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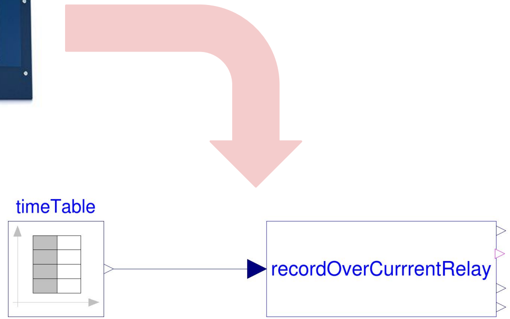

Over Current Relay Modeling using Modelica with Cross-Verification against a Validated Model

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- Background
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  - Model Testing
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  - Results & Analysis
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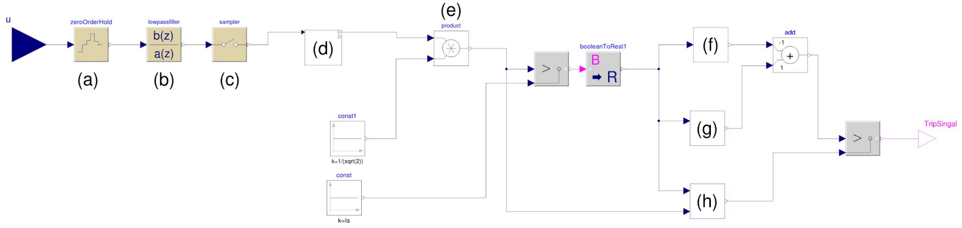
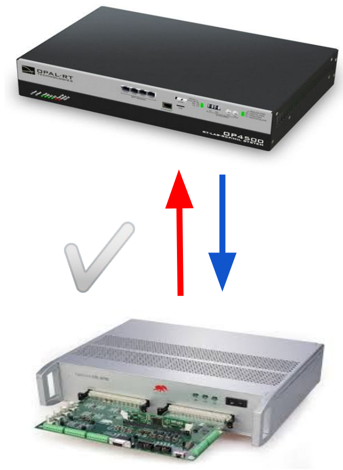
- References

Functionalities



- Needs for model portability in CPS development
  - Increased of Information and Communication Technologies (ICT) are transforming power grids into CPS → power system component models need to be exchanged and used in CPS dev. tools.
  - Power system tools, in general, make it difficult to exchange models of protection relays without the loss of information or ambiguity.
  - Modelica and the Functional Mockup Interface (FMI) are open access standards with open source implementations that would allow model exchange all the way from design stage to real-time (RT) simulation including Hardware-In-The-Loop simulation (HIL)
- Modelica
  - Non-Proprietary, open source language.
  - Efficient, equation-based multi domain modeling.
  - Model portability in RT and offline simulation, like using EMTP-RV or EPHASORSIM.
- The Modelica Language and FMI provide and inexpensive, stable, portable and compact way of scaling CPS

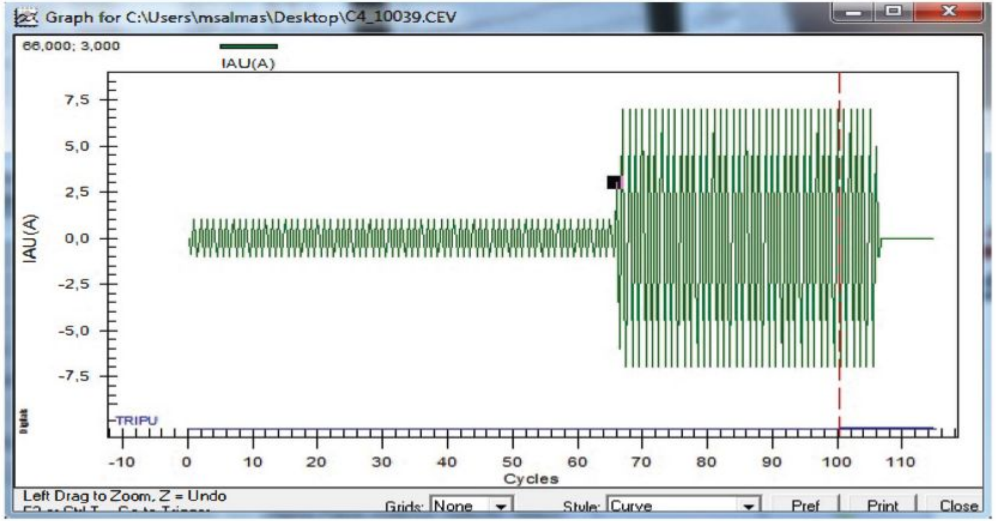


MODELICA

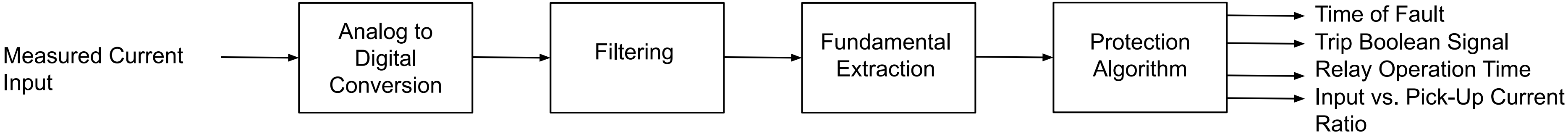
fmi FUNCTIONAL MOCK-UP INTERFACE

Background

- Goal:
    - Recreate, test and validate Over Current Relay (OCR) model presented by Almas et al [1].
    - Relay performance verification requires the use of HIL simulation, with a Modelica model, it is possible!



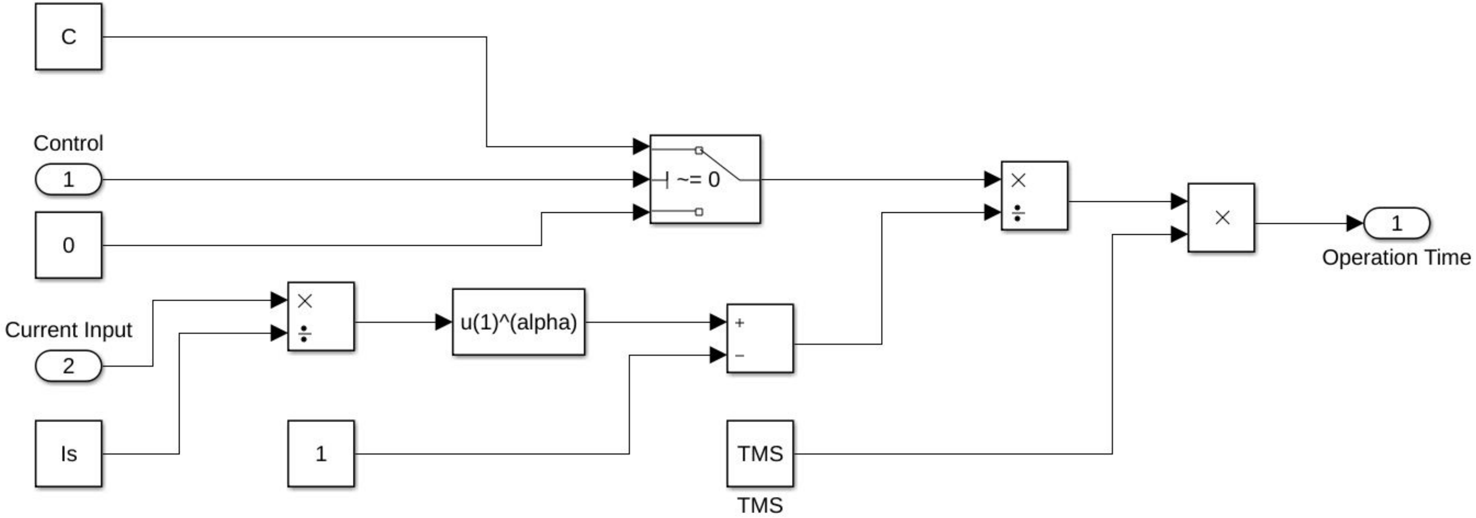
- Relay Functionalities



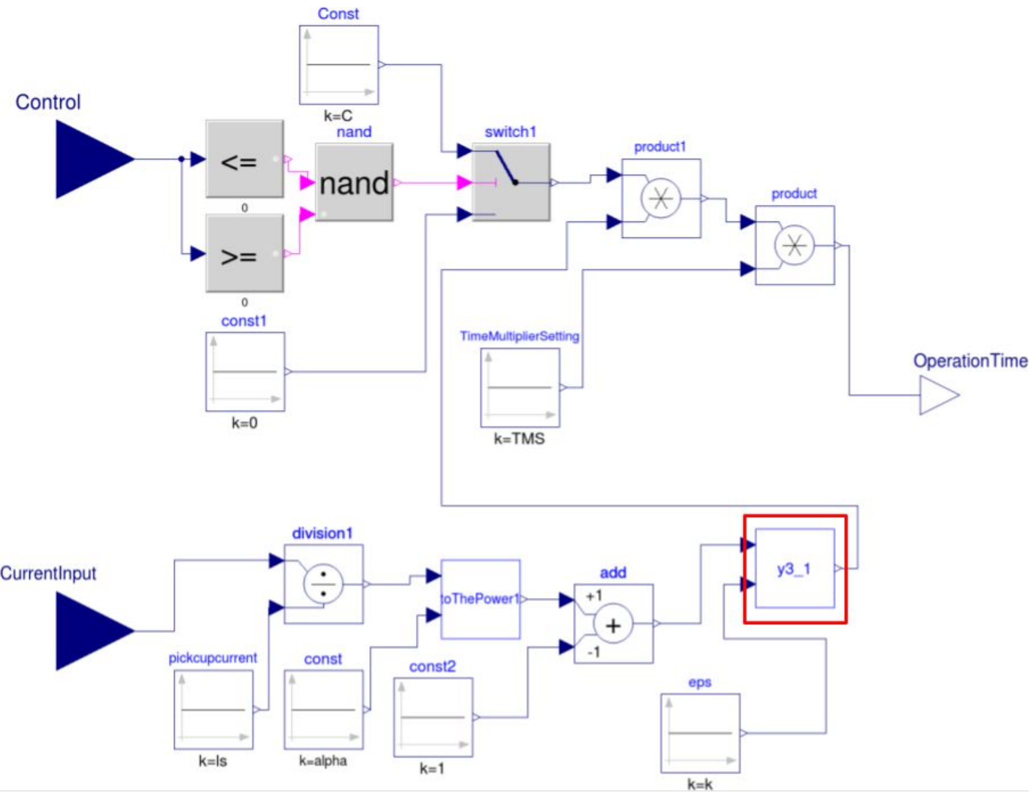
- The model re-implementation was created in a **bottom-up approach.**
- The figure below is the Relay
- The module follows the equation below, where (C, TMS and α are relay constants), and I is the input current and Is is the pick up current.

$$T = \frac{C}{\frac{I^{\alpha}}{I_s} - 1} * TMS$$

- The module determines which type of relay is being modeled:
  - Standard, Very, Extremely and Long Inverse



Component Model Re-Implementation (Modelica)



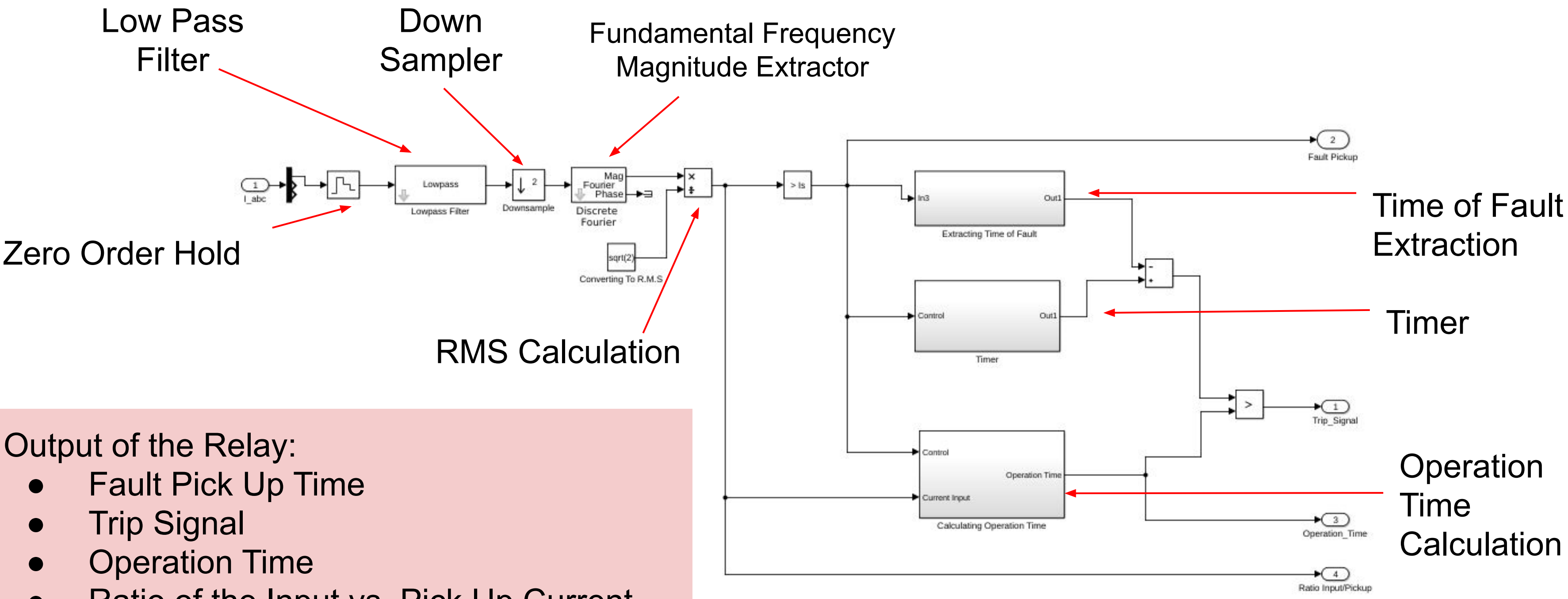
- The figure on the left show the Modelica re-implementation and calculates the operation time that the relay must wait until the trip signal is issued.
- An important design consideration is to avoid division by zero when the input current (I) is equal to current (Is) in:

$$T = \frac{C}{\frac{I^\alpha}{I_s} - 1} * TMS$$

- Hence, the block *y3_1* outlined in **red** implements the following expression to guard against division by zero:

$$y = \frac{1}{max(x, eps)}$$

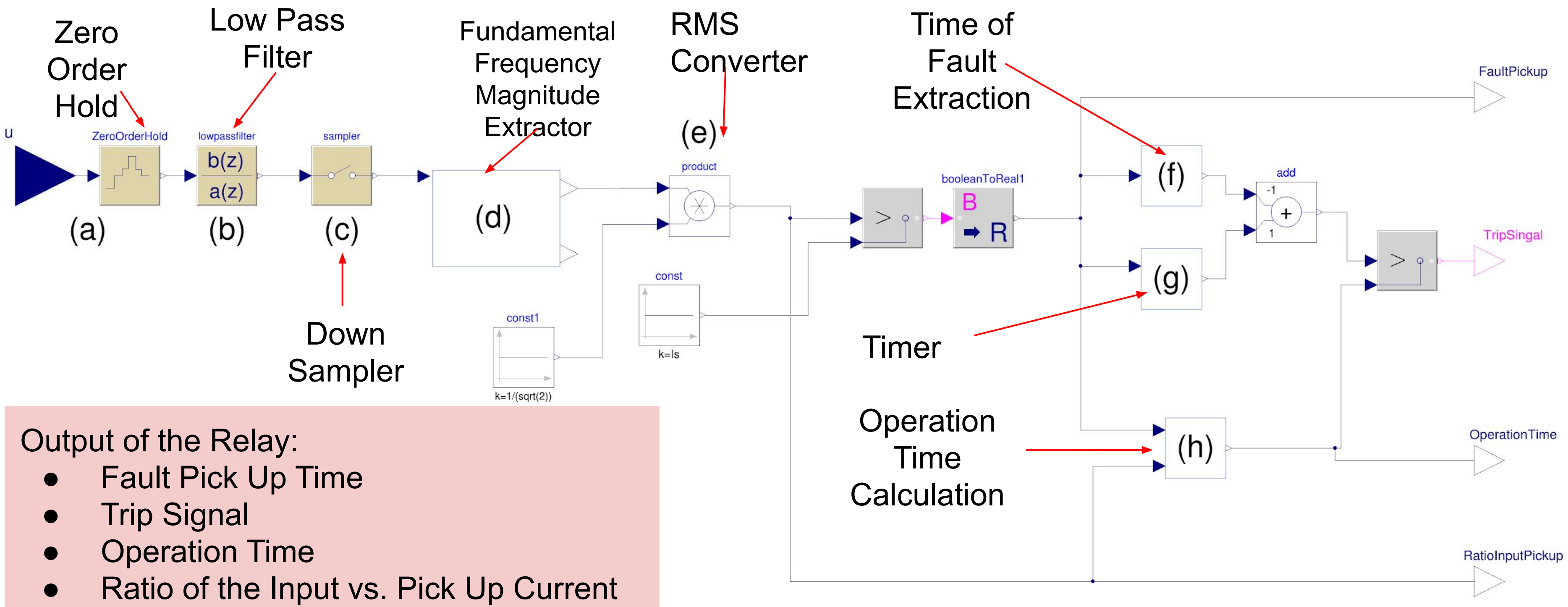
where *eps* is the tolerance.



Output of the Relay:

- Fault Pick Up Time
- Trip Signal
- Operation Time
- Ratio of the Input vs. Pick Up Current

Original Simulink Model presented by Almas et al in [1].

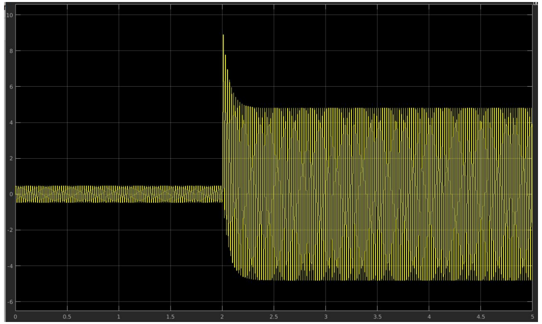


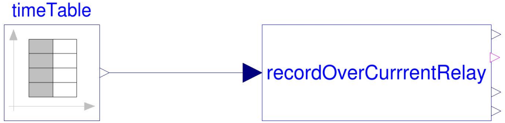
Output of the Relay:

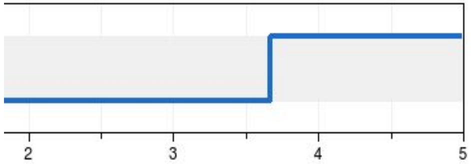
- Fault Pick Up Time
- Trip Signal
- Operation Time
- Ratio of the Input vs. Pick Up Current

Translated Modelica model with the same modules and the same output metrics.

- In order to be able to accurately verify the model these aspects were crucial:
    - **Input signal** - converting the Matlab fault signal into a Modelica `timeTable` relay source.



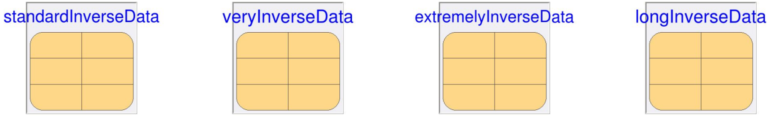




- **Relay types** - 4 different OCR types were implemented through the use of records.

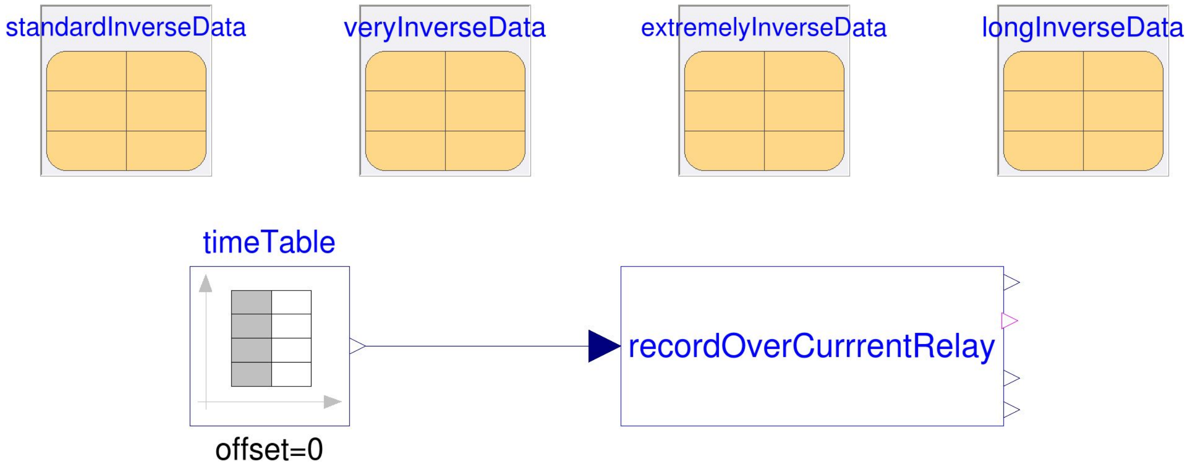
$$T = \frac{C}{\frac{I^{\alpha}}{I_s} - 1} * TMS$$

Type of Relay	α	C
Standard Inverse (SI)	0.02	0.14
Very Inverse (VI)	1	13.5
Extremely Inverse (EI)	2	80
Long Inverse (LI)	1	120

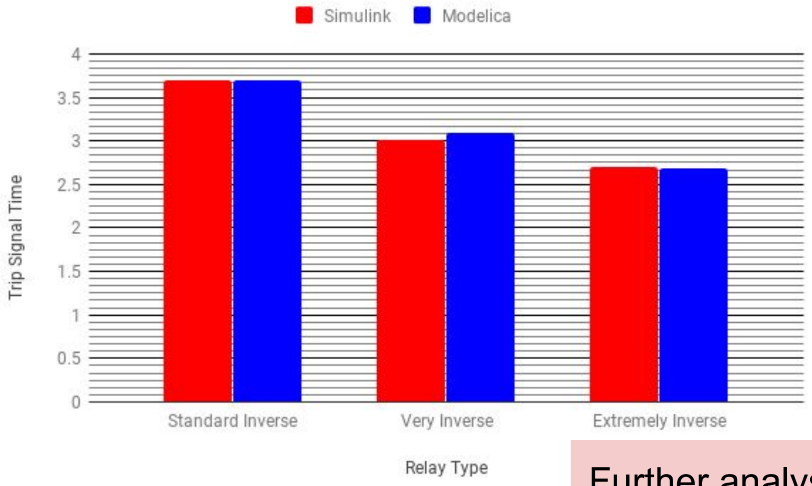


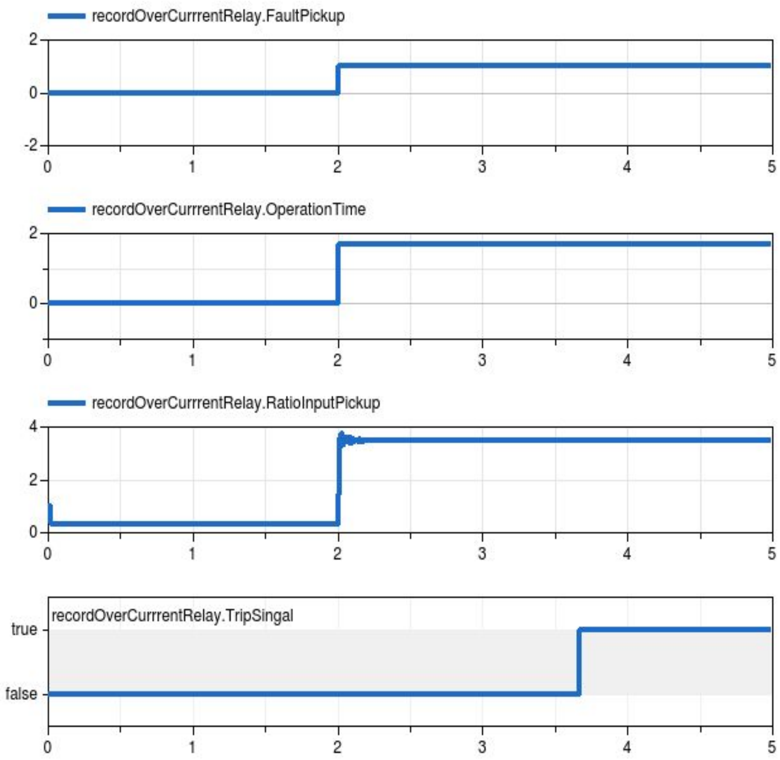
Testing Set Up

- In order to test the OCR by itself, the `timeTable` is set as a source in order to mimic a fault.
- Records were implemented for easy switch between types of OCR as well as storage of the type of OCR information.



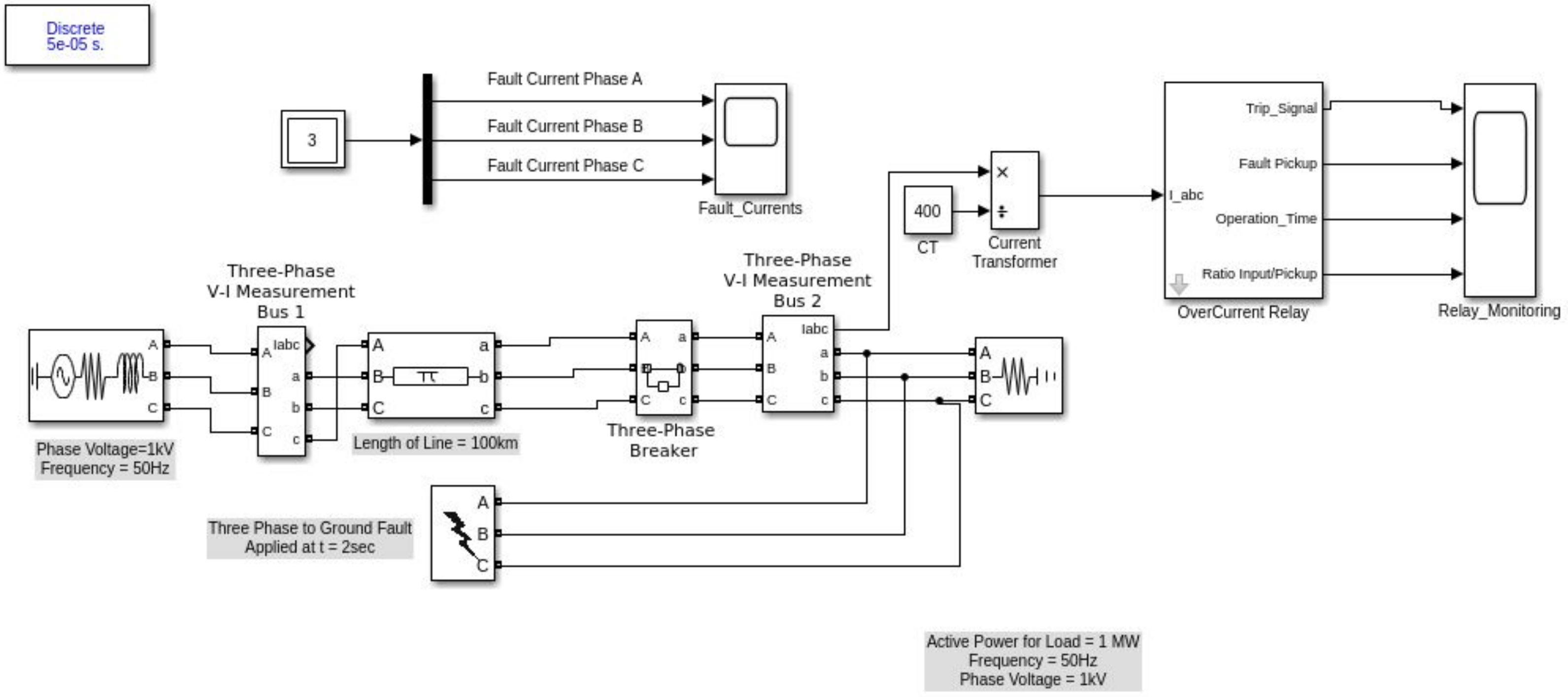
- Out of the 4 outputs given by the OCR, the Trip Signal is the most important one since it is the signal operating the breaker.
- Once tested for all of the different OCR types, average Trip Signal deviation between the Simulink and Modelica models was ~0.44%.
- The trip signal was nearly identical.





Further analysis on the effect of the solvers in the model are available in the paper!

- In [1], the relay was inserted in the power system below:



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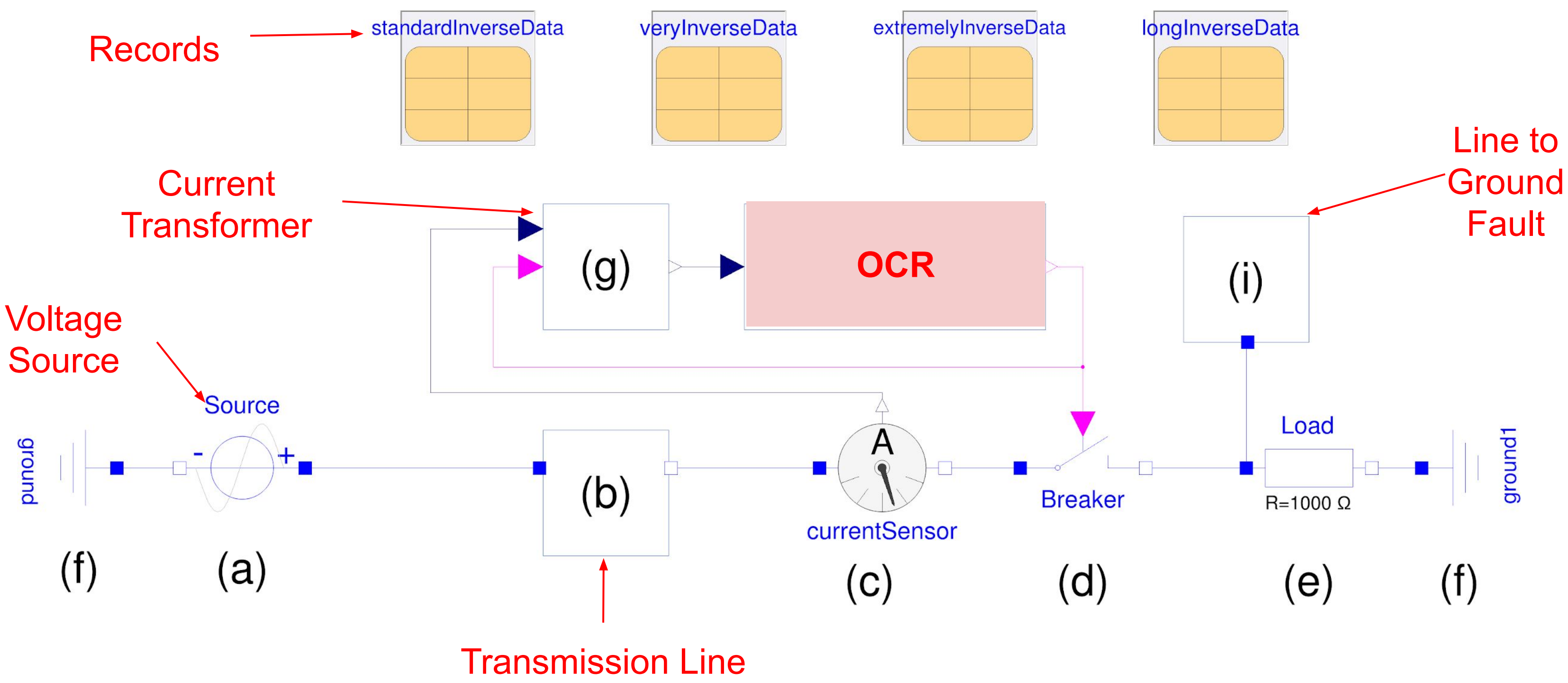
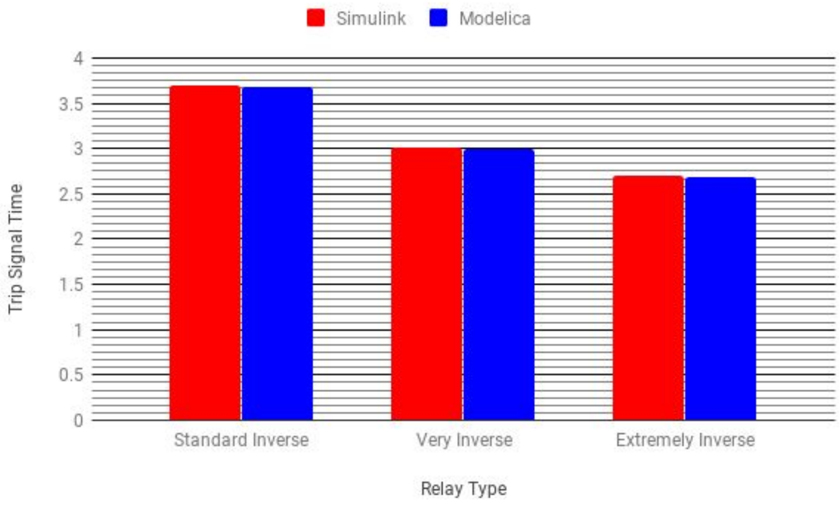
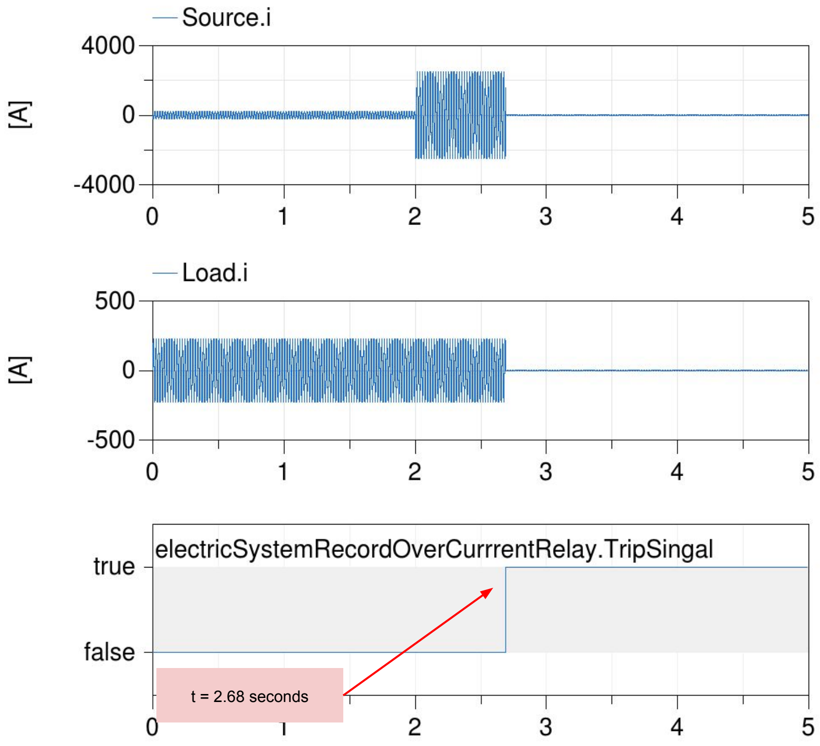
- In order to test and verify the OCR. The power system was recreated in Modelica:



- The results were satisfactory, the breaker opened and the fault was mitigated at the appropriate time of t = 2.68 secs.
- As seen on the figure below, the other OCR types matched with the Simulink model as well. The average discrepancy of all of the OCR types was ~0.40%. The trip signal was nearly identical.





Future Work

- Modify the OCR presented today in order to interact with the OpenIPSL library. This will allow for further and more complex OCR fault and coordination analysis.
- Asses the OCR using other tools such as ePHASOR SIM [4] and EMPT-RV [5] for RT and offline simulation.
- Using the FMI standard will also achieve reusability and portability of the OCR model.

- The model is available at:

  https://github.com/alsetlab/2019_clayton_griffin_overcurrentrelay

[1] Almas, Muhammad Shoaib, Rujiroj Leelaruji, and Luigi Vanfretti. "Over-current relay model implementation for real time simulation & Hardware-in-the-Loop (HIL) validation." IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society. IEEE, 2012.

[2] O. Chilard, J.-P. Tavella, and O. Devaux, “Use of modelica language to model an mv compensated electrical network and its protection equipment : comparison with emtp,” in Proceedings of the 8th International Modelica Conference; March 20th-22nd; Technical University; Dresden; Germany, no. 63. Linkoping University Electronic Press; Linkopings universitet, 2011, pp. 406–413.

[3] “Functional Mock-Up Interface”, https://fmi-standard.org

[4] A. Stefanov and C.-C. Liu, “LTC modeling for integrated simulation of cyber-physical power systems,” in 2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe). IEEE, 2012, pp. 1–8.

[5] V. Jalili-Marandi, “ePhasorSim: real-time transient stability simulation tool,” Event Lecture, 2015.

[6] “Multi-time-step and multi-core simulations in EMTP using the new FMI options,” http://emtp-software.com/page/fmi-options

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