Adaptive Out-of-Step Protection Based on Wide Area Measurements

Marko Tealane

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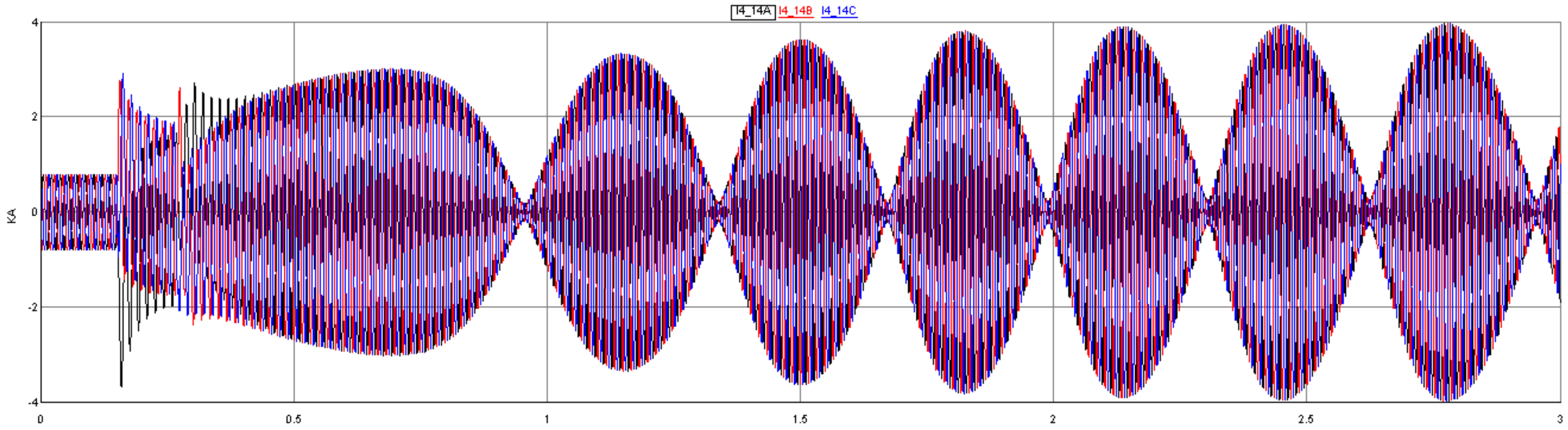
Outline

- 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.
- Testing results.

Out-of-step condition

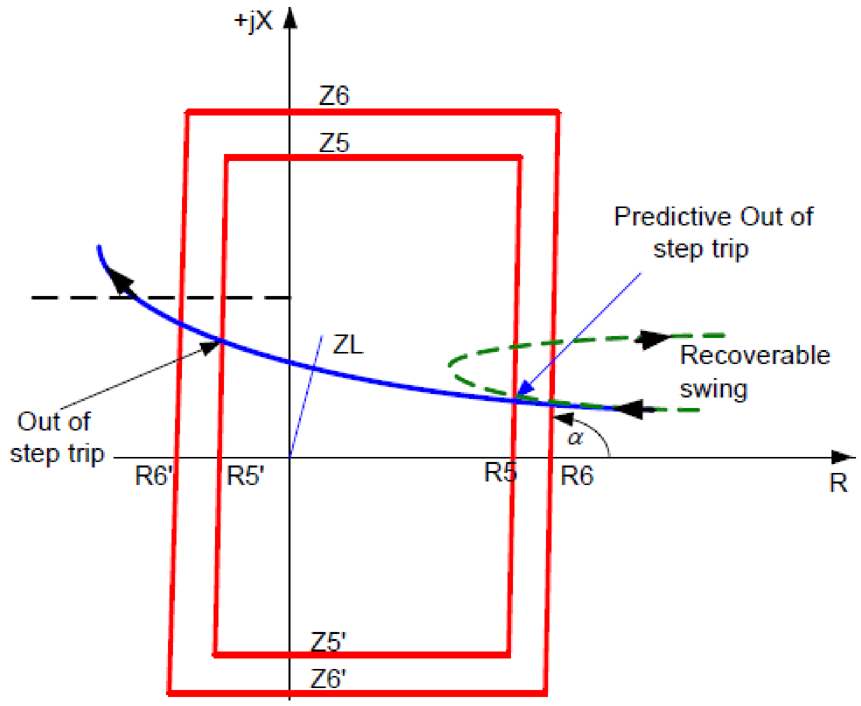
- What is an out-of-step condition?

- 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 correct settings to function as intended.
- 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 measurement is proposed and tested.



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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]:

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

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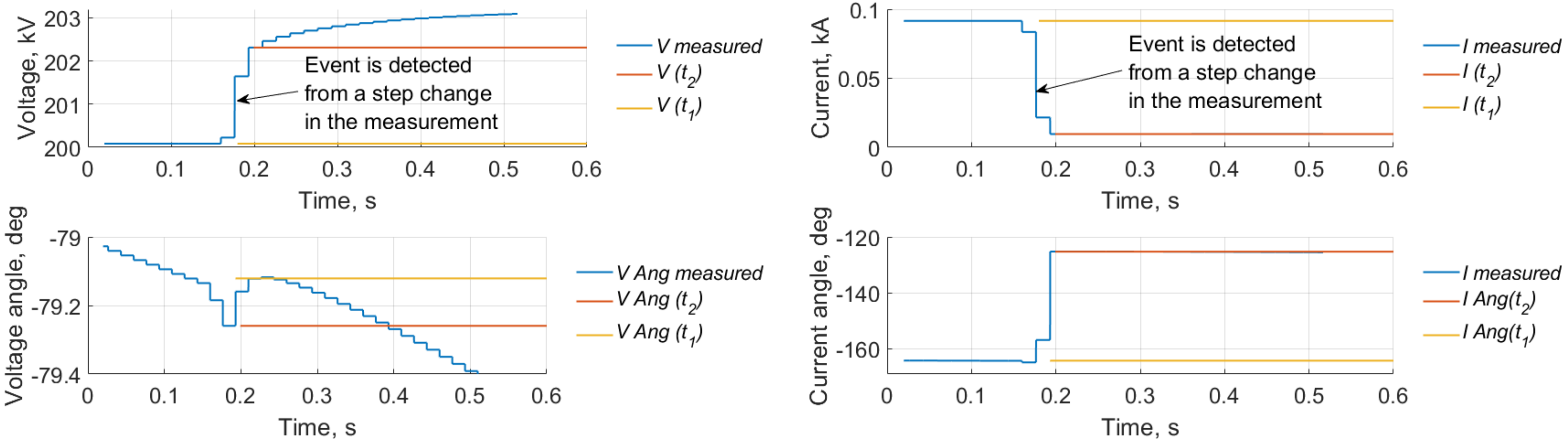
[1] K. O. H. Pedersen, A. H. Nielsen, and N. K. Poulsen, “Short-circuit impedance measurement,”IEE Proceedings - Generation, Transmissionand Distribution, vol. 150, no. 2, pp. 169–174, 2003.

The new adaptive algorithm (1)

- How it works?



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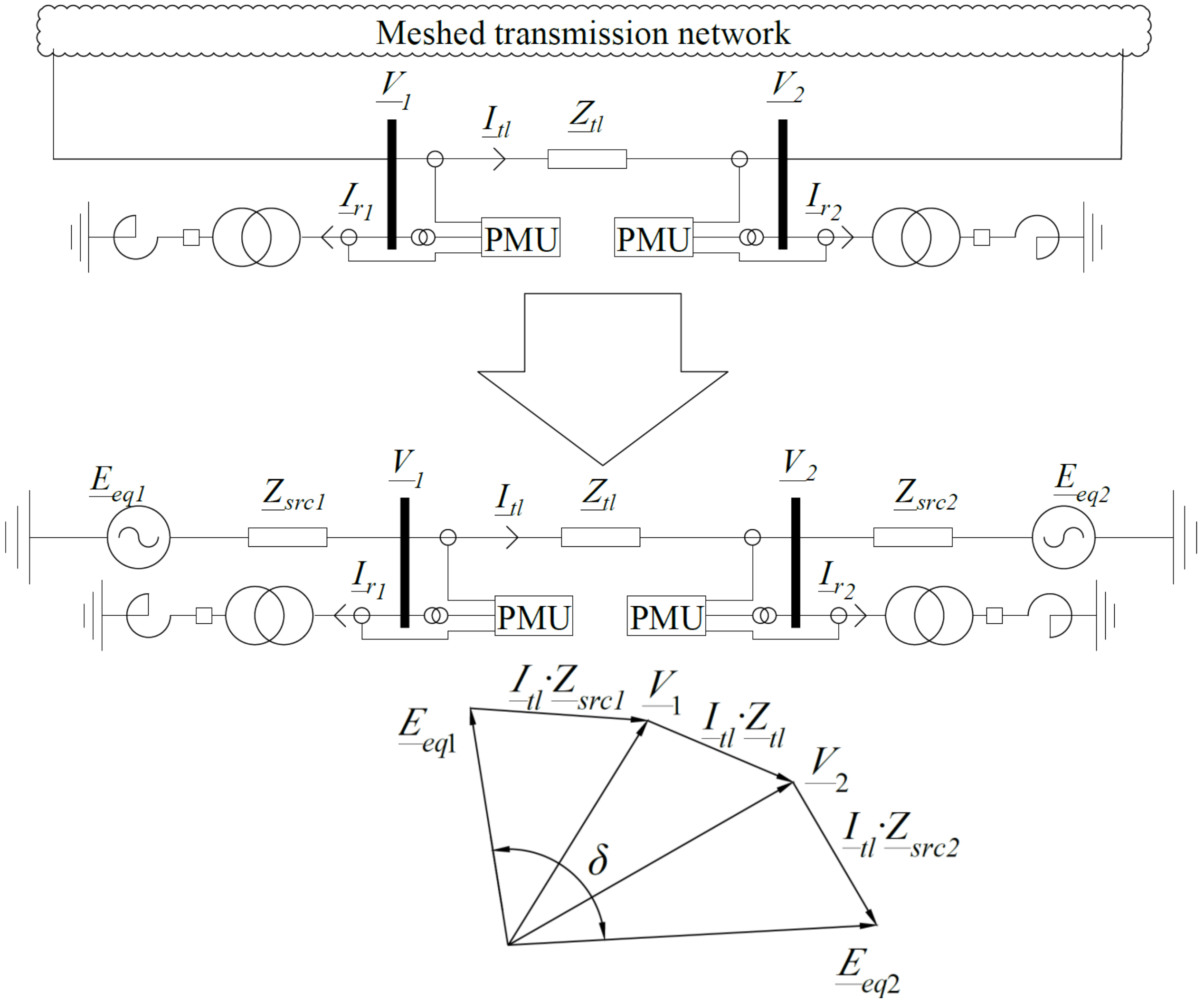
The new adaptive algorithm (2)

- 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:

- $$\underline{Z}_{src1} = -\frac{\underline{V}_1(t_2)-\underline{V}_1(t_1)}{\underline{I}_{r1}(t_2)-\underline{I}_{r1}(t_1)} \cdot \frac{\underline{I}_{r1}(t_1)-\underline{I}_{r1}(t_2)}{\left(\underline{I}_{r1}(t_1)-\underline{I}_{r1}(t_2)\right)-\left(\underline{I}_{tl}(t_1)-\underline{I}_{tl}(t_2)\right)} = -\frac{\Delta\underline{V}_1}{\Delta\underline{I}_1}\frac{\Delta\underline{I}_{r1}}{\Delta\underline{I}_{r1}-\Delta\underline{I}_{tl}} = \frac{\Delta\underline{V}_1}{\Delta\underline{I}_{r1}-\Delta\underline{I}_{tl}}$$

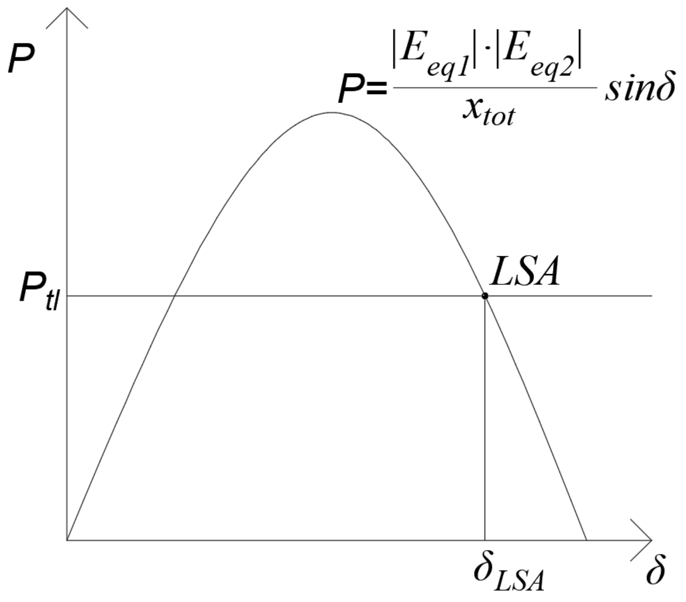


The new adaptive algorithm (3)

- 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:

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



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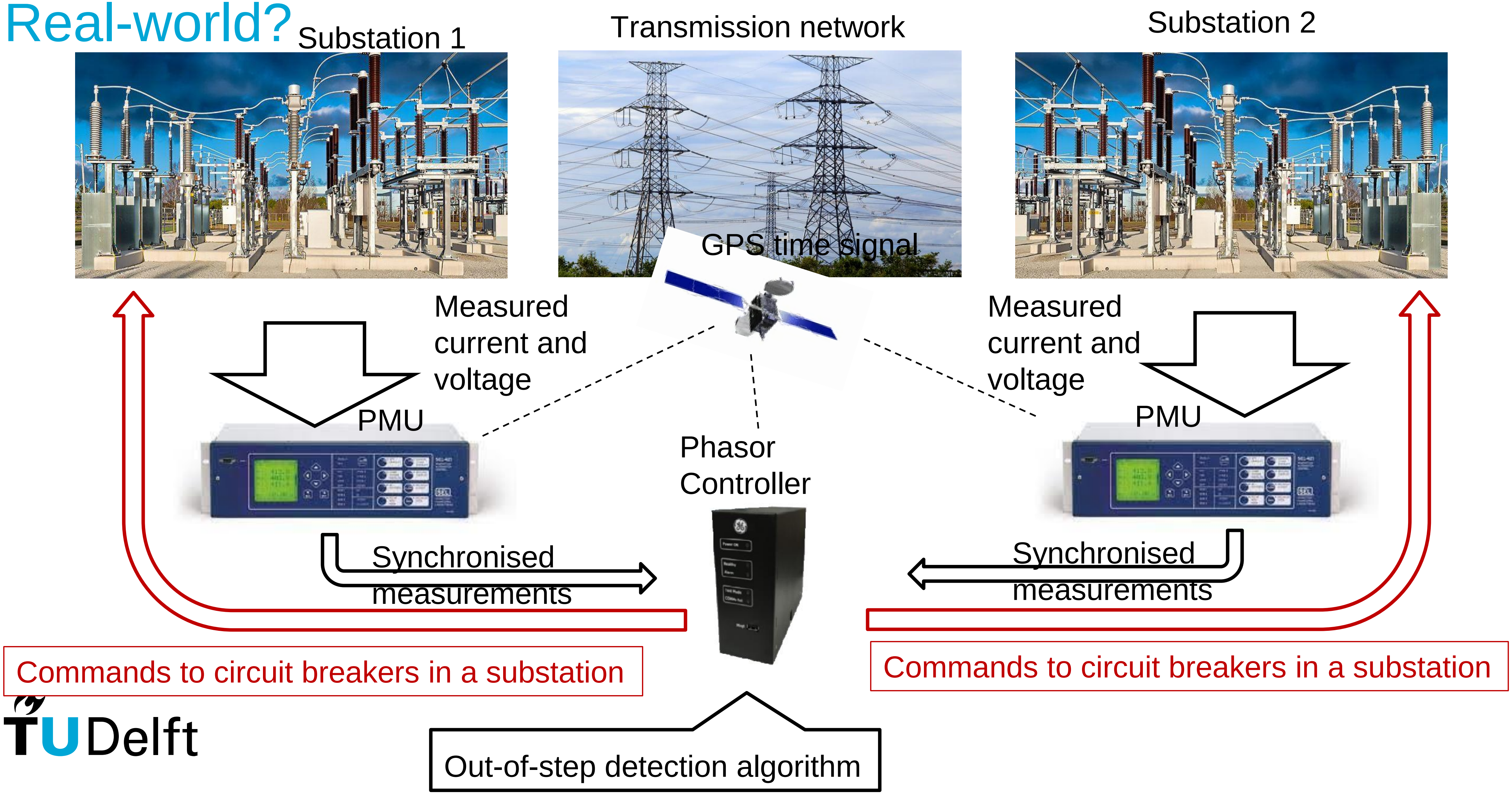
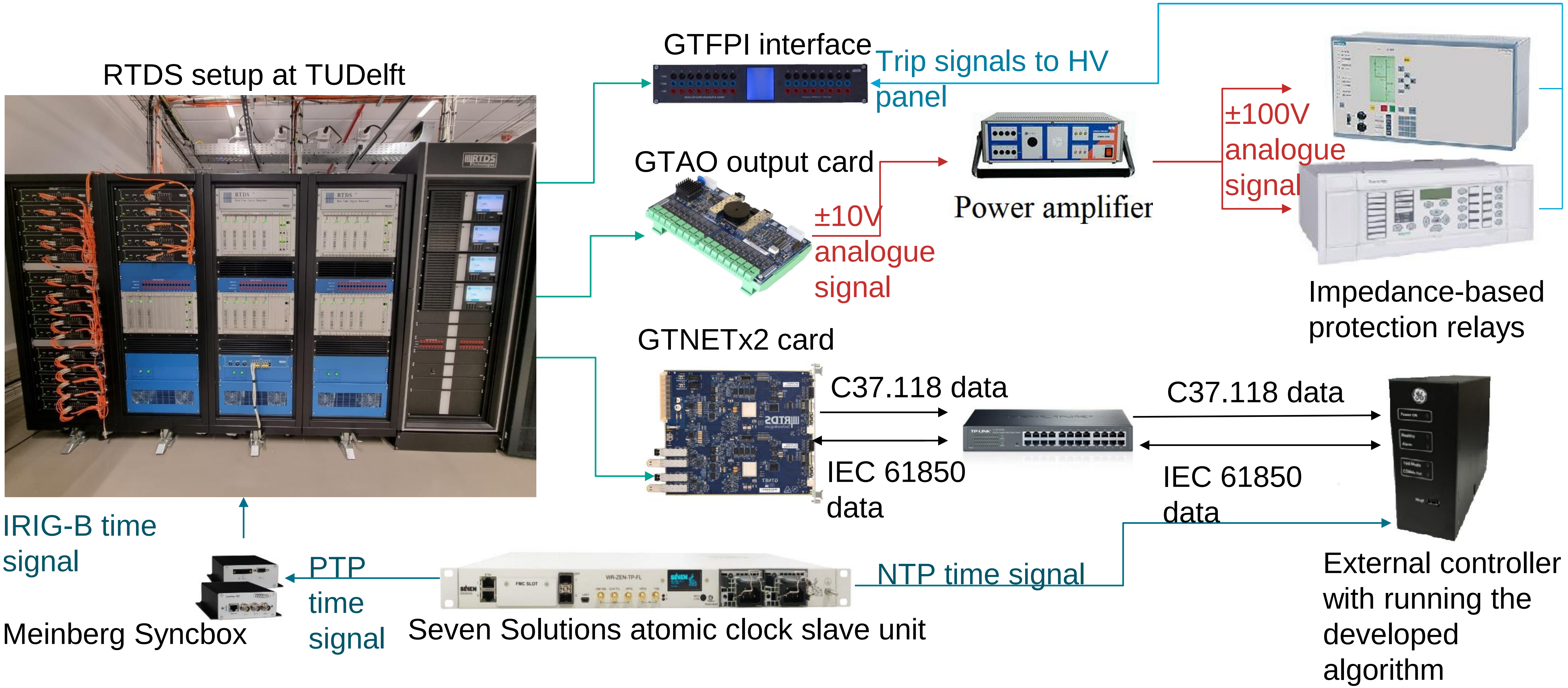
Real-world?



Substation images: https://www.pinterest.com/pin/858428378953096585/ Transmission network image: https://www.tdworld.com/overhead-transmission/article/20972742/linevision-launches-asset-health-model-for-utility-transmission-lines

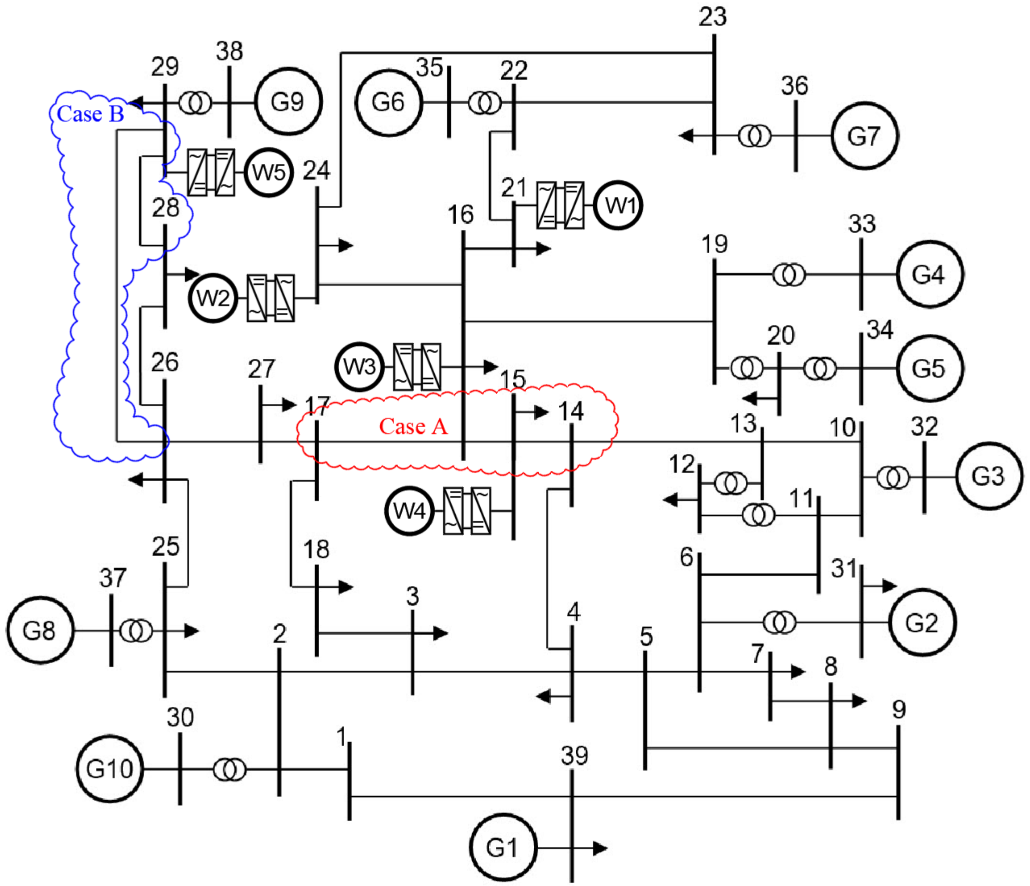
HiL test setup



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.



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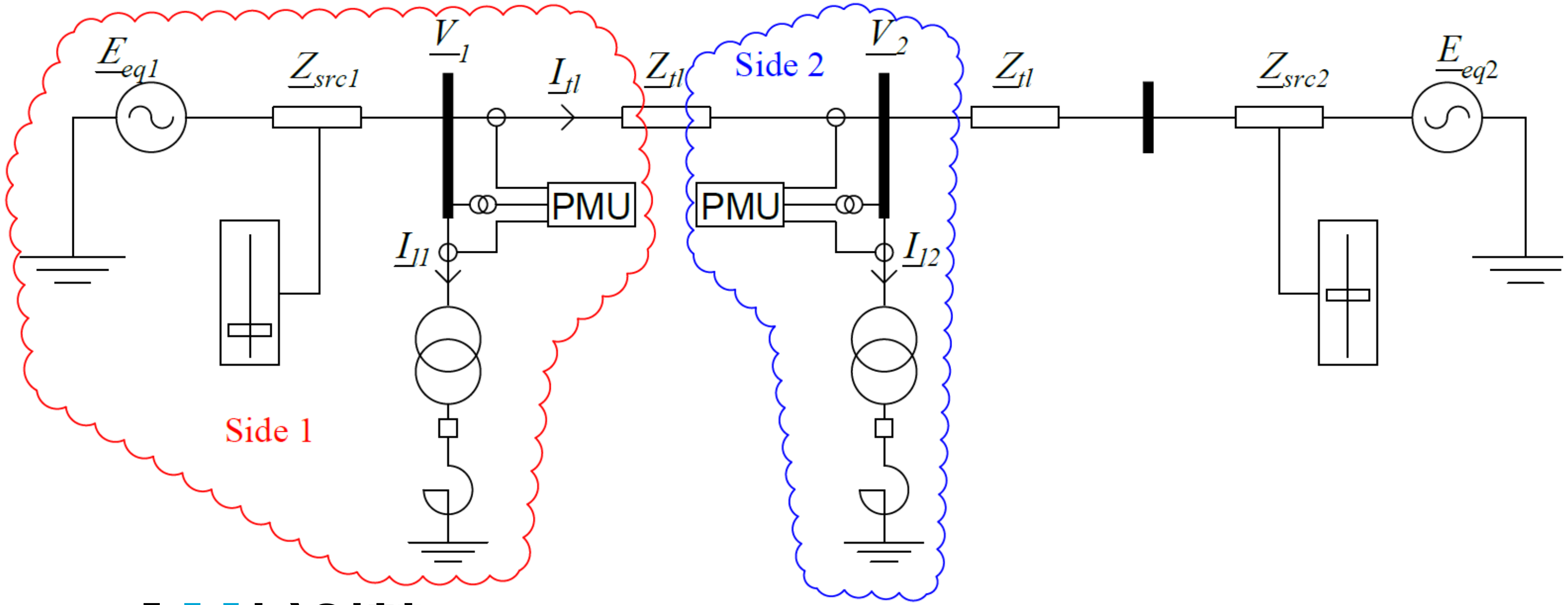
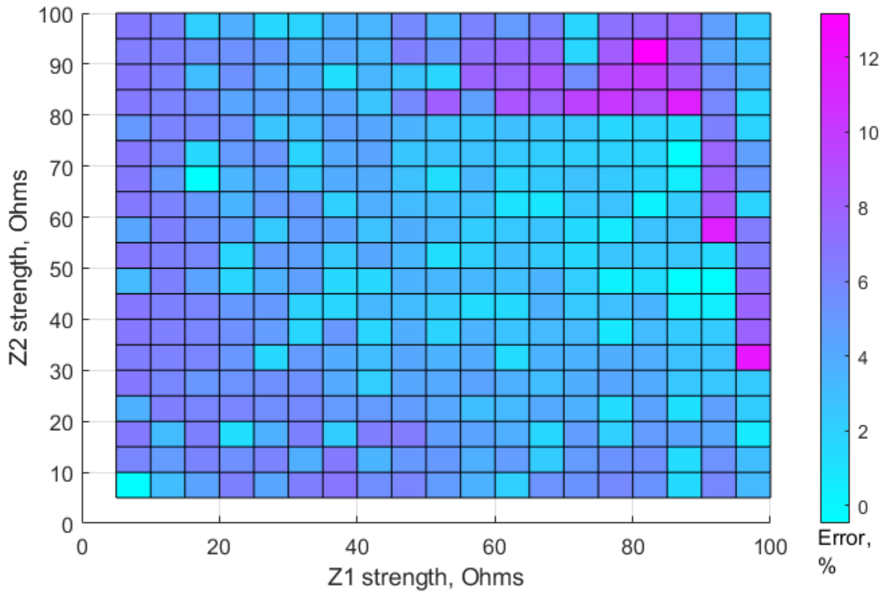
Testing results

- 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.

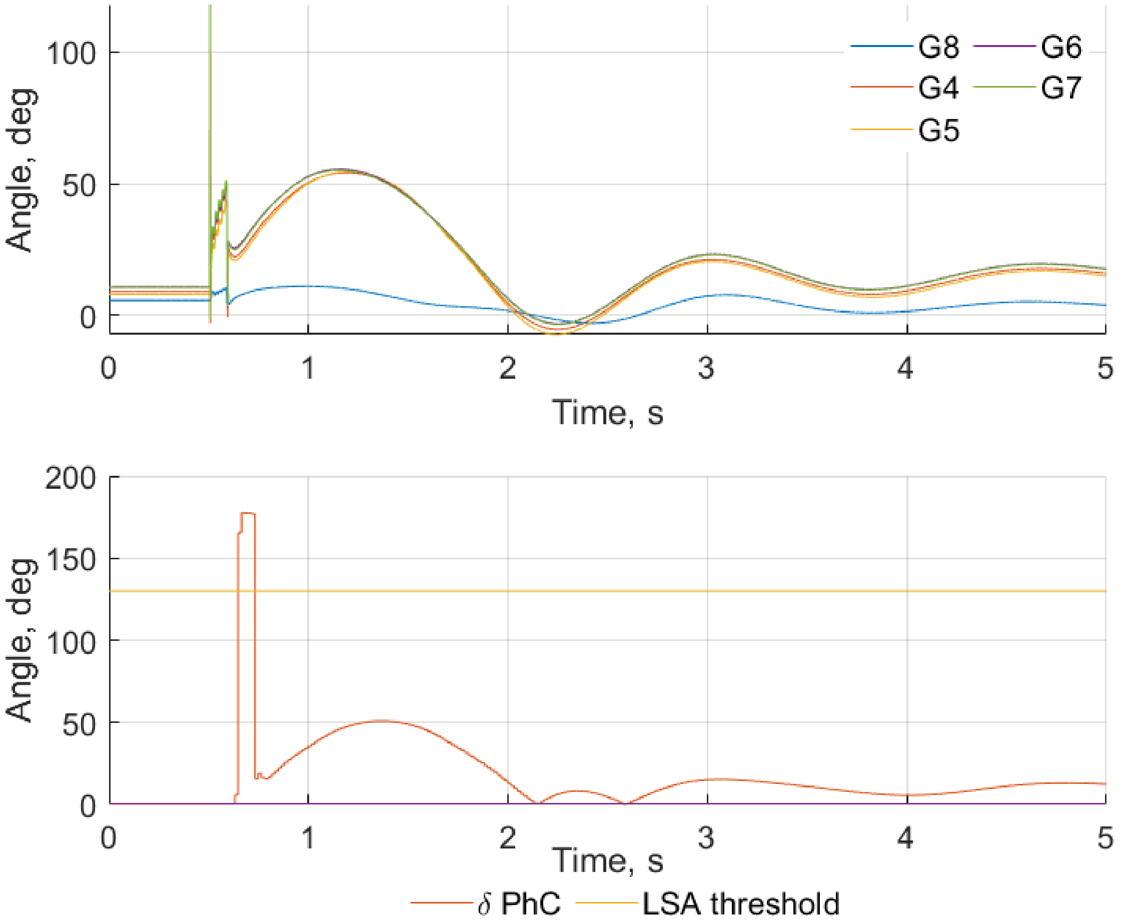




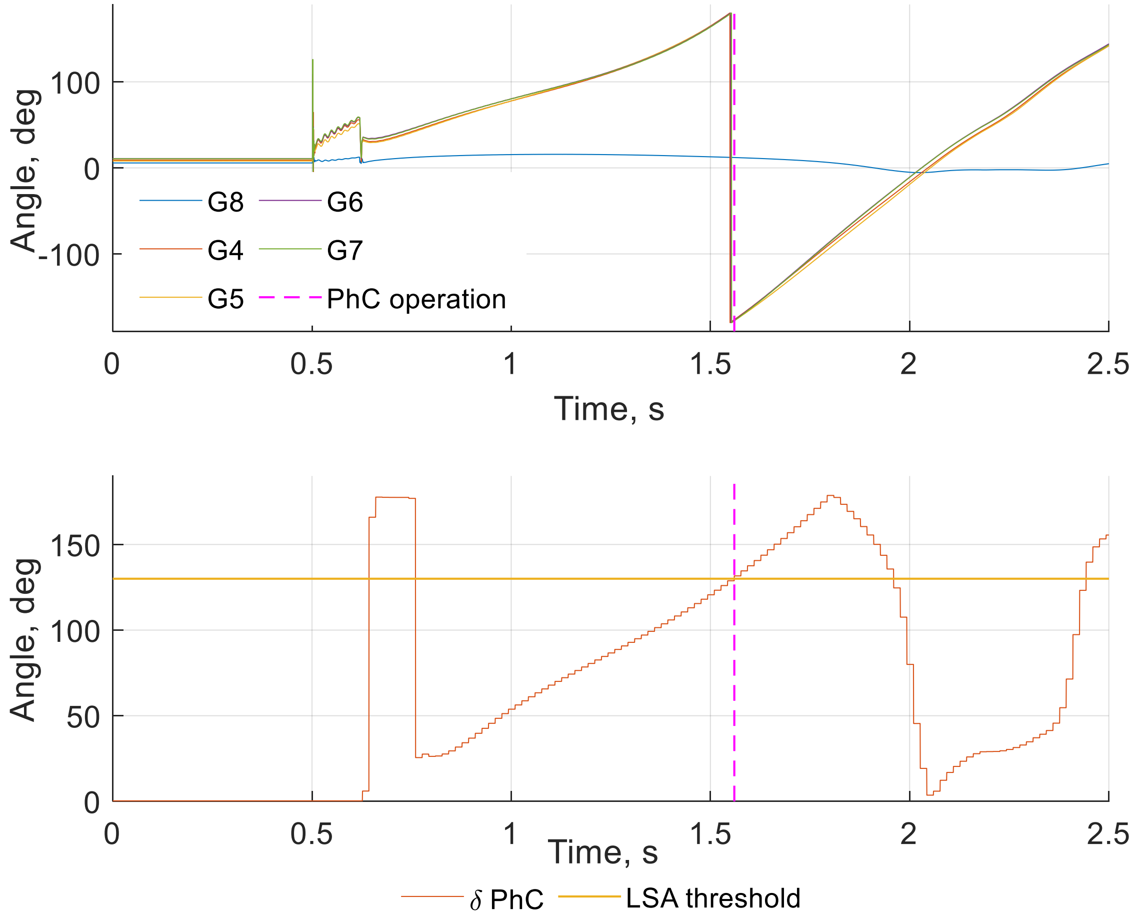
Hil testing of the algorithm using RTDS (1)

- Algorithm behavior for stable and unstable power swings in the network

Stable power swing



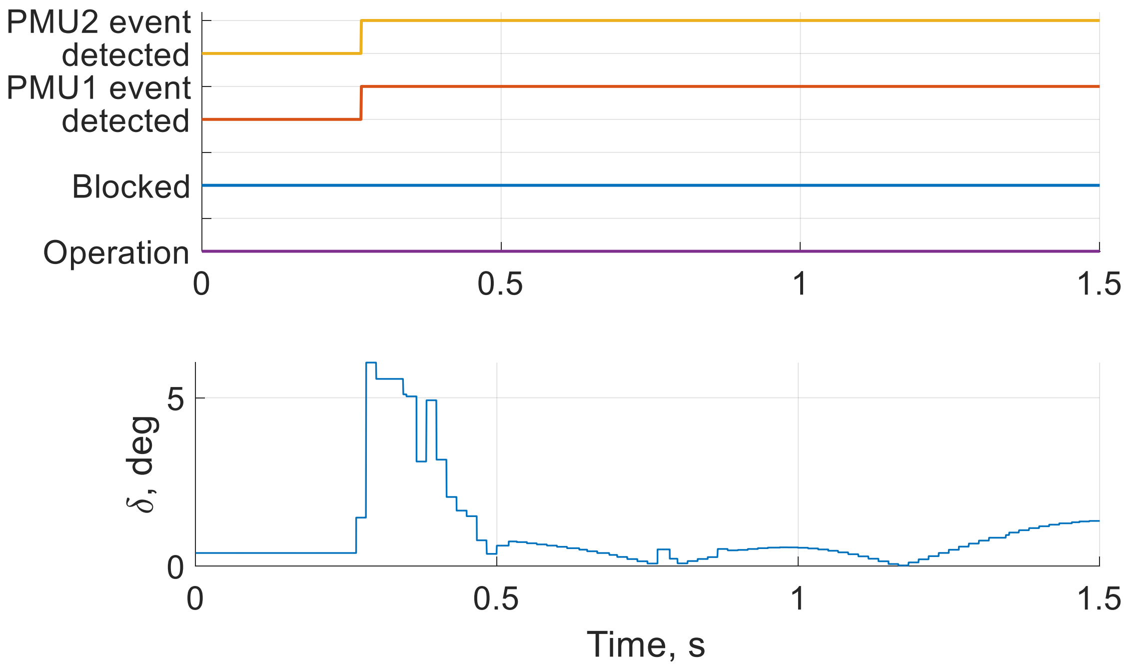
Unstable power swing



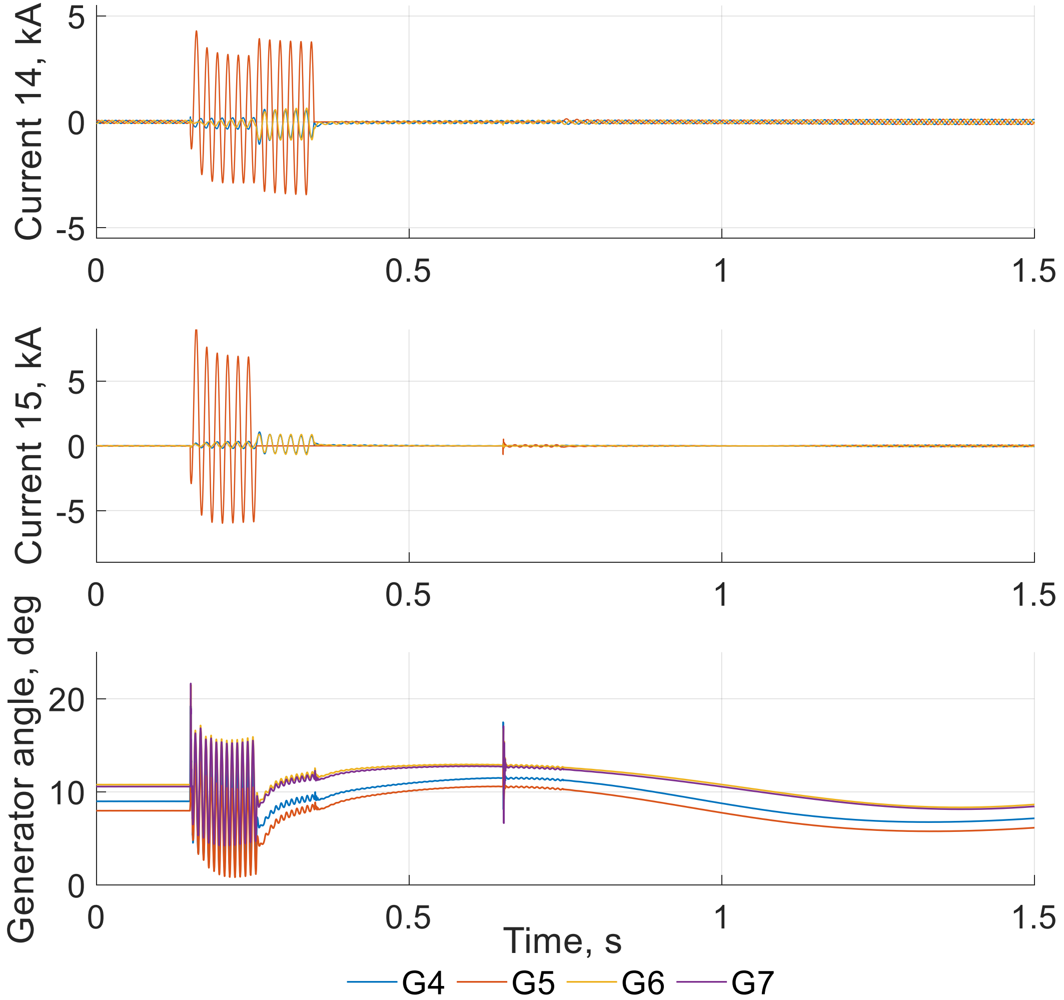
Hil testing of the algorithm using RTDS (2)

- Algorithm behavior for grid events – SLG on protected line

Algorithm signals from the controller



Measured quantities



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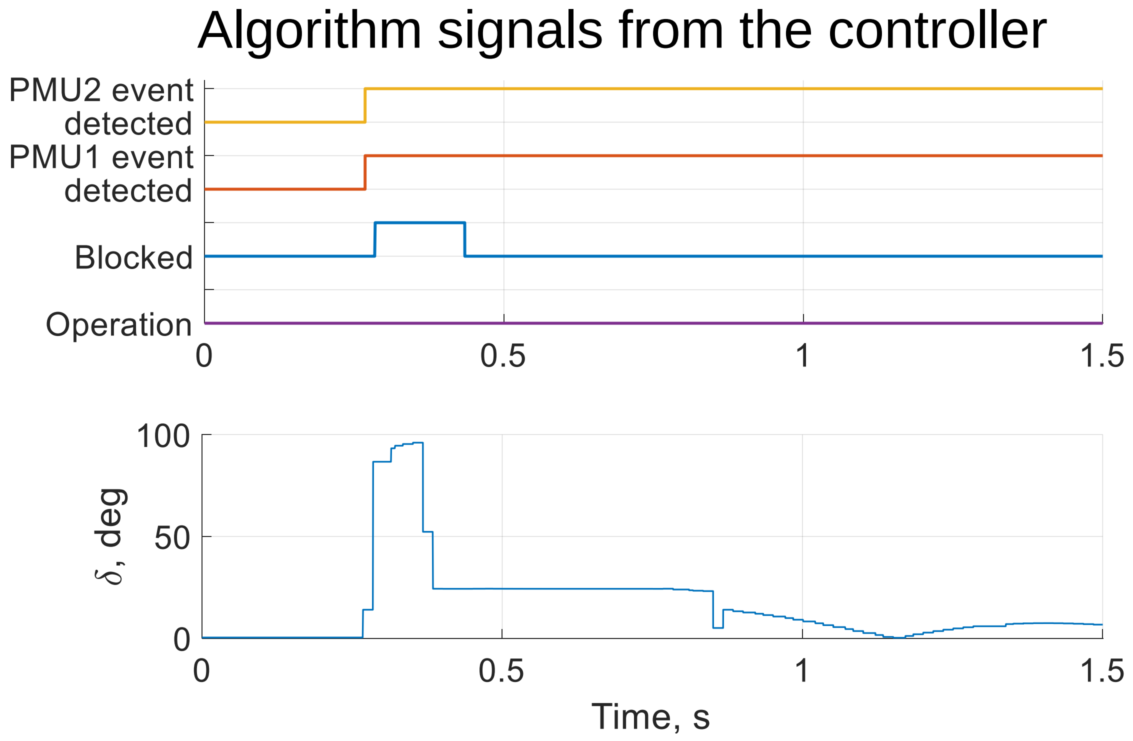
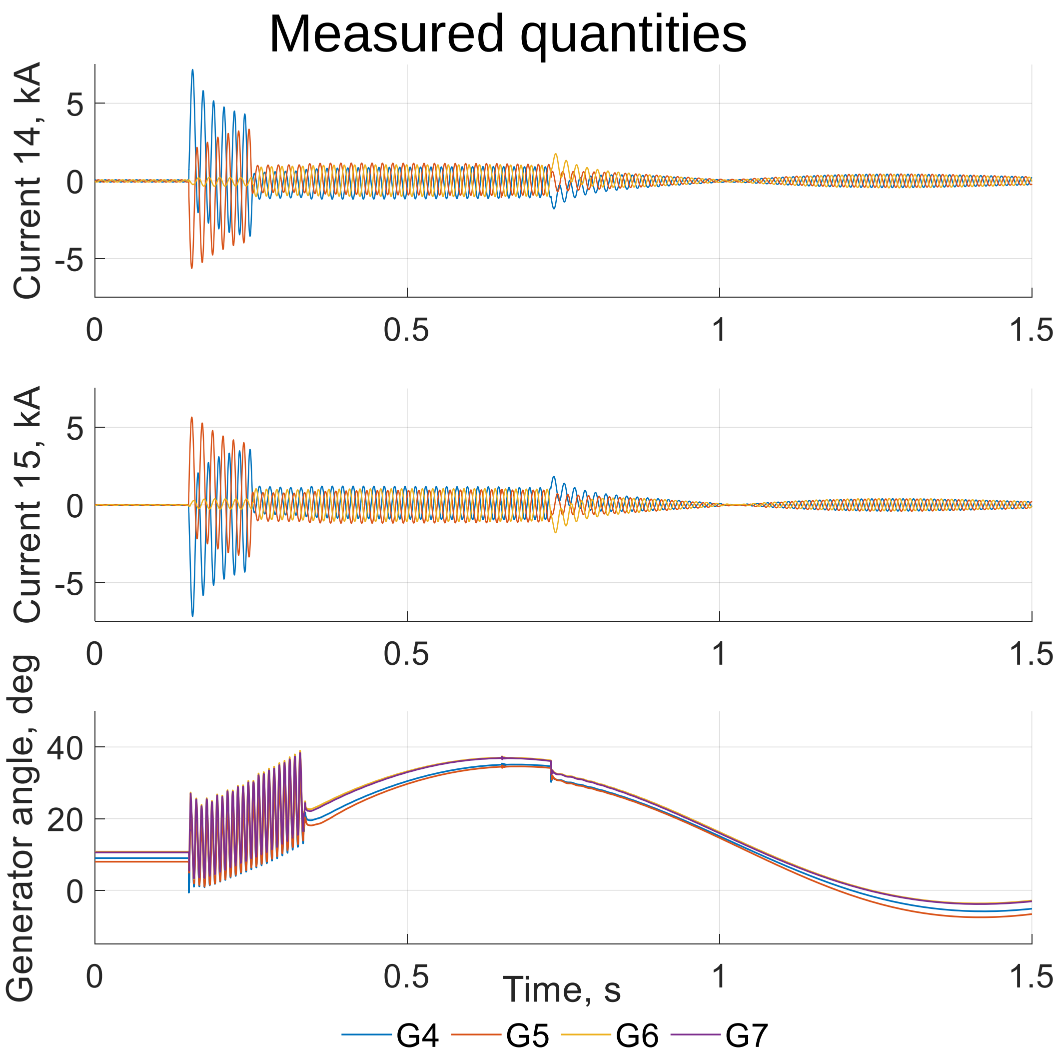
Hil testing of the algorithm using RTDS (3)

- Algorithm behavior for grid events – LL outside of the protected line





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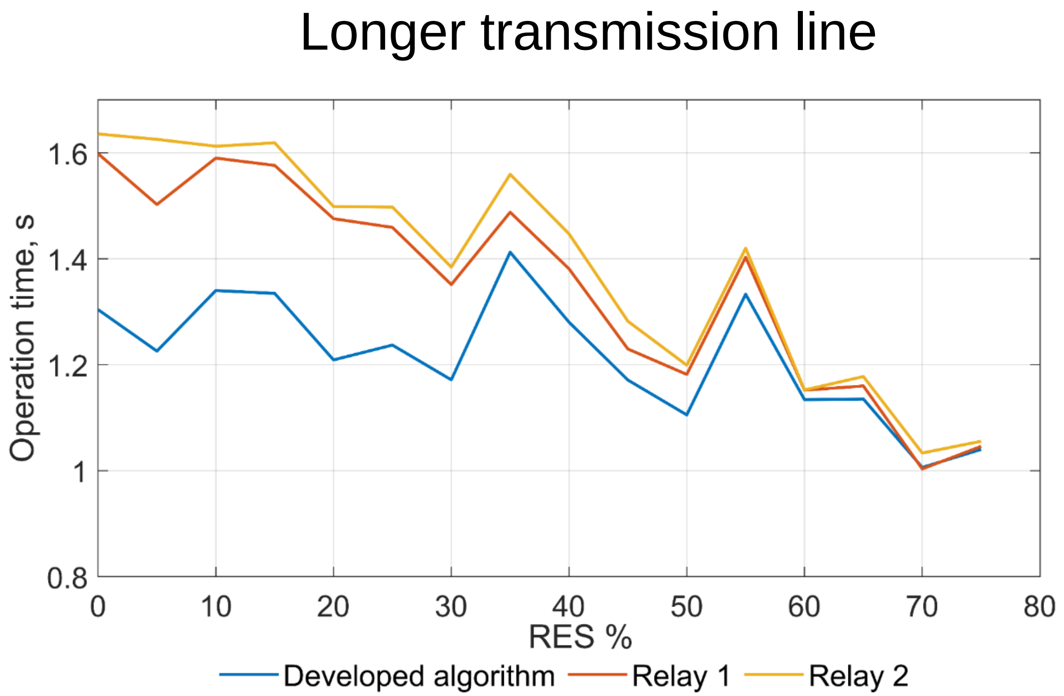
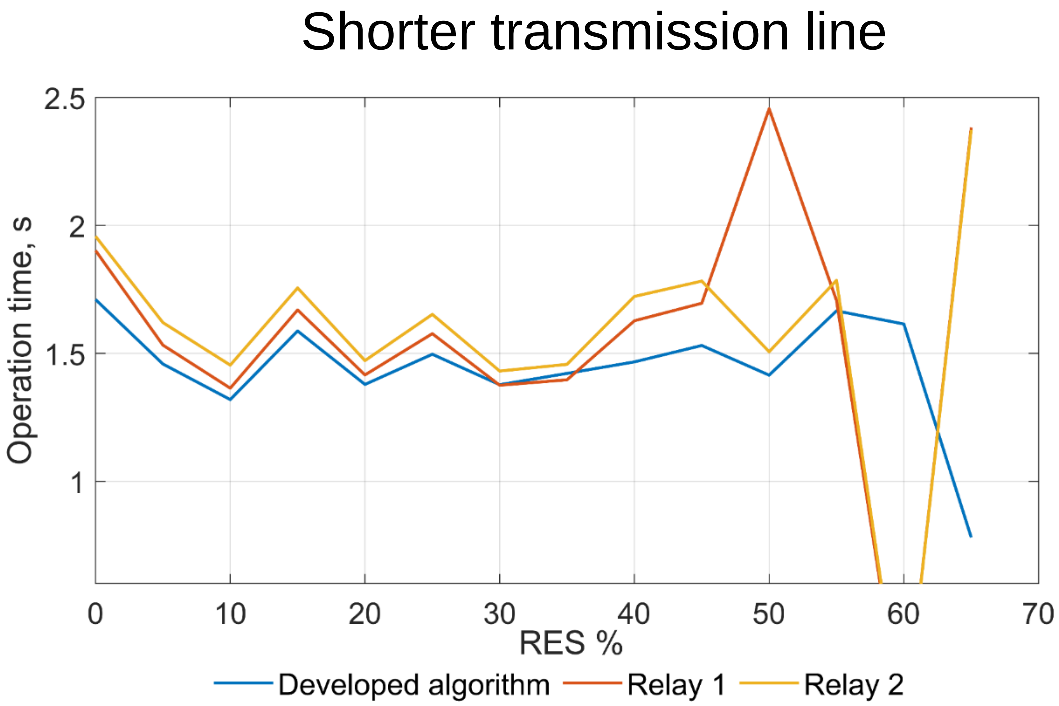
Hil testing of the algorithm using RTDS (4)

- Results for Case study A

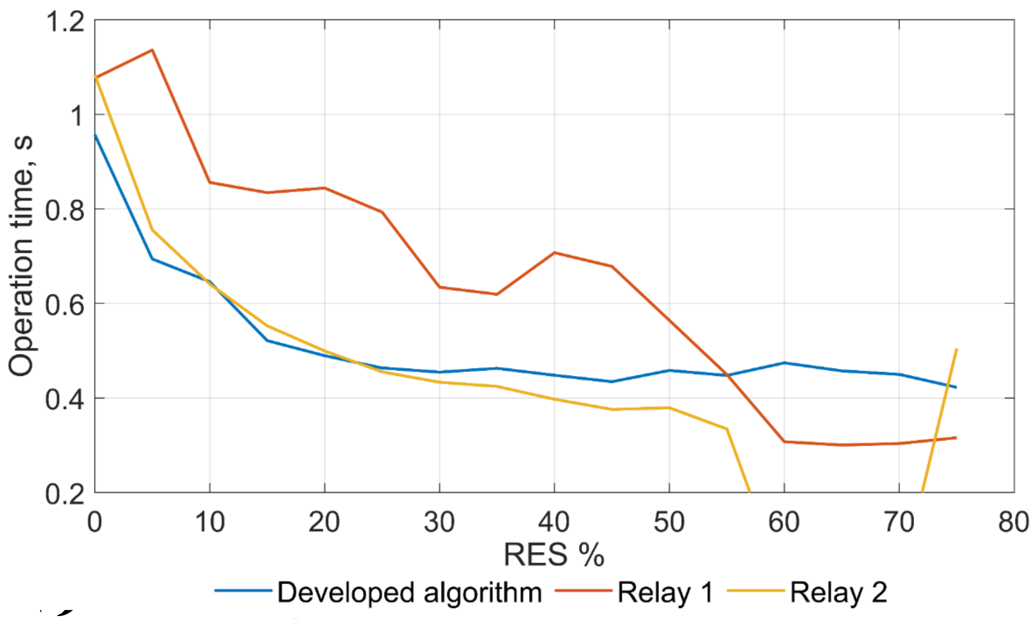




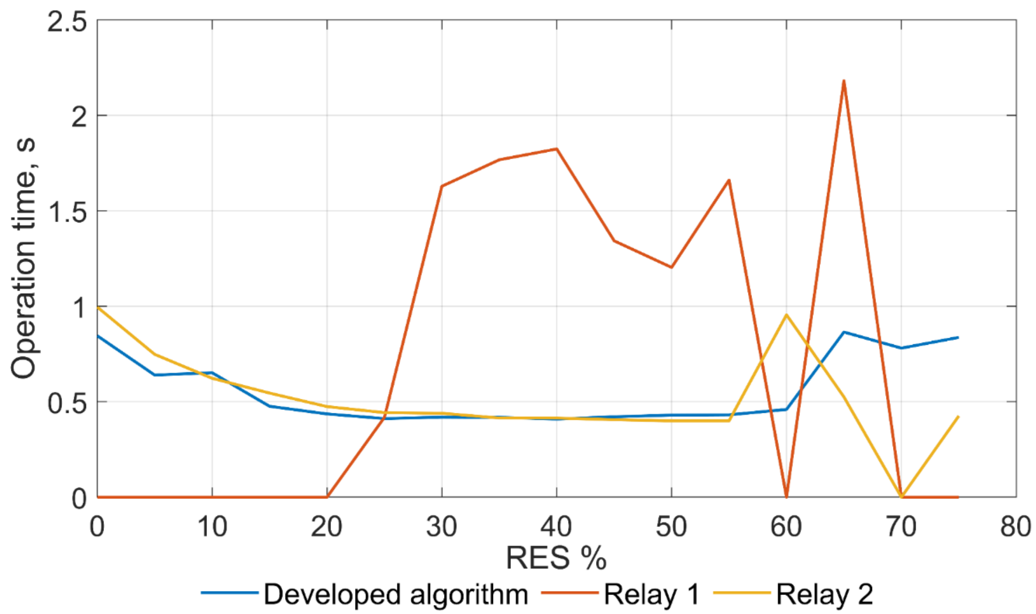
Hil testing of the algorithm using RTDS (5)

- Results for Case study B

Longer transmission line



Shorter transmission line



Contributors

TAL TECH

TenneT Taking power further

General Electric

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NWO Nederlandse Organisatie voor Wetenschappelijk Onderzoek

SIHTASUTUS ARCHIMEDES

Thank you for your attention

email: M.Tealane@tudelft.nl / marko.tealane@taltech.ee

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