Hardware-in-the-loop testing of innovative under-frequency load shedding with TOR 300 device

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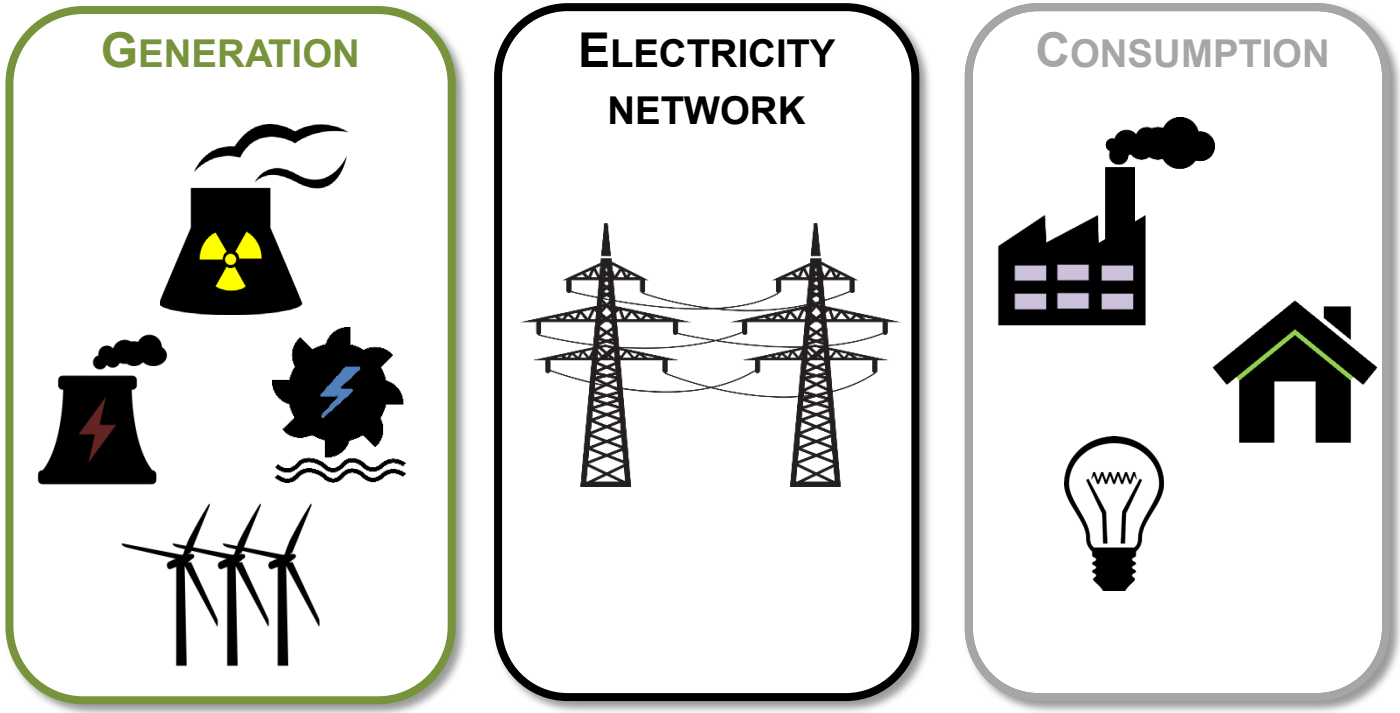
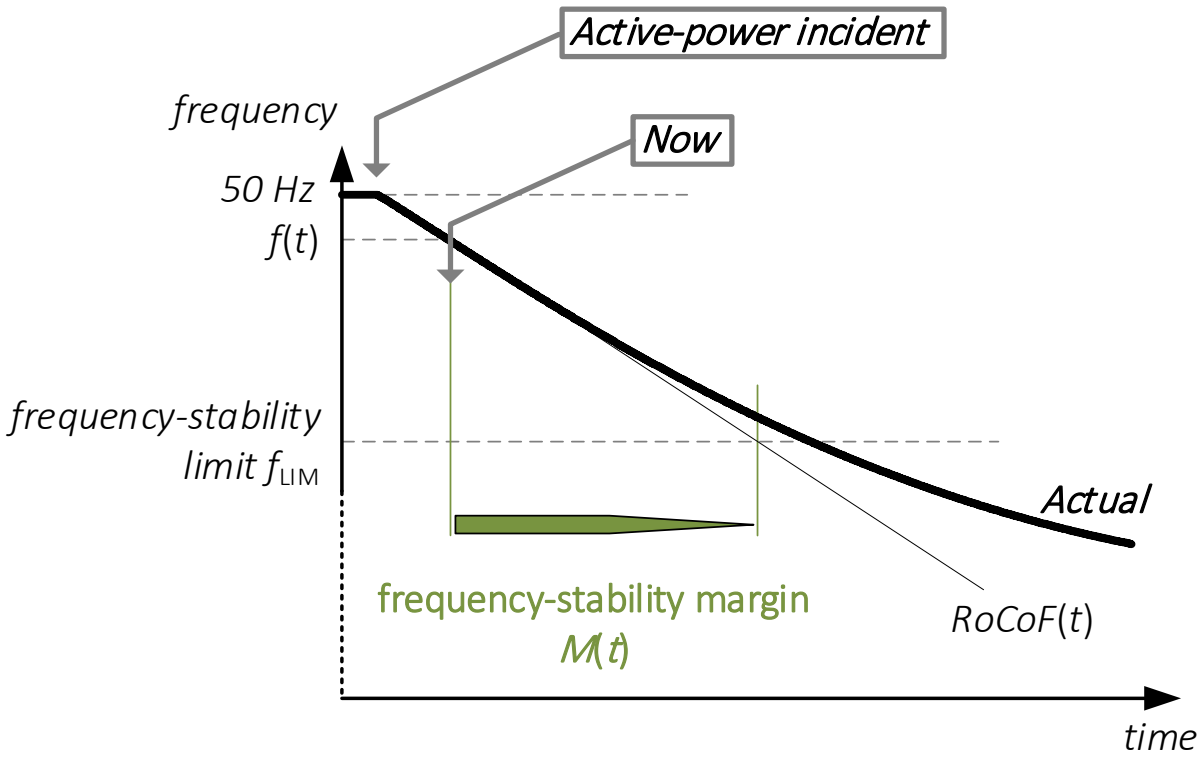
Project background

- Under-Frequency Load Shedding (UFLS) innovation in 2018
- NDA agreement signed between University of Ljubljana (UL) and Relematika Ltd. in 2019
- Implementation to intelligent electronic device (IED) TOR 300 EA 525
- Hardware-in-the-loop (HIL) testing with Real-Time Digital Simulator (RTDS)

UFLS basics

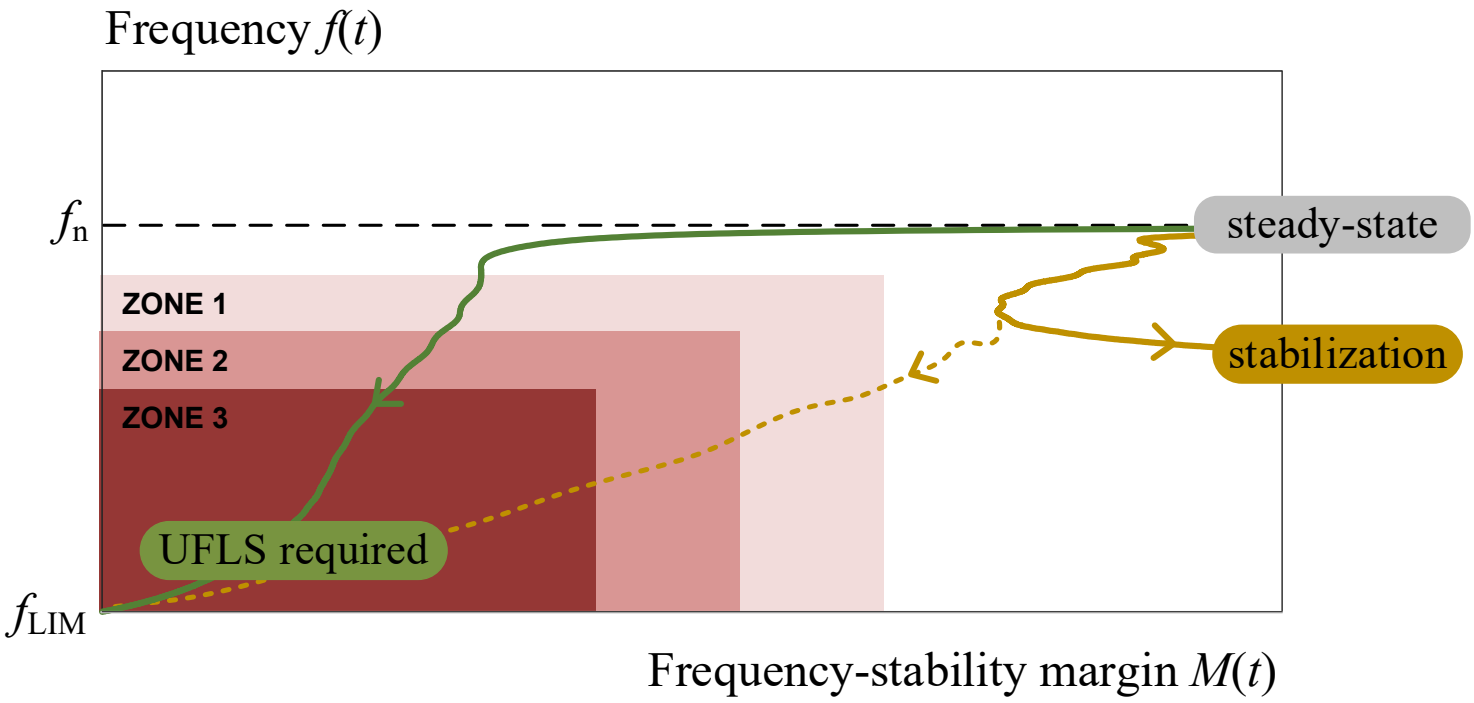


Frequency-stability margin

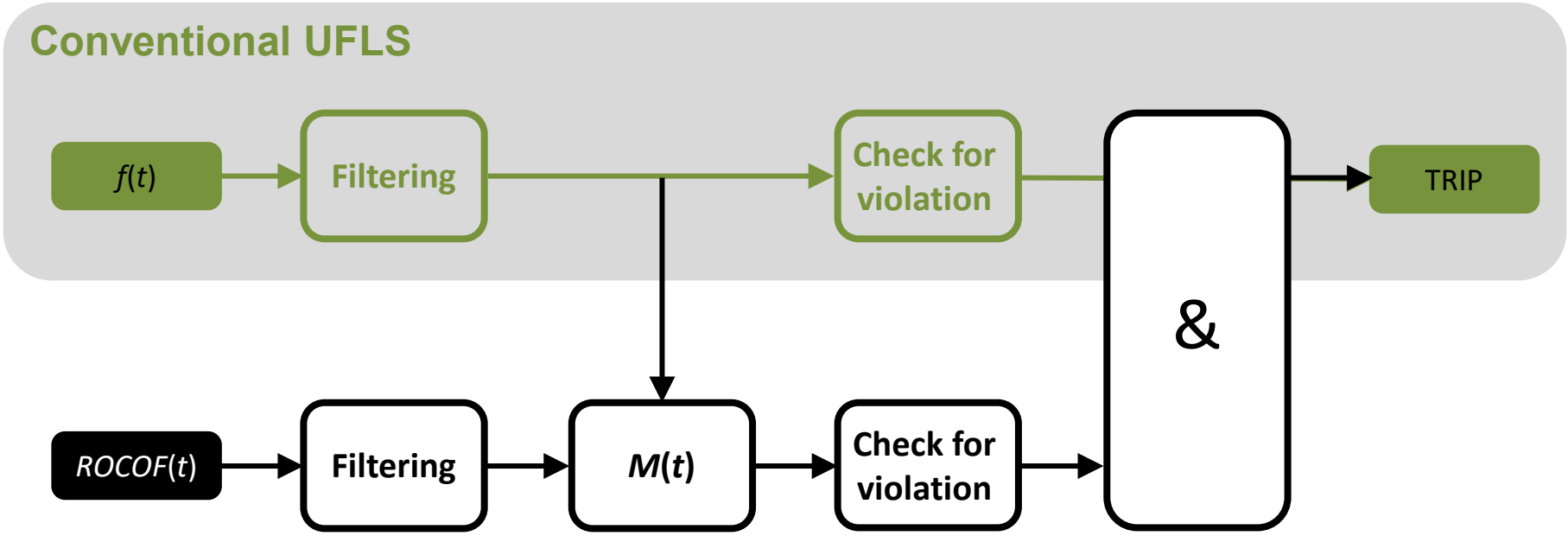


$$M(t) = \frac{f_{\mathrm{LIM}} - f(t)}{RoCoF(t)}$$

Definition of f-M zones

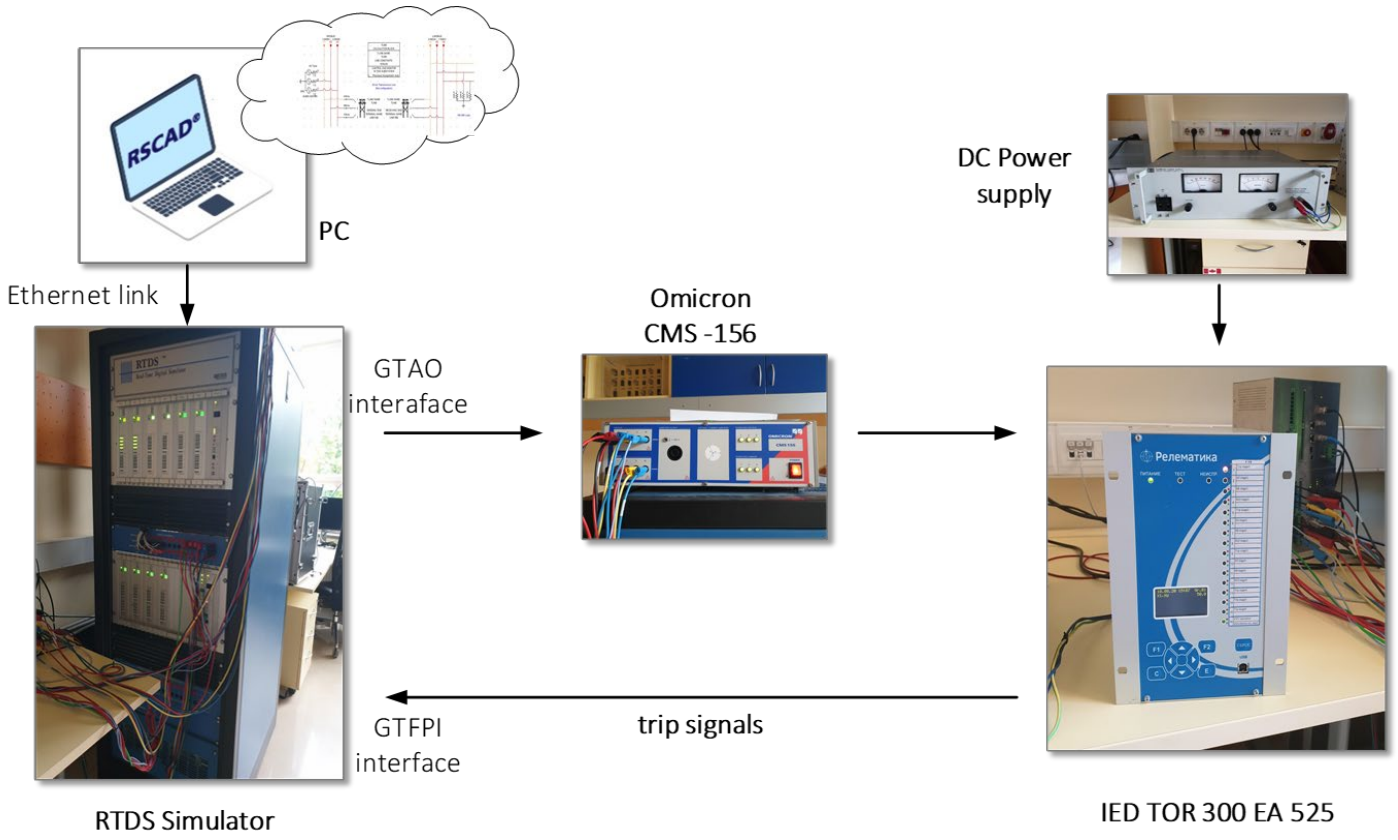


Implementation logic

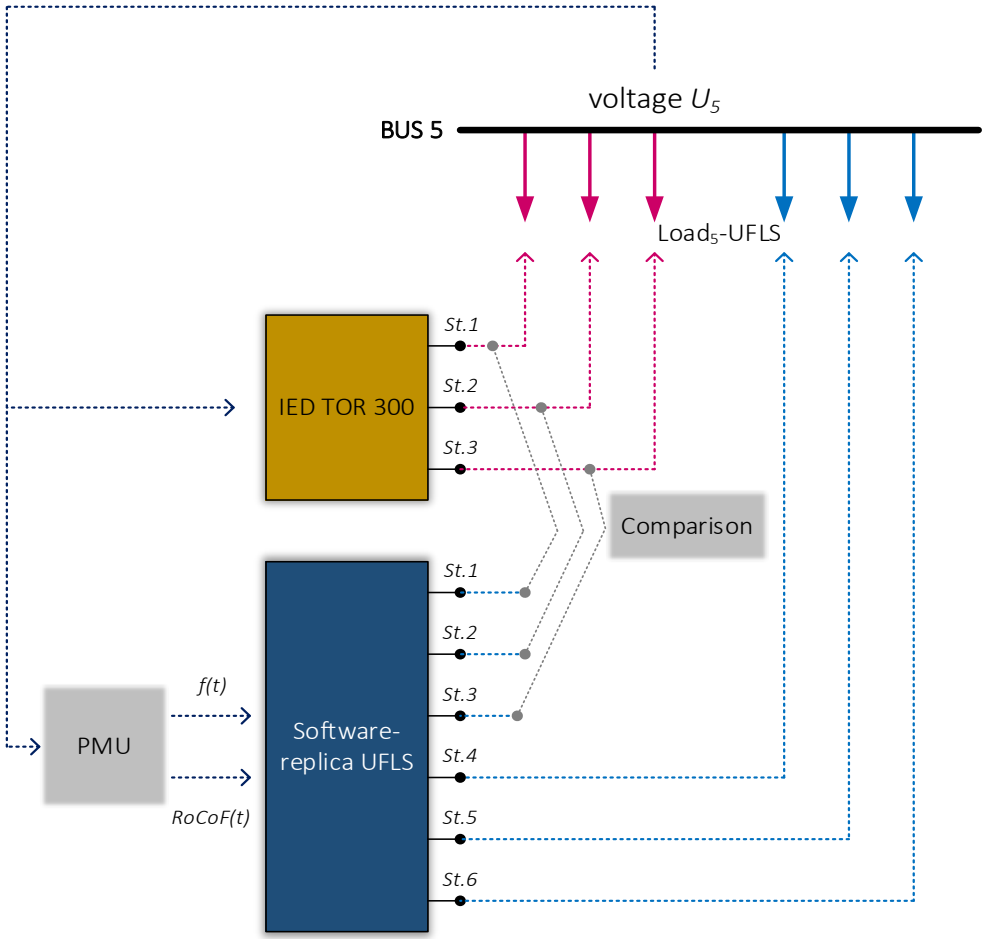


Innovative UFLS

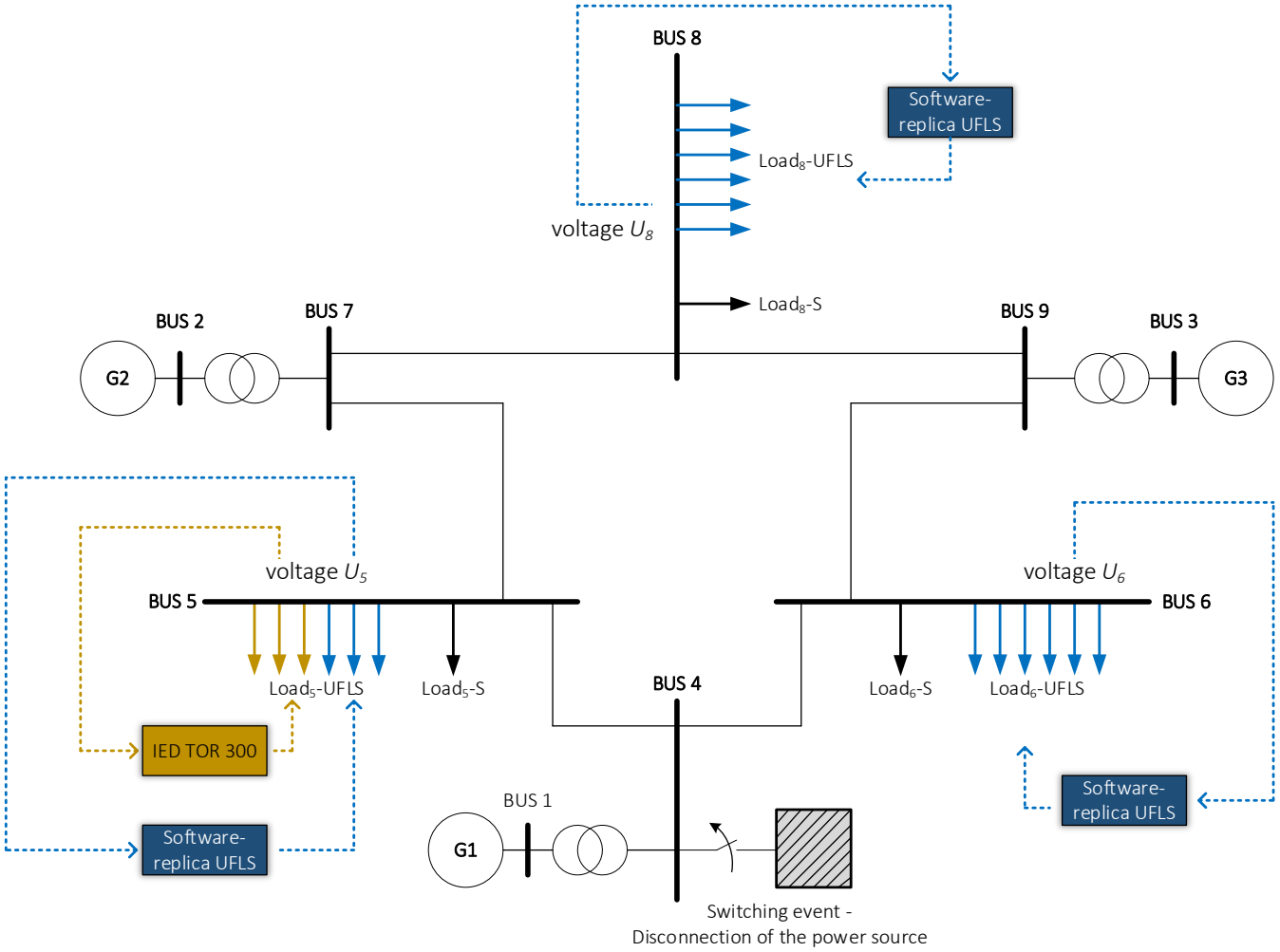
Hardware-in-the-loop setup



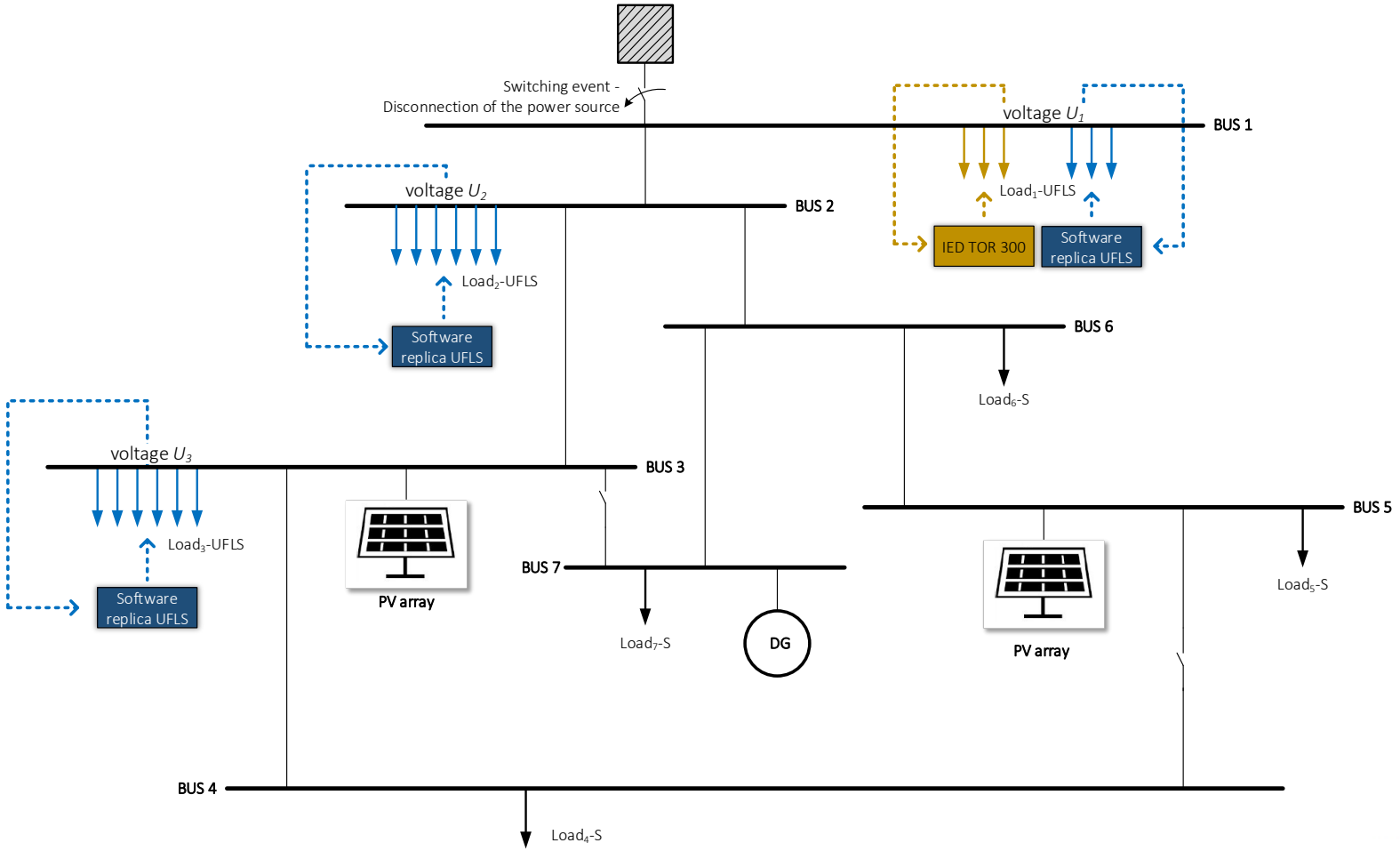
Software replica UFLS



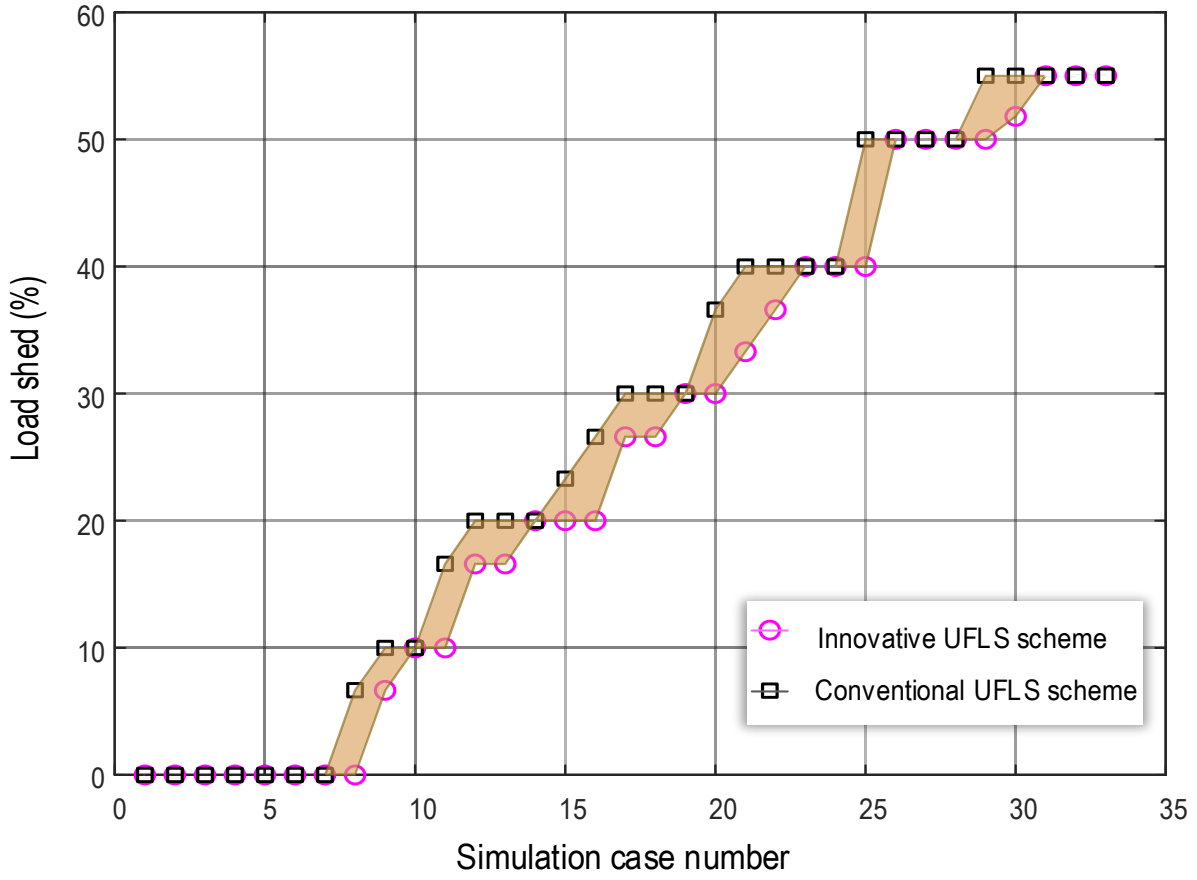
Power system 1 – IEEE 9 bus system



Power system 2 – Microgrid

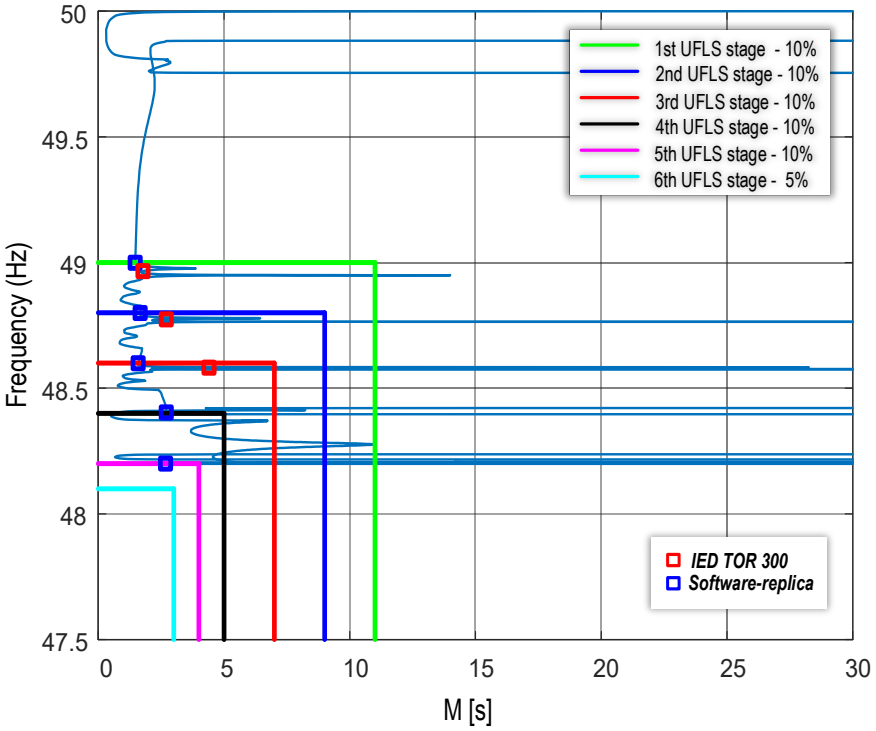


Simulation results – System 1

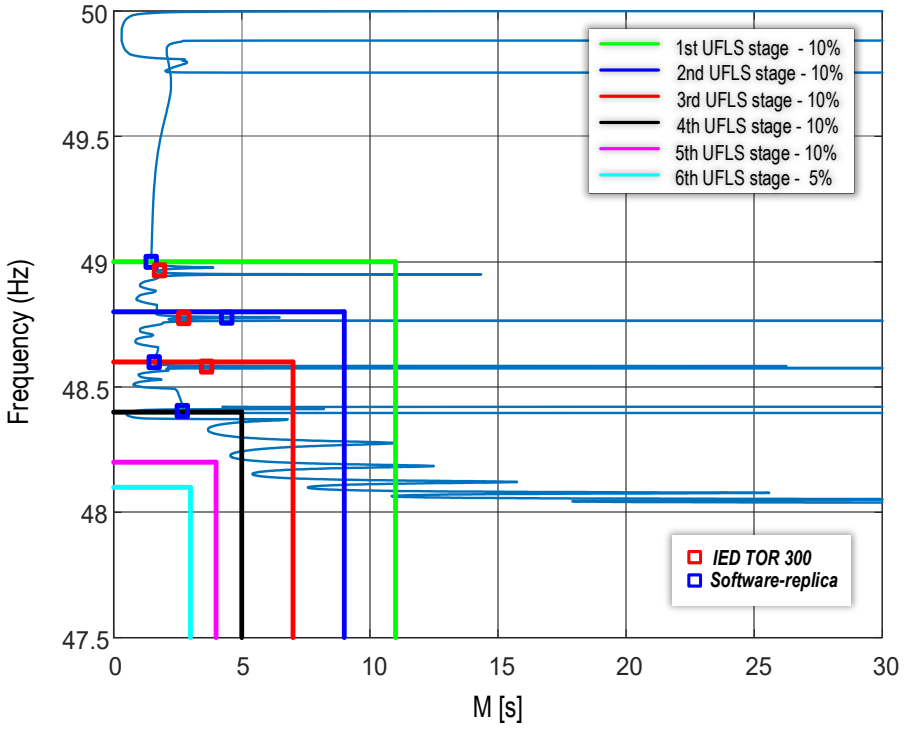


Simulation results – System 1

- Conventional UFLS scheme



- Innovative UFLS scheme
  - Improved filtering method



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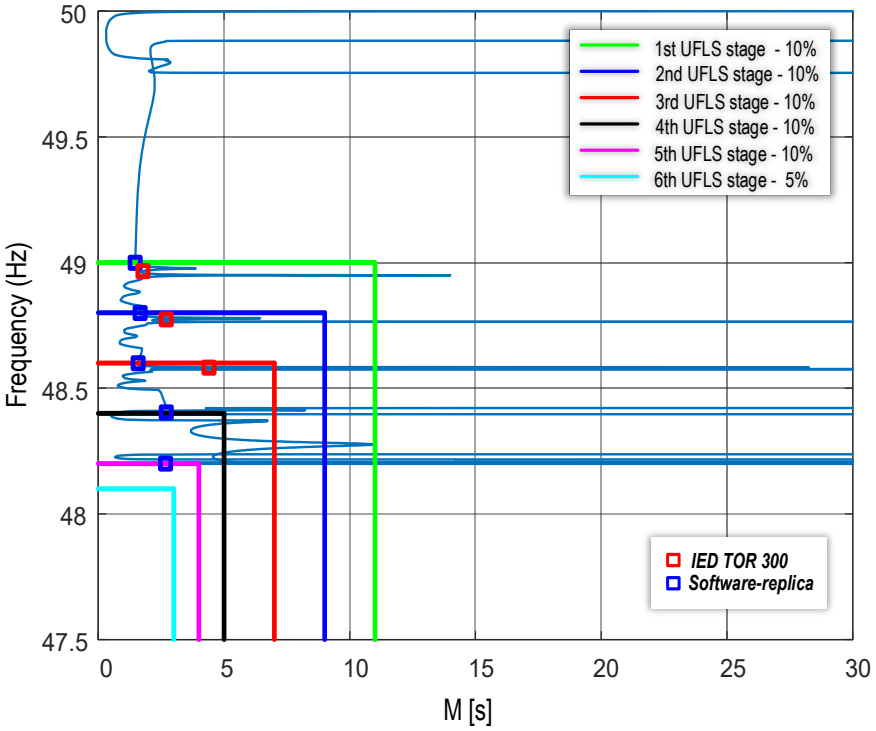

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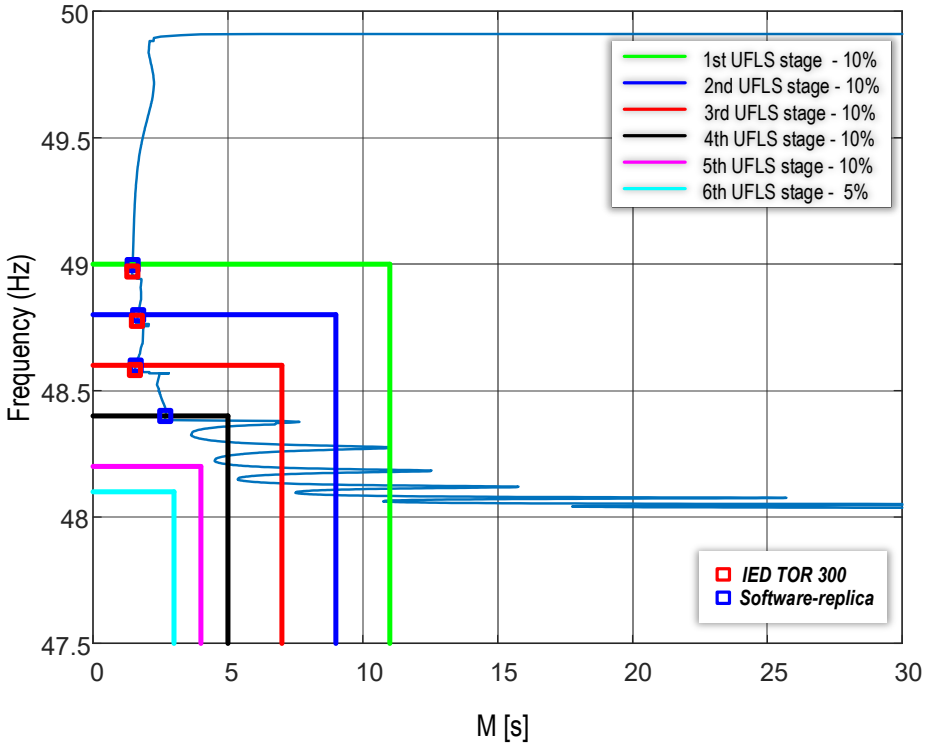
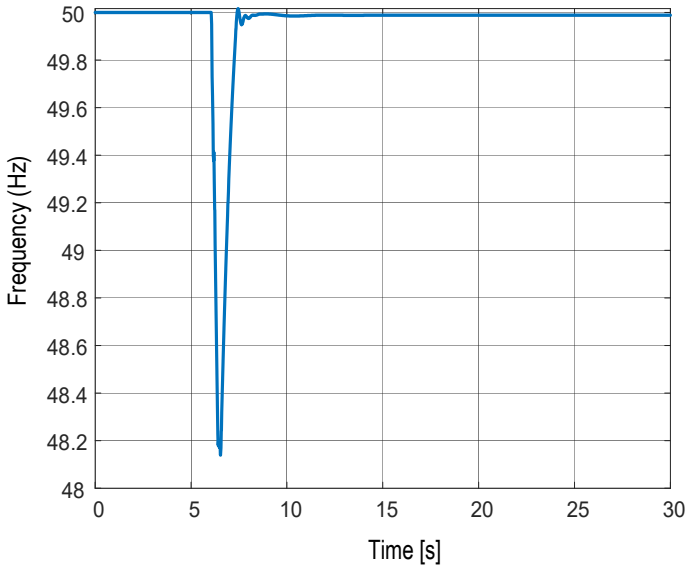
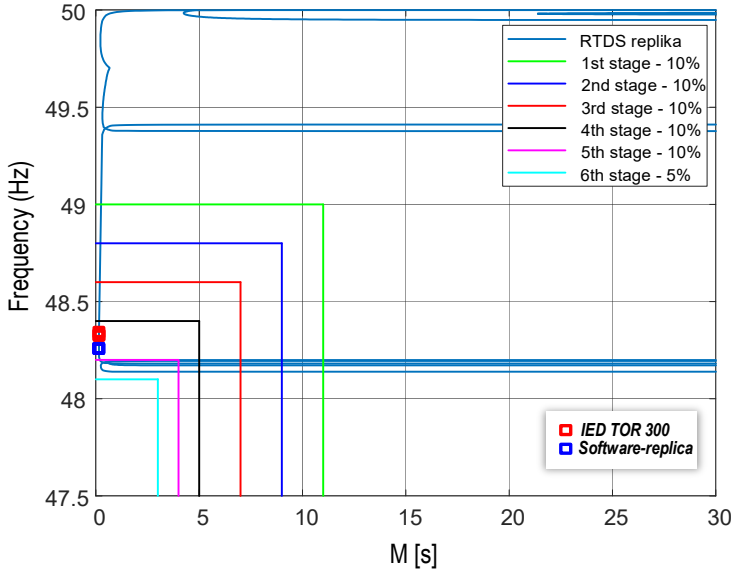


Simulation results – System 2

- Low-inertia system with high *RoCoF(t)* values
- Time delay introduced for the duration of M_{thr} violation affects the operation of the UFLS function
- Improved filtering of the input data





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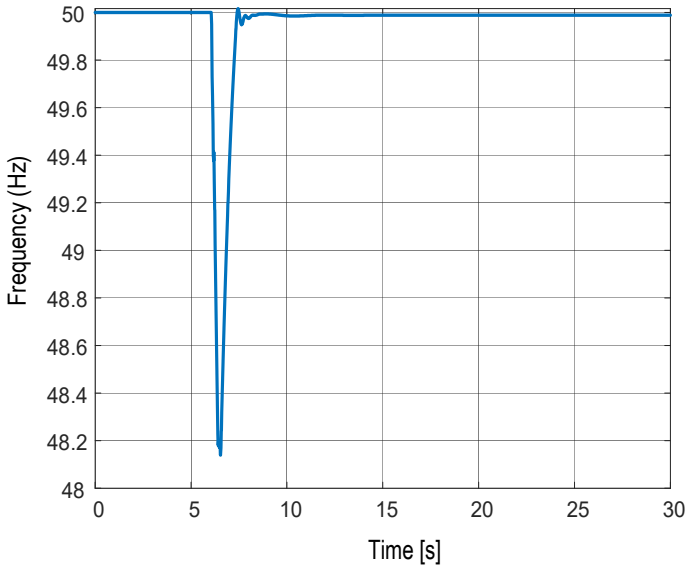

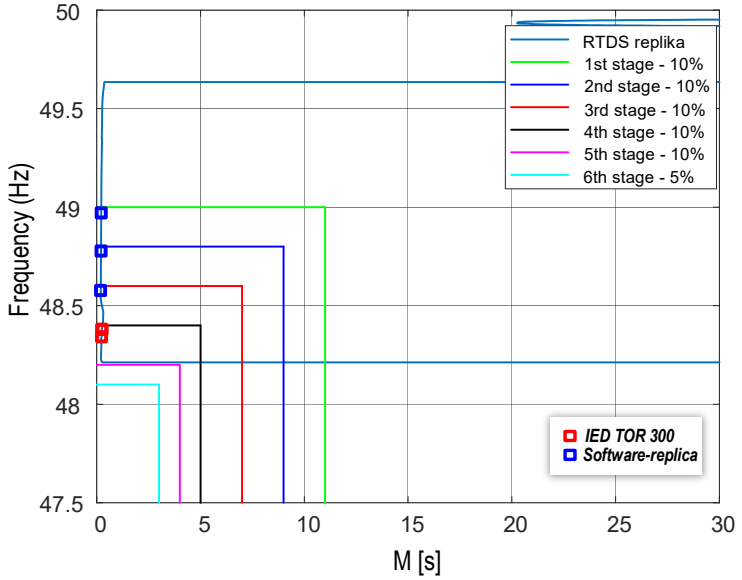

Project outcomes and conclusions

- Frequency-stability margin $M(t)$ was successfully merged with frequency measurement $f(t)$, improving the existing situational awareness of an IED.
- The existing IED single-criterion tripping functionality was successfully expanded into a double-criteria tripping functionality.
- In an IEEE 9-bus test system model, the innovative UFLS functionality keeps more load supplied compared with the conventional UFLS.
- In high $RoCoF(t)$ conditions, innovative UFLS acts identically to conventional UFLS, posing no risk to power-system security under extreme conditions.

Future plans

- Modelling and testing on other EPSs
- Upgrading the innovative UFLS technology – frequency thresholds f_{thr} dependent on *M(t)*
- Implementation of frequency-stability margin *M(t)* in WAMS