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Robust and Interoperable Control Strategies for Grid-Forming and Grid-Following Inverter-Based Power Systems

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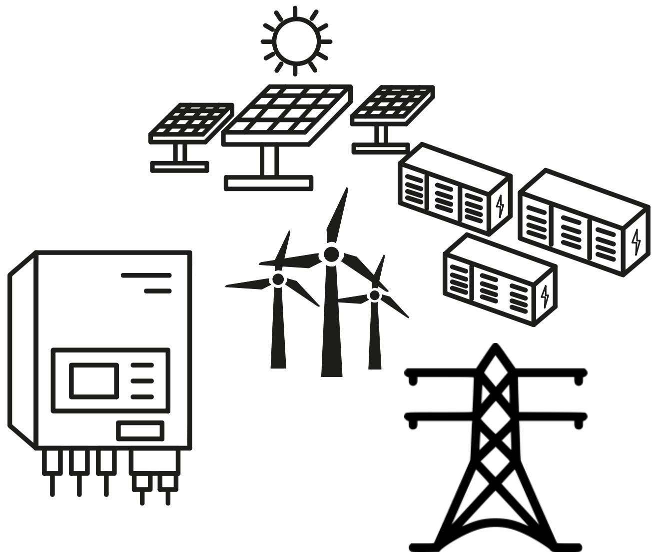
UNIVERSITY OF TWENTE. | POWER ELECTRONICS GROUP

Motivation

- *What is interoperability?*
- *Observed issues*
- *How to investigate it?*
- *Results*



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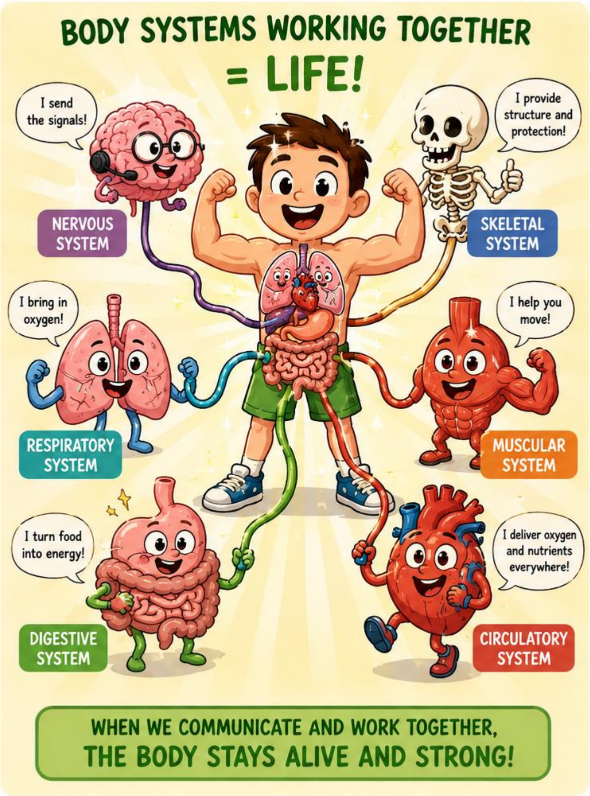
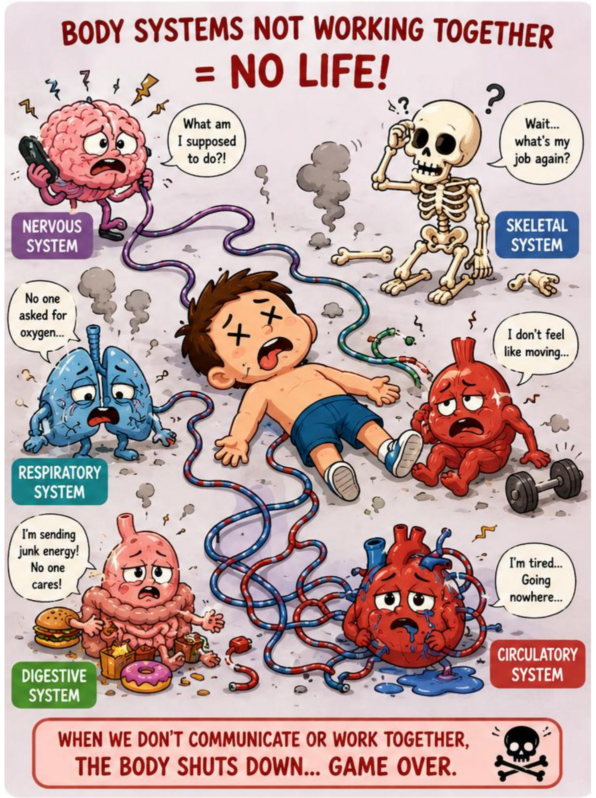
Interoperability

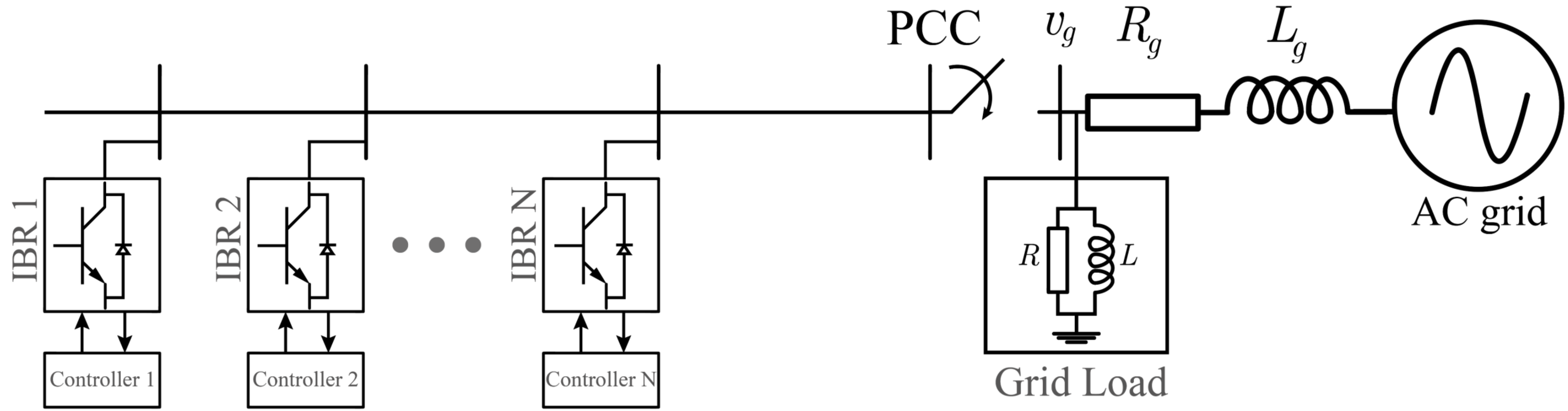
"Interoperability is the ability of different systems, devices, or components to operate together in a compatible and coordinated manner by exchanging information and functioning without conflicts."



VS



Interoperability



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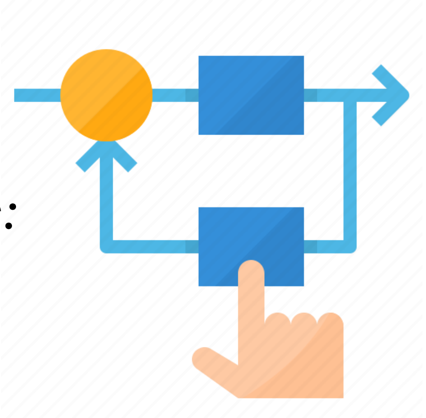
Issues

- *Decrease in inertia*
- *Curtailments*
- *Blackouts*
- *Damage*

Investigation

- *Control analysis and design*
- *Simulations*
- *Real-time hardware-in-the-loop simulations:*
  - *HIL*
  - *C-HIL*
  - *P-HIL*



Investigation

Control analysis and design

MATLAB & SIMULINK

Controller Evaluation

plexim
electrical engineering software

plecs

rt box

Controller Validation (C-HIL)

Typhoon HIL

Investigation

C-HIL

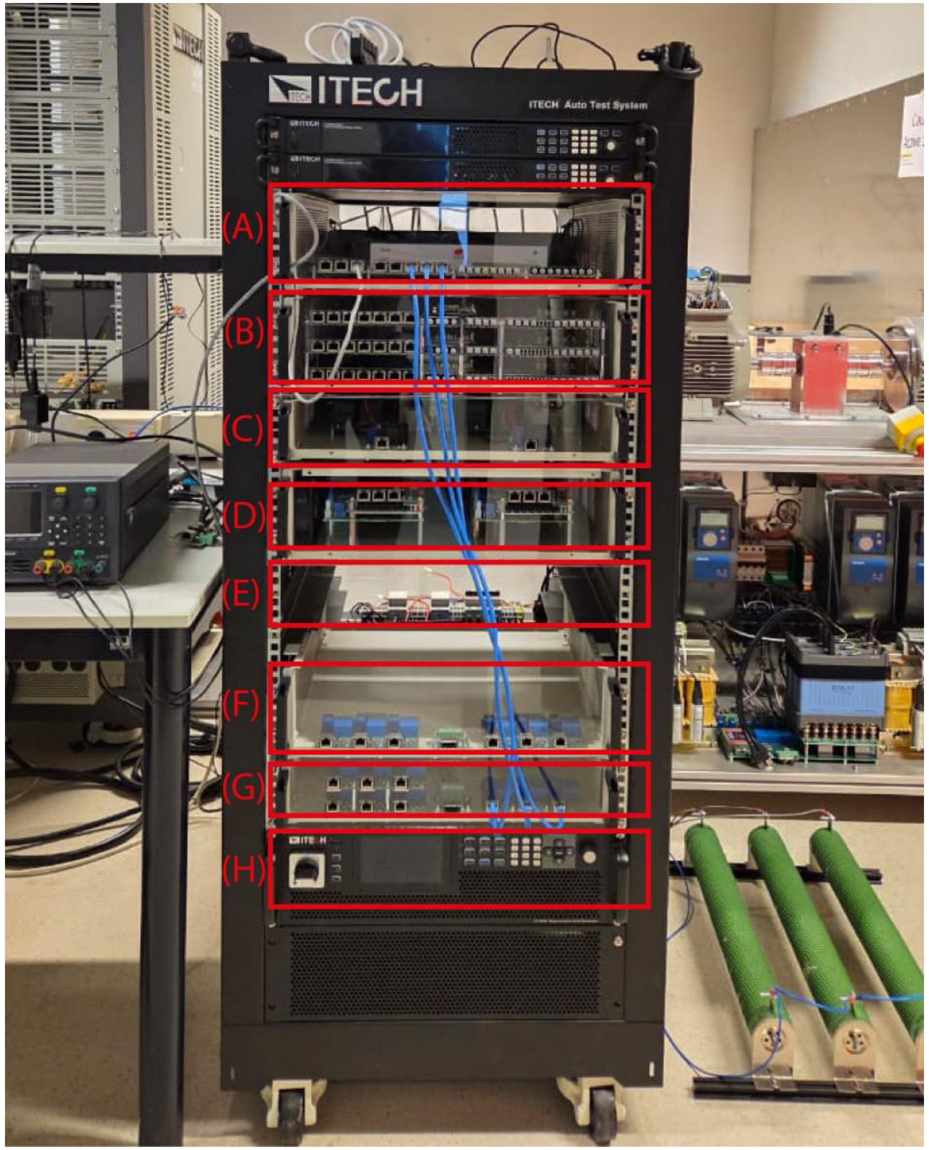
(i) Typhoon HIL Schematic editor and SCADA

(ii) C-HIL
- Typhoon HIL 604 (x2)
- Texas Instruments F28379D LaunchPads (x2)
- Computer

Investigation

P-HIL

(A) x1 RTS – Typhoon HIL 404
(B) x3 MCUs
(C) x2 DC filters
(D) x2 Inverters
(E) x2 AC filters (missing)
(F) x2 AC measurements
(G) x1 Grid Connection



Investigation

Classical approaches (PI):

- Forward voltage loop
- Current feedback loop
- Cascade Voltage-current loop

Advanced methods:

- State-space control
- Fuzzy
- Sliding mode control
- Passivity control
- MPC
  - LQR
  - H2
  - Hinf
  - MJLS

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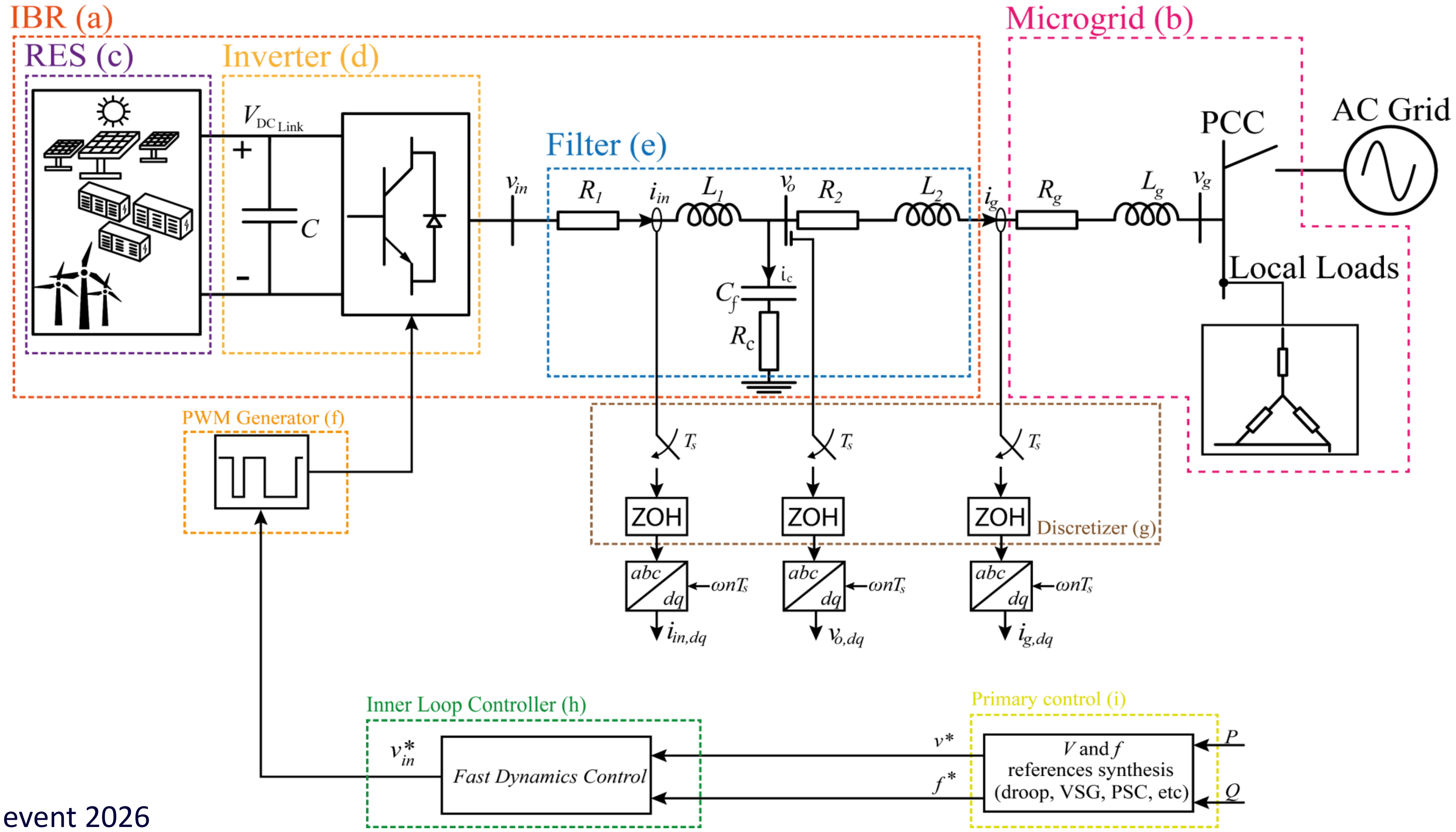
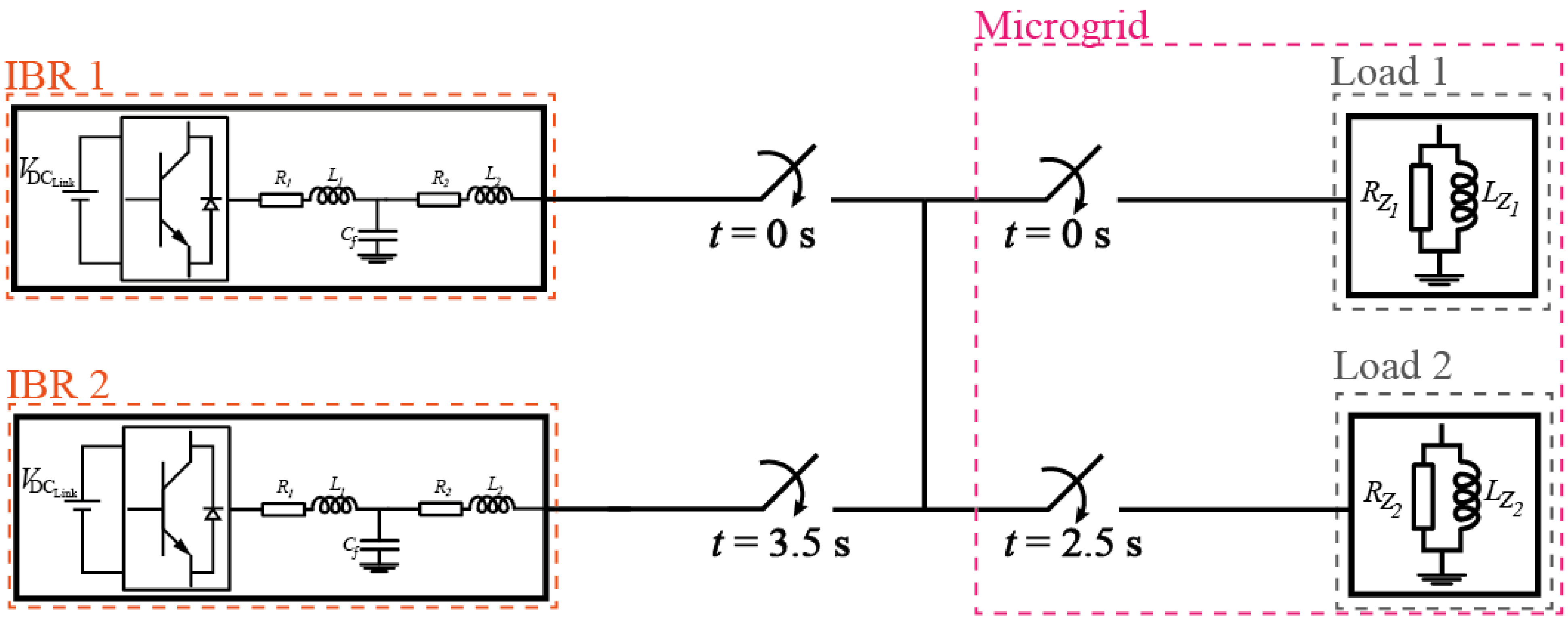
Results



Results


Microgrid
IBR 1
IBR 2
Load 1
Load 2
$V_{DC_{Link}}$
R_1
L_1
R_2
L_2
C_f
$t = 0$ s
$t = 0$ s
$t = 3.5$ s
$t = 2.5$ s
R_{Z_1}
L_{Z_1}
R_{Z_2}
L_{Z_2}

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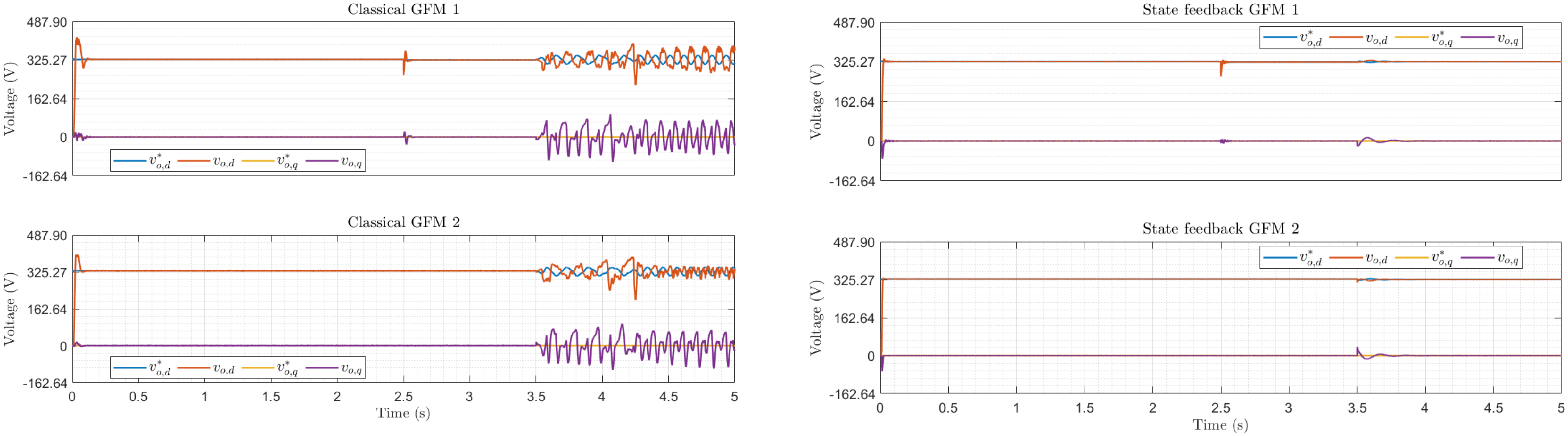
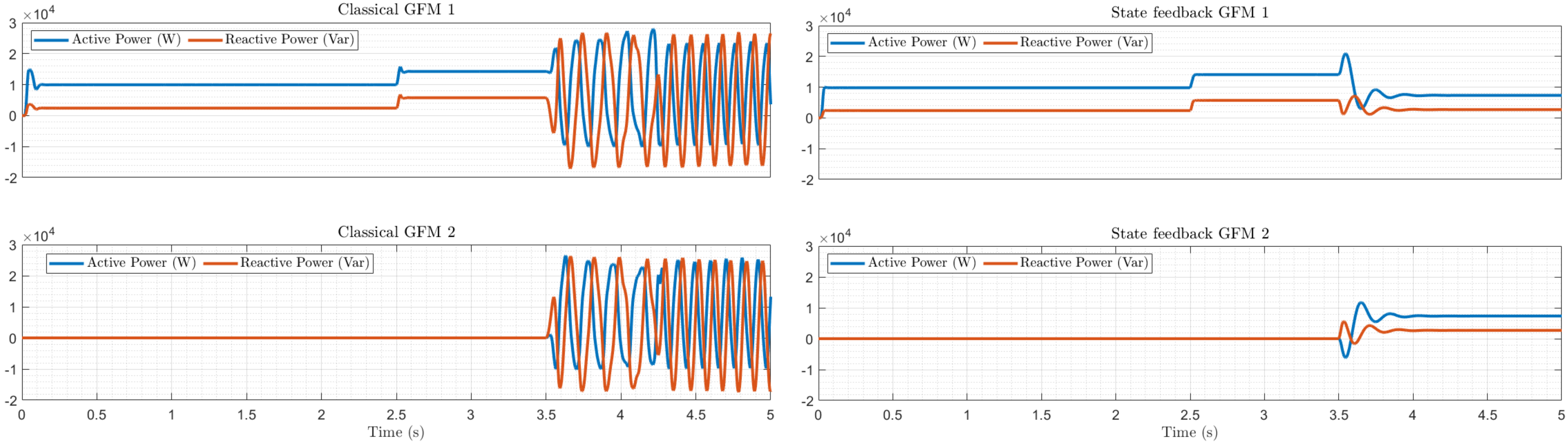
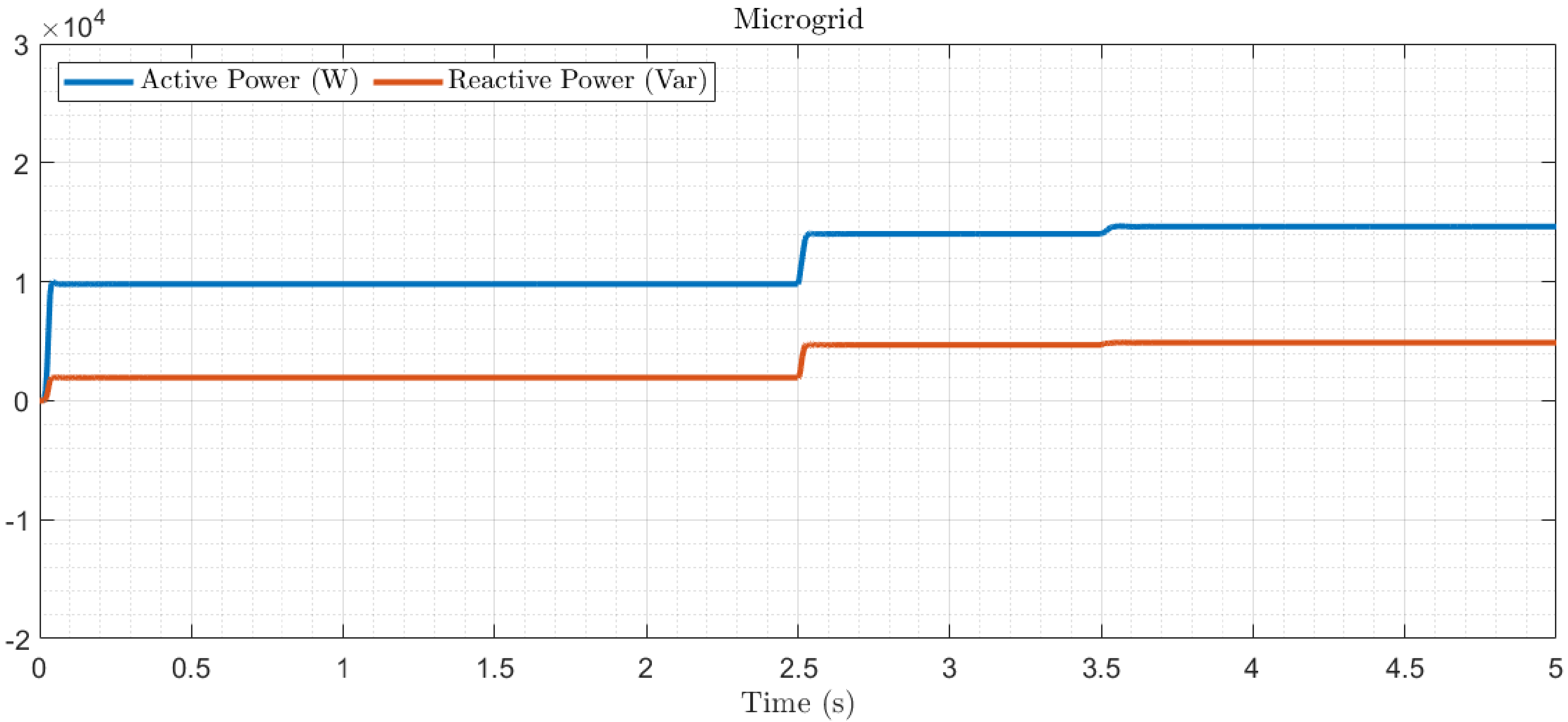
Results – Voltage control



Results – Power sharing



Results – Power supplied



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Results

Conclusion

- Better performance
- No need for Virtual Impedance
- Reliable power sharing

Future work

- Adding more parallel IBRs
- Modelling disturbances
- Power Hardware-in-the-loop implementation

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Results - Paper

Enhancing Robustness and Interoperability of Grid-Forming Inverters via State Feedback Control

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***Abstract*—This paper evaluates, through simulations, the performance and robustness of grid-forming (GFM) inverter-based resources (IBRs) using state feedback and conventional proportional-integral (PI) controllers, both in the *dq* reference frame. The objective is to investigate whether a standardized control strategy among paralleled IBRs can improve system stability and contribute to the ongoing energy transition, where the penetration of renewable energy sources (RES) enabled by power electronics is steadily increasing. A linear quadratic regulator (LQR)-based state feedback control model is derived and implemented, and its performance under parallel operation is compared with the most commonly used control strategy for GFM inverters. The state feedback approach exhibits better performance under the studied conditions, demonstrating robustness under variations in grid parameters. Moreover, the IBRs show to be interoperable, capable of operating in parallel without interfering with each other. Notably, this stability is**

When multiple IBRs operate in parallel, an outer-loop controller is required to ensure proper power sharing. This control layer, block (i) in Fig. 1, is commonly referred to as primary control and includes strategies such as droop control [3]. Although primary control is crucial for power-sharing performance, and increasingly robust approaches have been proposed (see, e.g., [4]), this work focuses instead on the inner-loop controller, that is, the fast switching governor of the inverter's semiconductor switches. Numerous studies describe a classical PI-based control structure for GFMs, typically consisting of cascaded voltage- and current-control loops [5]. Even though this control architecture achieves good performance in managing the output voltage and frequency, connecting inverters in parallel and load/grid changes can

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THANK YOU!

"Robust and interoperable control powers the future grid."

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