HIL TESTING AN ADAPTIVE OUT-OF-STEP PROTECTION ALGORITHM BASED ON WIDE-AREA MEASUREMENTS

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USER SPOTLIGHT SERIES 2.0 BY RTDS Technologies

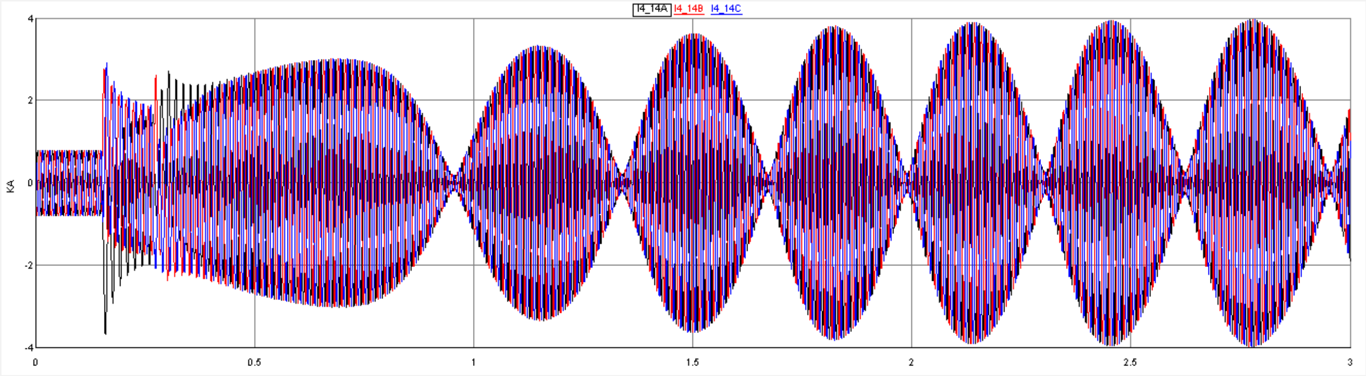
OUTLINE

- What is an out-of-step condition and conventionally used protection.
- The developed adaptive out-of-step protection concept.
- Hardware-in-the-Loop (HiL) test setup.
- Test results.
- Demonstration.

OUT-OF-STEP CONDITION

What is an out-of-step condition?

- Disturbances can propagate into a larger scale event, causing a major imbalance between the mechanical input and electrical output power of generators. This major imbalance can result in a loss of synchronism in the power system and is referred to as an out-of-step (OOS) condition.
- During the OOS condition large oscillations of currents and voltages occur, which cause additional mechanical and thermal stresses on power system components.



OUT-OF-STEP CONDITION

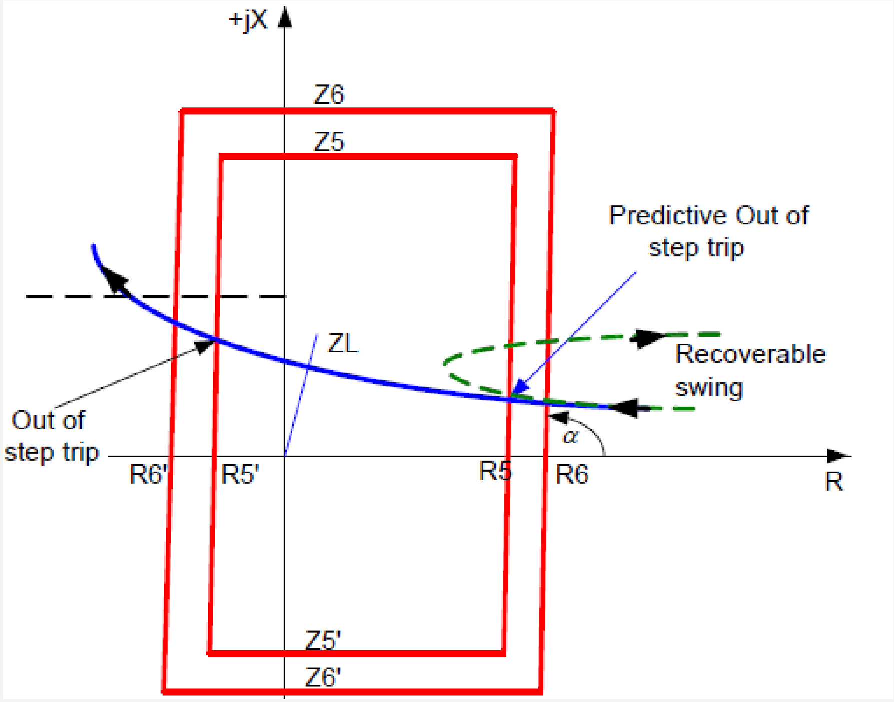
Protection?

- The conventional OOS protection is realized by impedance relays which use the apparent impedance seen by the relay to detect an OOS condition.

- These relays require functional settings to function properly.

- With more renewable energy sources being integrated into the power system, the generator composition becomes harder to predict. This complicates the calculation of settings further.

- A new OOS protection algorithm, using wide-area measurements is proposed and tested.



THE DEVELOPED ADAPTIVE ALGORITHM

How it works?

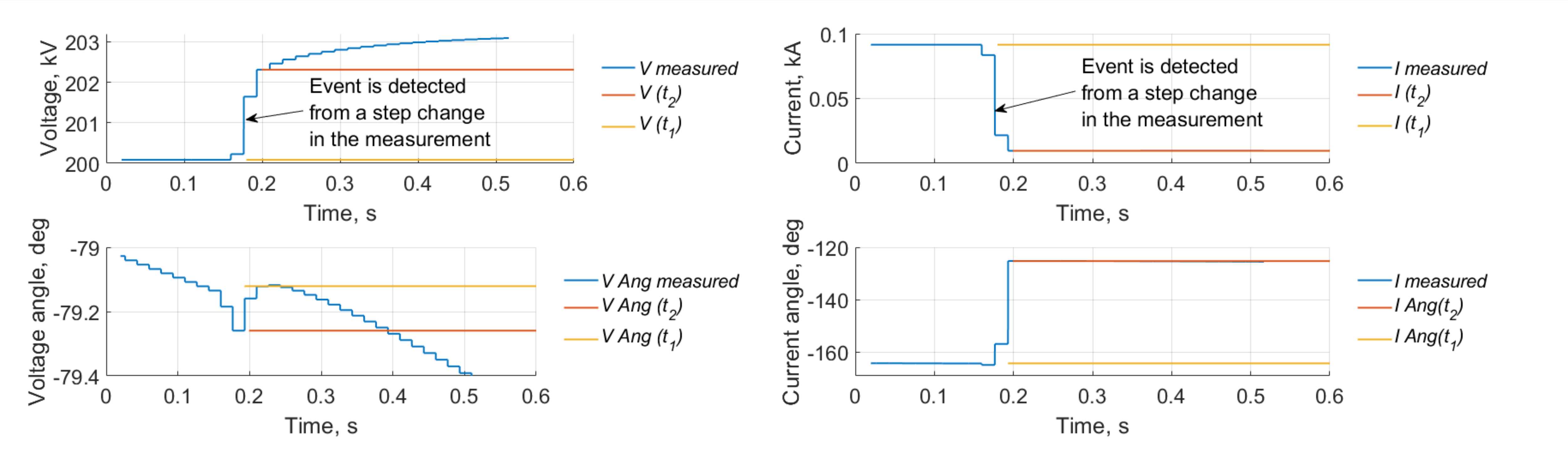
- The goal is to develop an easily implementable out-of-step tripping algorithm that is adaptive in real-time and requires minimal settings.
- The developed algorithm relies on the computation of system impedances seen from remote ends of a transmission line.
- To compute the system impedances on seen from the remote ends of transmission lines the following equation is used [1]:

$$\underline{Z}_{eq} = \frac{\underline{V}(t_2) - \underline{V}(t_1)}{\underline{I}(t_2) - \underline{I}(t_1)} = -\frac{\Delta \underline{V}}{\Delta \underline{I}}$$

[1] K. O. H. Pedersen, A. H. Nielsen, and N. K. Poulsen, “Short-circuit impedance measurement,”IEE Proceedings - Generation, Transmissionand Distribution, vol. 150, no. 2, pp. 169–174, 2003.

THE NEW ADAPTIVE ALGORITHM (1)

How it works?

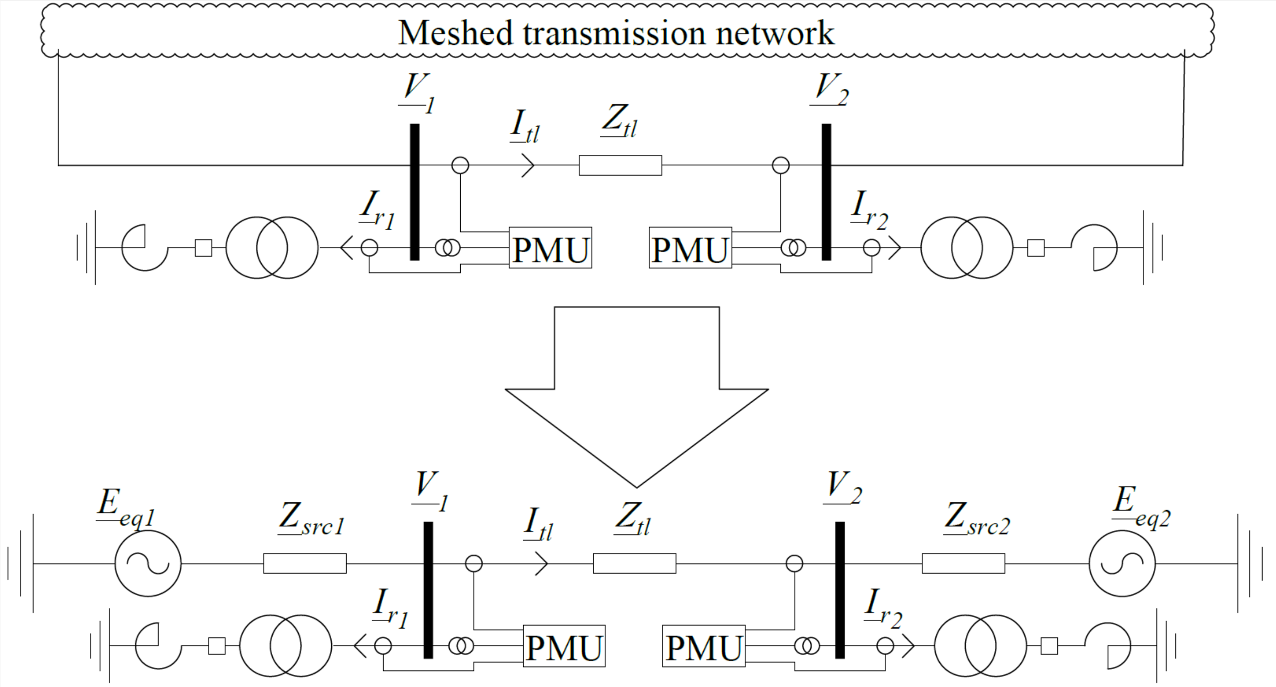


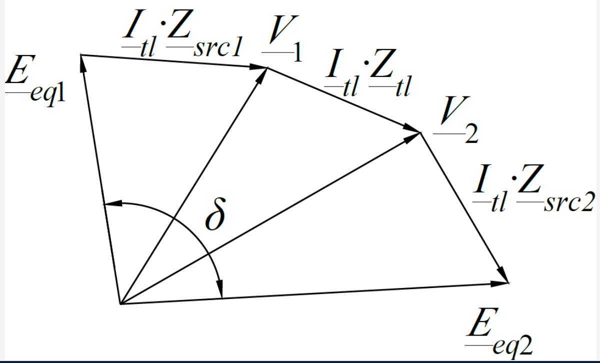
THE NEW ADAPTIVE ALGORITHM (2)

How it works?

- Full system impedance is computed on the bus and reduced to only $\underline{Z}_{src}$ on both ends of the transmission lines by using the following formula:
- $\underline{Z}_{src1} = -\frac{\underline{V}_1(t_2)-\underline{V}_1(t_1)}{\underline{I}_{r1}(t_2)-\underline{I}_{r1}(t_1)} \cdot \frac{\underline{I}_{r1}(t_1)-\underline{I}_{r1}(t_2)}{\left(\underline{I}_{r1}(t_1)-\underline{I}_{r1}(t_2)\right)-\left(\underline{I}_{tl}(t_1)-\underline{I}_{tl}(t_2)\right)} =$

$$-\frac{\Delta \underline{V}_1}{\Delta \underline{I}_1}\frac{\Delta \underline{I}_{r1}}{\Delta \underline{I}_{r1}-\Delta \underline{I}_{tl}} = \frac{\Delta \underline{V}_1}{\Delta \underline{I}_{r1}-\Delta \underline{I}_{tl}}$$



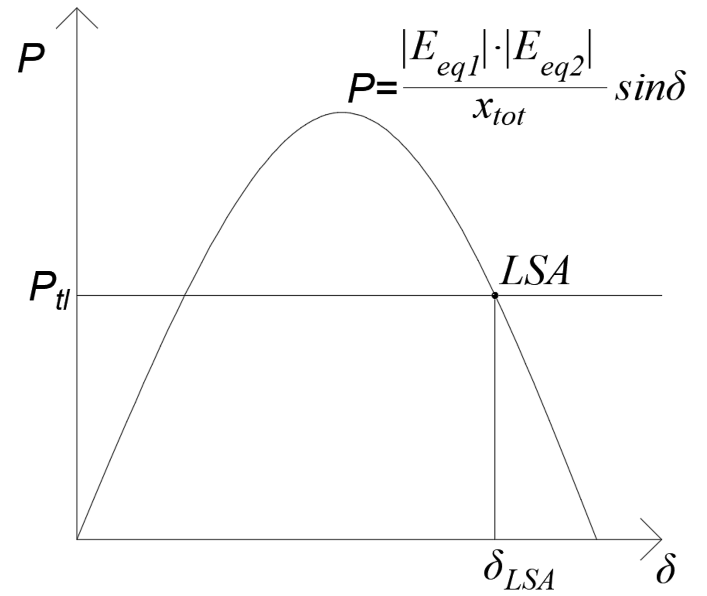


THE NEW ADAPTIVE ALGORITHM (3)

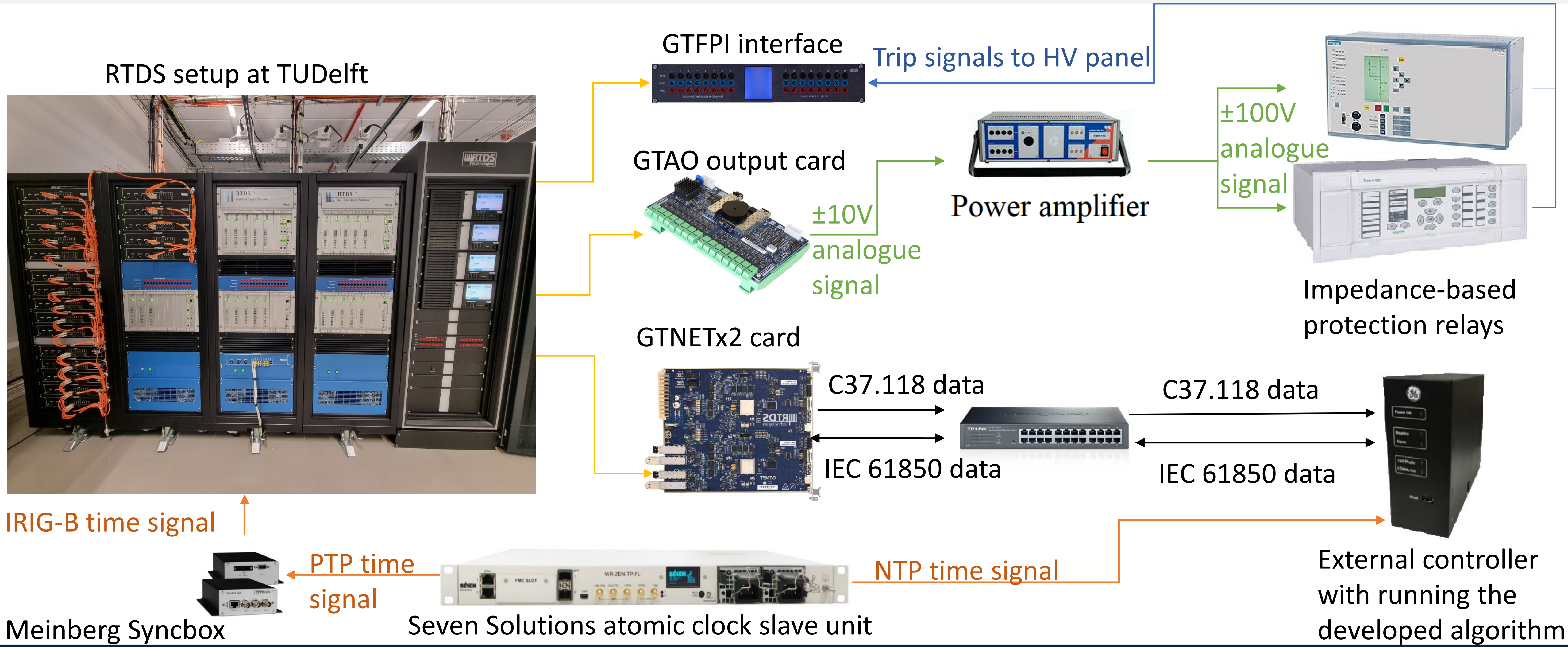
How it works?

- From computed system impedances a power-angle curve is built.
- On power-angle curve the last stable angle is fixed by using the computed angle difference between the sources ($90° < LSA < 130°$).
- The angle δ between two equivalent sources is computed using measured voltages and currents and computed impedances.
- Operation criteria:

$$\begin{cases} \delta > \delta_{LSA} \ \text{ for two conscutive measurements} \\ \dfrac{d\delta}{dt} > 0 \ \text{ for two conscutive measurements} \\ V_1 > 0.5\ pu \\ V_2 > 0.5\ pu \\ \dfrac{d\delta}{dt} < 20\pi \text{ rad } \ \text{for two conscutive measurements} \end{cases}$$



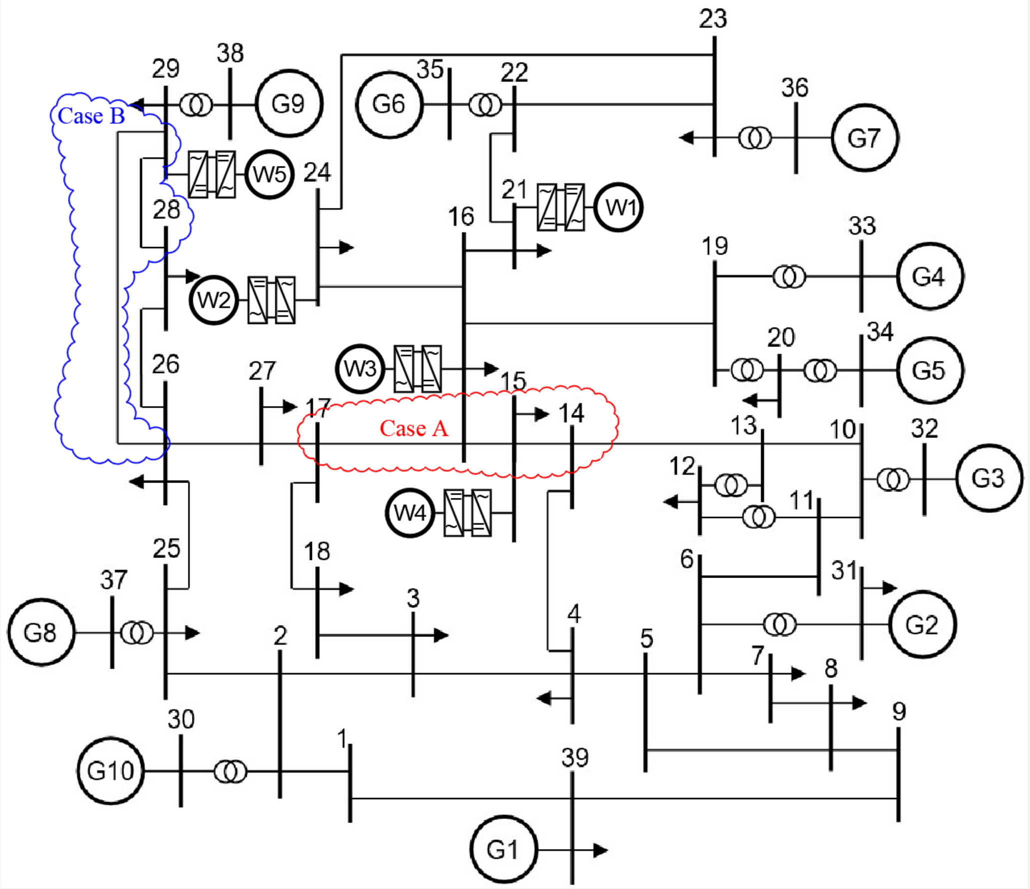
HIL TEST SETUP



HIL TEST SETUP

Test network

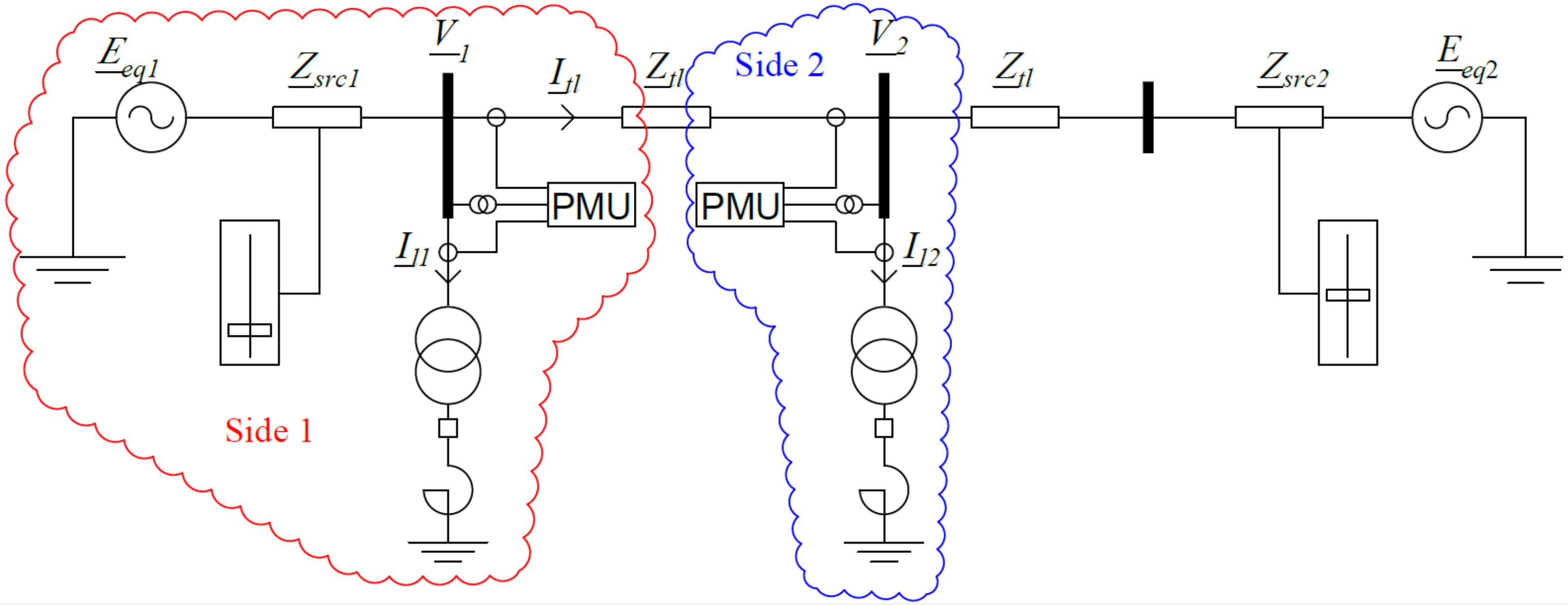
- IEEE 39 bus benchmark system is taken as a basis for larger system studies to investigate the out-of-step protection performance.
- Implementation of wind power plants into the network.
- Two scenarios are demonstrated in the network:
  - Case study A, in red, to represent swings between two system parts.
  - Case study B, in blue, to represent swings between single machine – infinite bus.

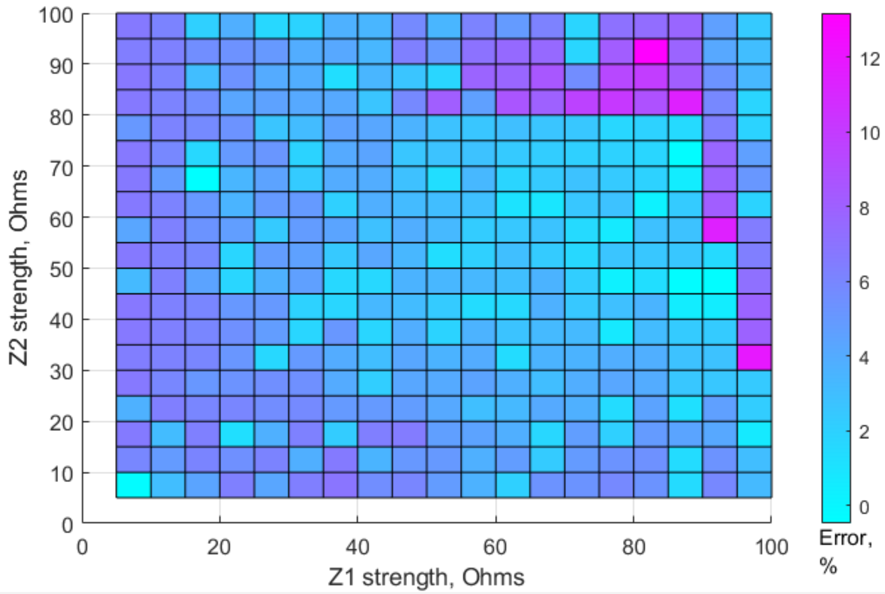


TESTING RESULTS

Impedance computation

- To test and validate the impedance computation part of the new algorithm a simple system was developed and the following results were obtained.





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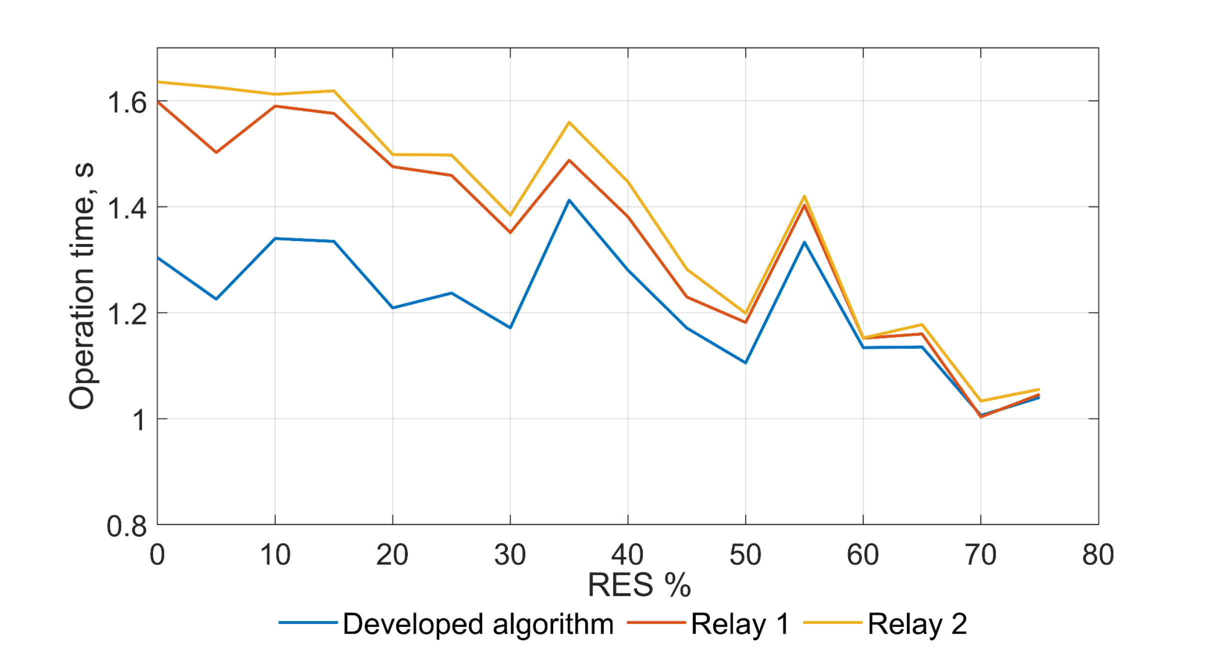
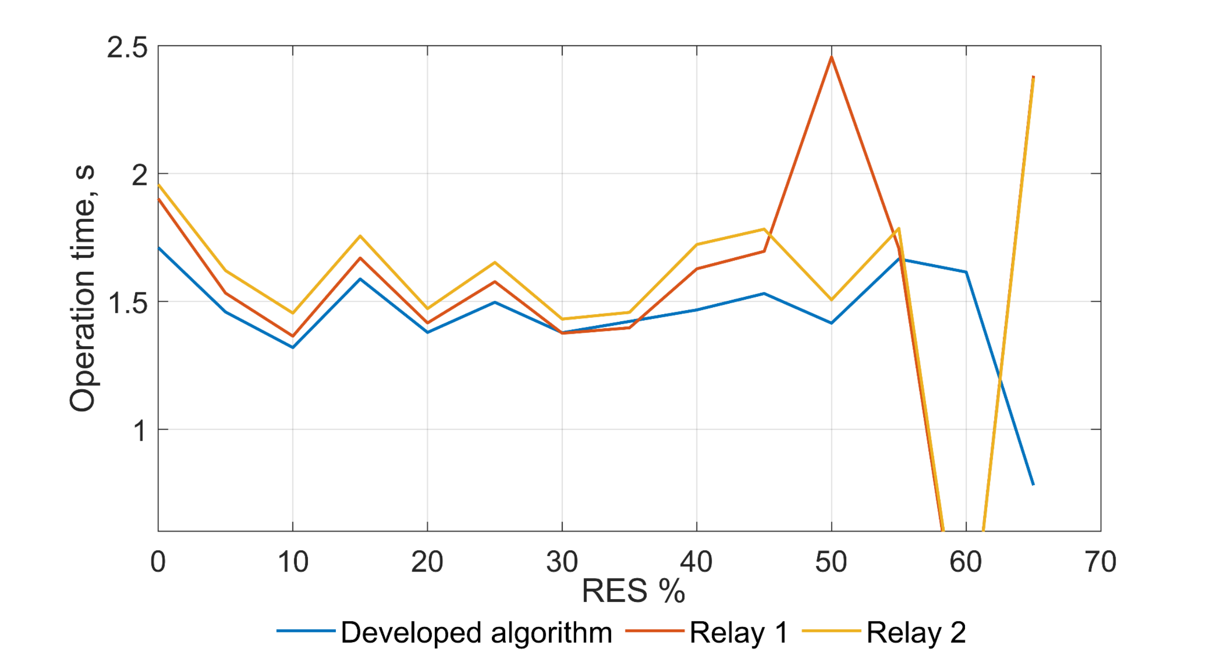
Results for Case study A

Longer transmission line



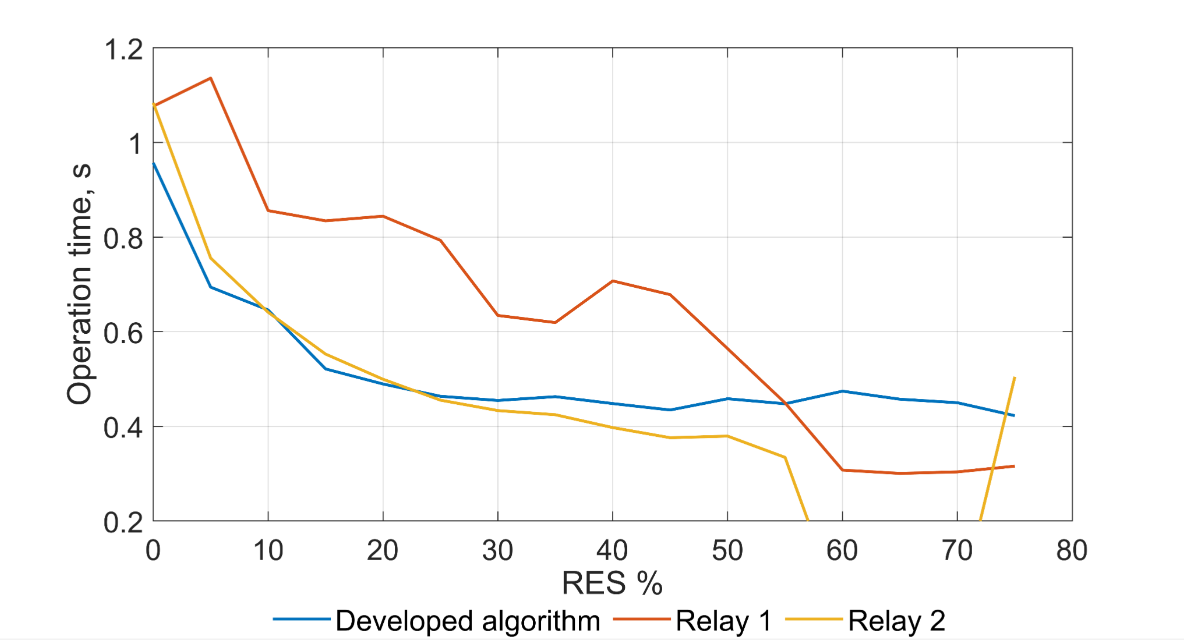
Shorter transmission line



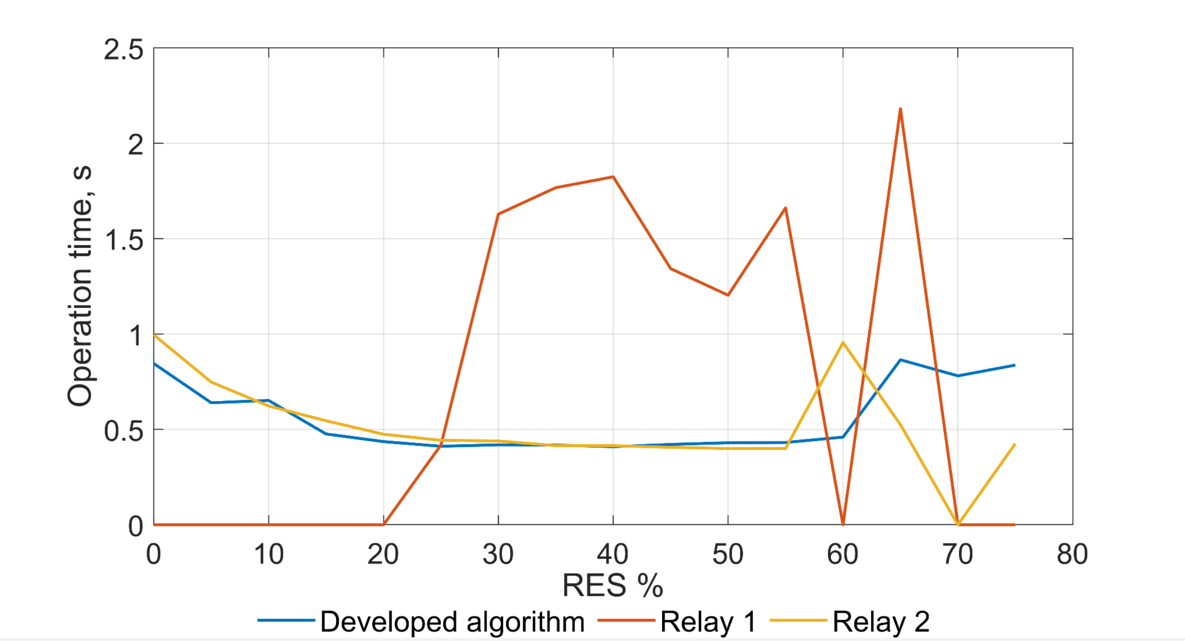
HIL TESTING OF THE ALGORITHM USING RTDS

Results for Case study B

Longer transmission line



Shorter transmission line



CONTRIBUTORS

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