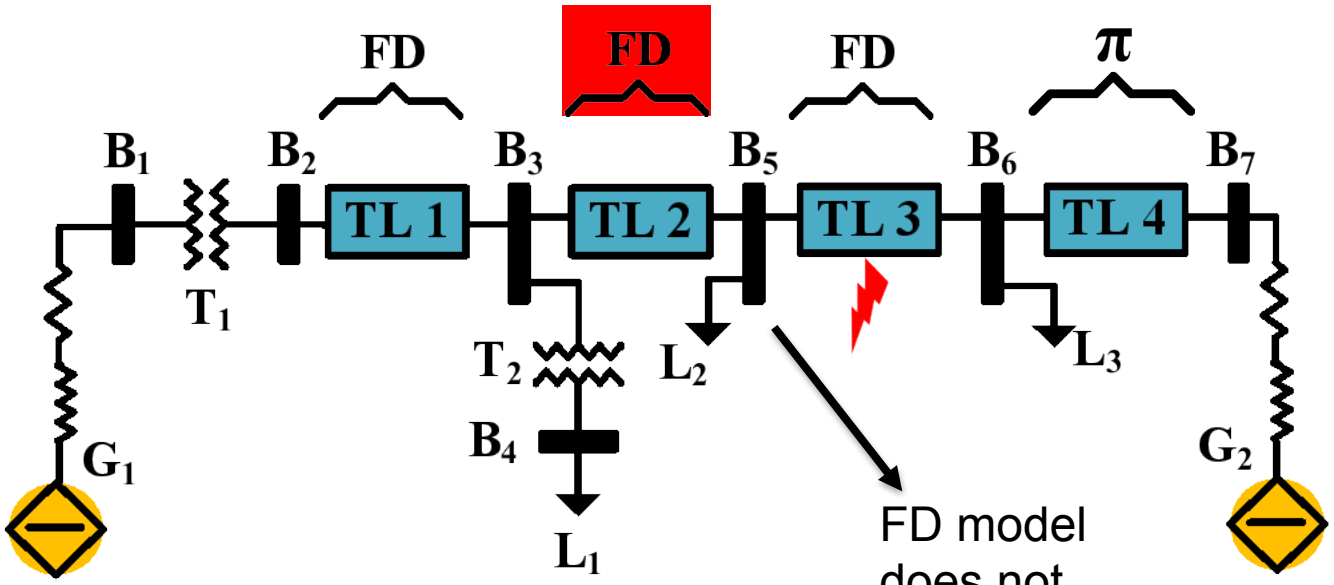
Capacitor of the π-model acts as a good reflective element at Bus B5

- t_0 = 0.11 s (fault inception).
- t_1 = 0.1100906 s (first TW arrival).
- t_2 = 0.1100363 s (reflection arrival).

$$d = \frac{t_2 - t_1}{2} \cdot \mathrm{v} = 8.06\ \mathrm{km}$$

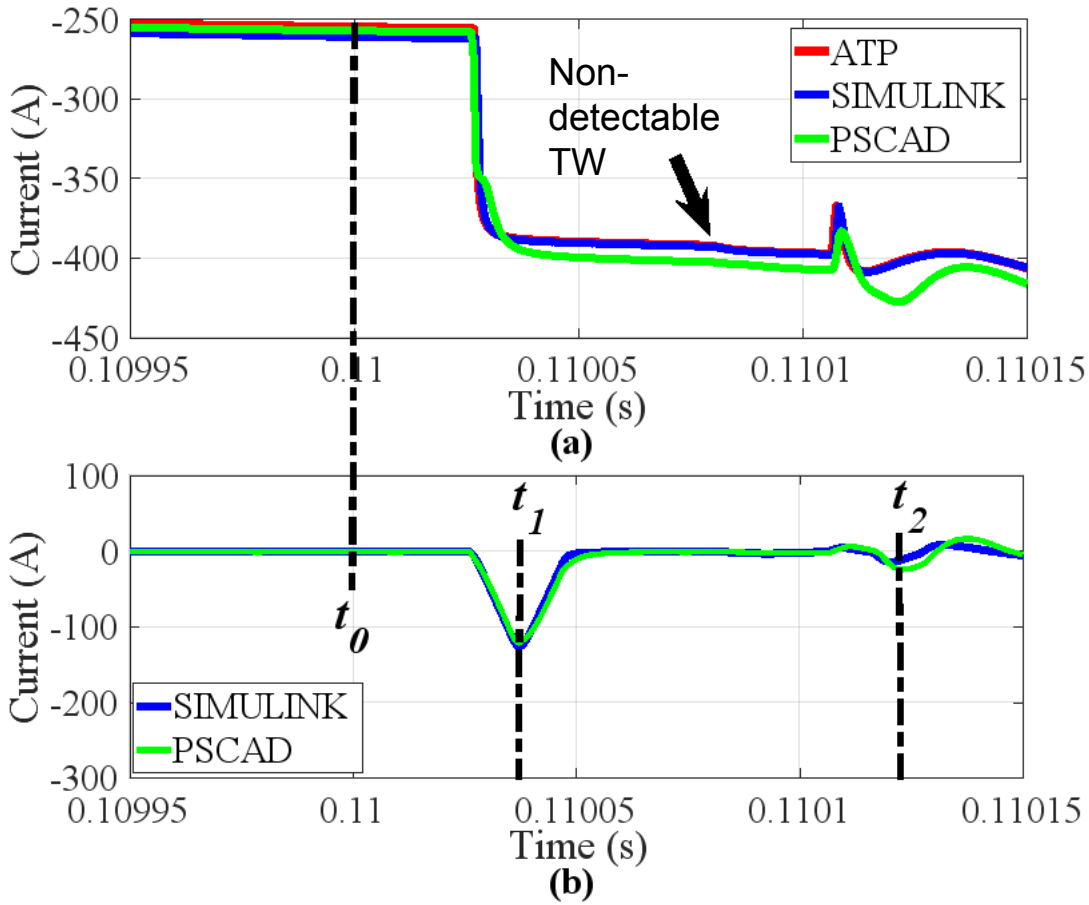


Results (Simulation Case #2). Failure to Detect Correct Fault Location.



- t_0 = 0.11 s (fault inception).
- t_1 = 0.1100365 s (first TW arrival).
- t_2 = 0.110123 s (reflection arrival).

$$d = \frac{t_2 - t_1}{2} \cdot \mathbf{v} = \mathbf{12.8\ km}$$



Conclusions/Recommendations

- With the aid of real-time and offline simulations, results pointed out the effects that different circuit elements can have over TWs reflections.
- Qualitative analyses showed that under certain operating conditions and simulation assumptions (transmission line models), the arrival of TWs might not be detected.
- Under single-ended protection schemes , the relay will calculate the wrong fault location if the second arrival of TWs are not detected.
- This type of analysis could set the basis when attempting to use TW relays to protect systems with transmission lines connected in series.