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

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Introduction:

- Legacy distance protection schemes are starting to transition from impedance-based to time-based using traveling wave (TW) detections.
- 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 HIL for transmission-level simulations to illustrate some limitations when combining different types of transmission lines models and load types.

Brief Analytical Background:

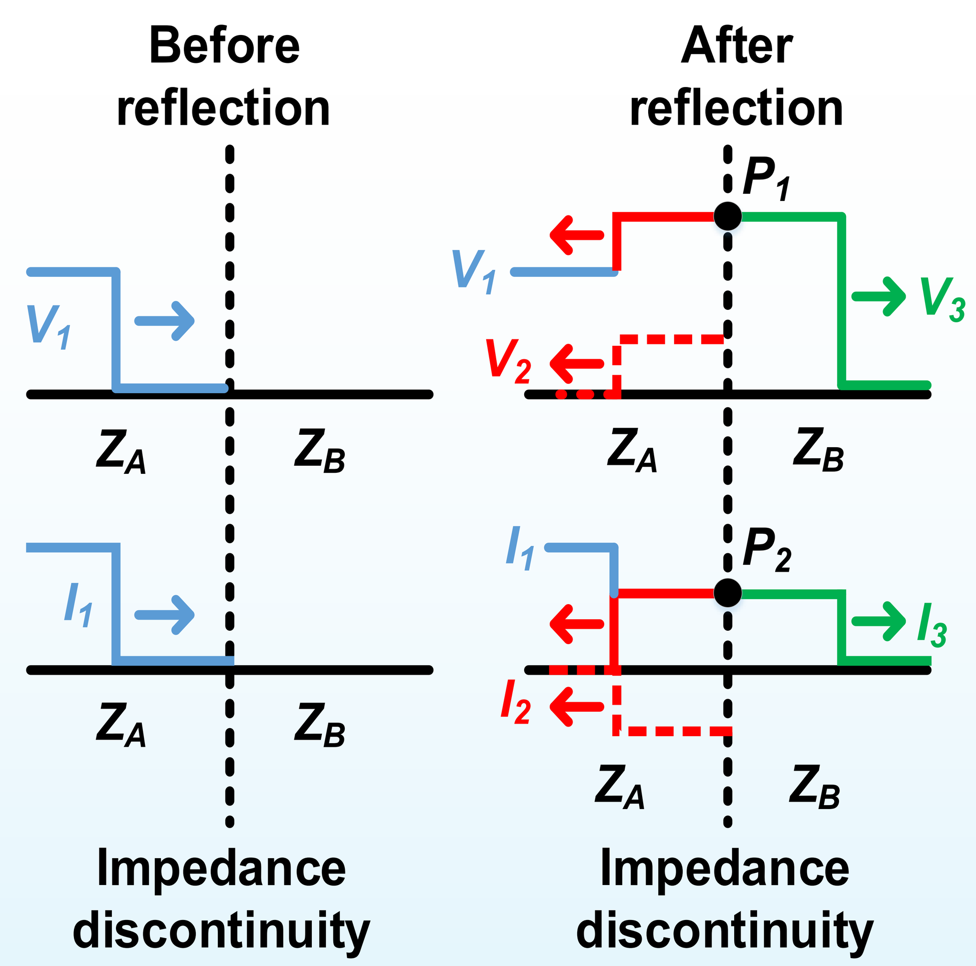
- TWs in transmission lines are described by:

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

- Whose solution is given by:

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

- Impedance discontinuities will cause reflections and refractions of a TW.

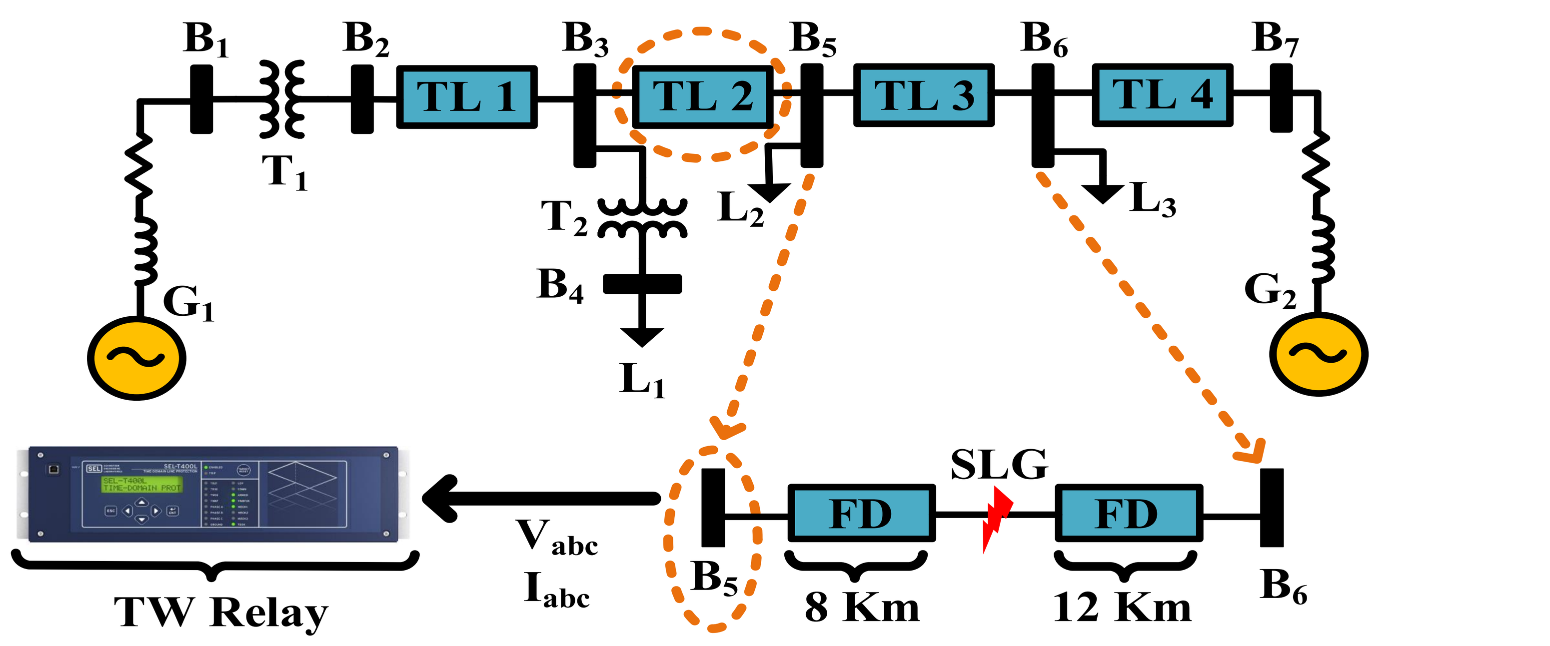


$$a = \frac{Z_B - Z_A}{Z_B + Z_A} \qquad b = \frac{2Z_B}{Z_B + Z_A}$$

Where ***a*** and ***b*** are the reflection and the refraction coefficients.

Simulated Power System:

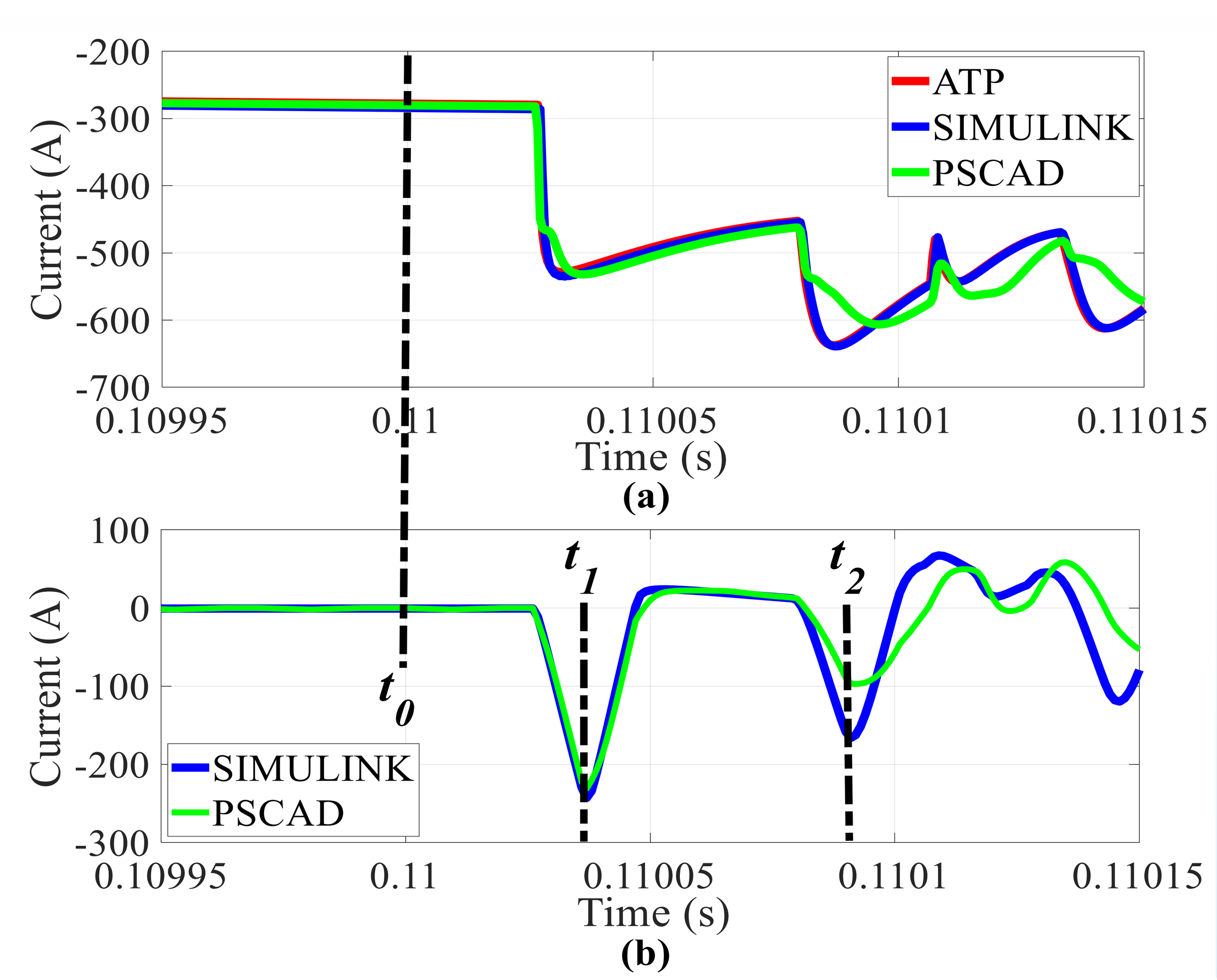
- To validate the results, simulations with a single-line to ground fault (SLG) were performed in three different simulation packages: Simulink (real-time HIL setup), ATP, and PSCAD.



- V_{abc} and I_{abc} were monitored at bus B_5 and sent to the TW relay.
- Changes in the transmission line model TL 2 and the magnitude of load L_2 directly affect the reflection and refraction coefficients in B_5, which can lead to a weak TW reflection point, as depicted in the following simulation cases.

Case 1 (Relay gives the correct fault location):

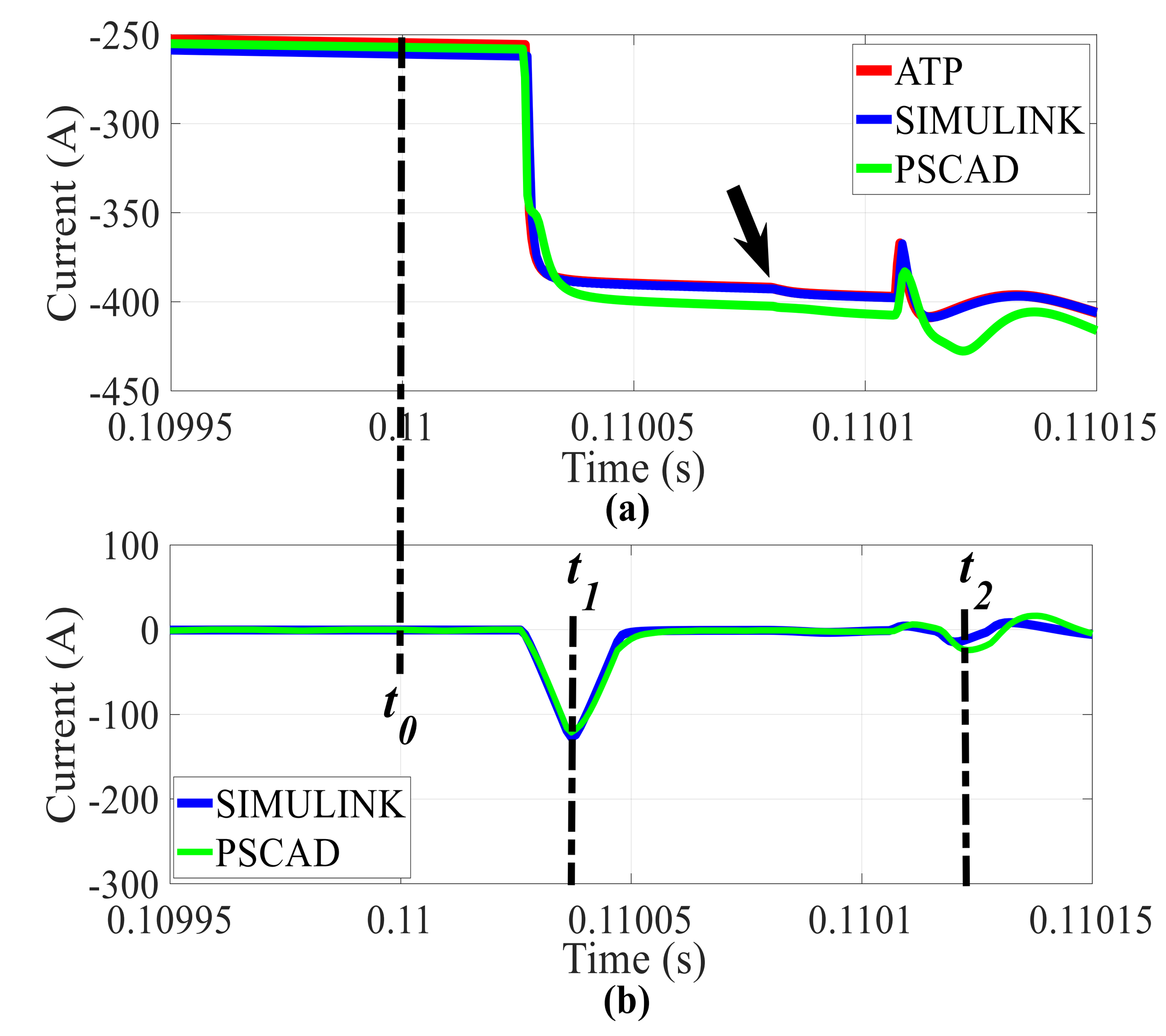
- **TL 2 is modeled as a π-line and L_2 = 2 MW**



From adjacent Figure (b), notice the sharp reflections. The capacitor of the π-model of TL 2 provides a good reflection coefficient at bus B_5.

Case 2 (Relay gives an incorrect fault location):

- **TL 2 is modeled as Frequency Dependent and L_2 = 2 MW**



From adjacent Figure (a), the arrow indicates the arrival of the TW. Notice that the FD model of TL 2 provides a very weak reflection coefficient, which leads to an incorrect fault location provided by the relay.

Conclusions:

- 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.

Future work:

- Once a second relay is available, a double ended protection scheme between B_5 and B_6 will be implemented and tested.

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