Harvesting MHK Energy through Grid-Connected Offshore Microgrid Cluster and Multi-Terminal HVDC Link

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1. Objective

- **Designing an offshore microgrid (MG) cluster with multiple MHK sources for energy harvesting and implementing appropriate hierarchical control**
- **Implementing grid-forming controller in each microgrid to ensure islanded operation**
- **Achieving accurate power sharing among on-shore grids connected with off-shore generation via MT-HVDC**
- **Testing hardware-in-loop and control in hardware as a proof of concept of offshore microgrid architecture**

2. Offshore Microgrid Cluster Connected to Onshore Grid via HVDC System

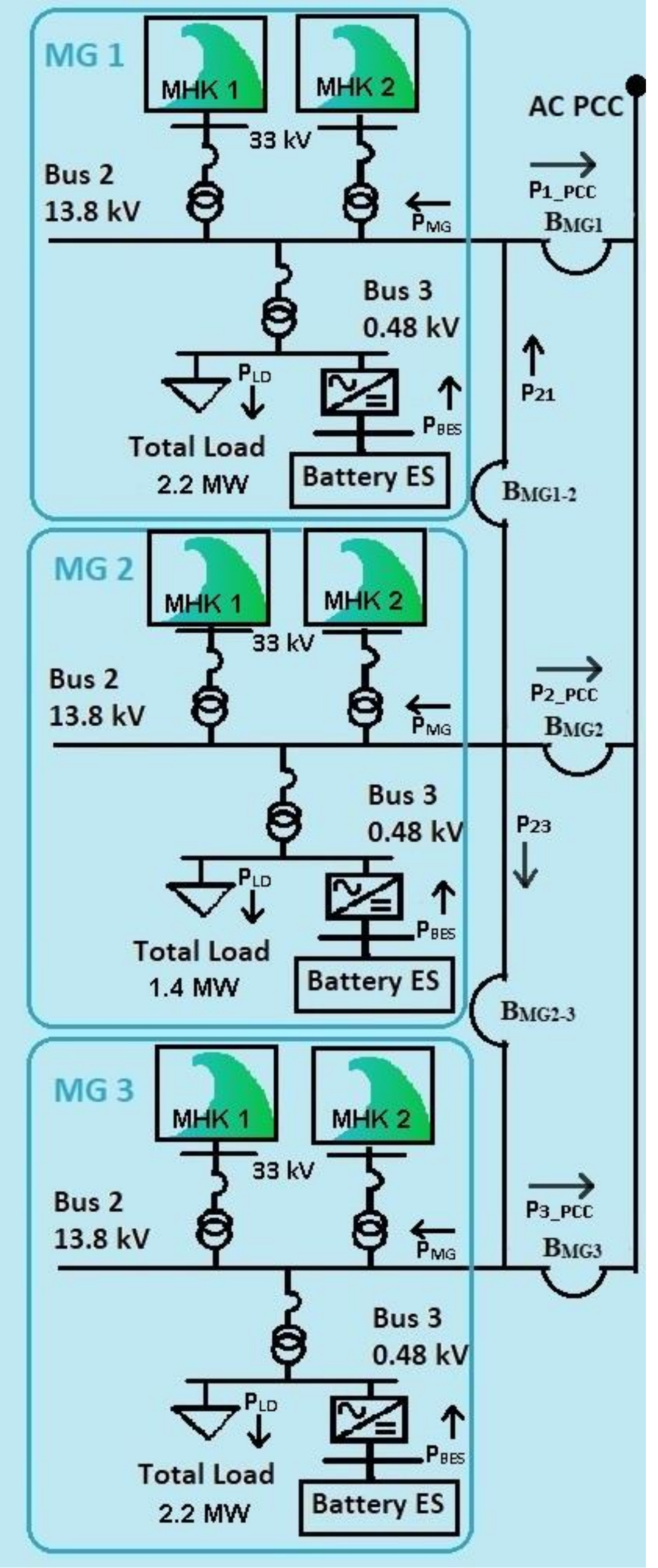


Fig. 2.1. Cluster of three offshore microgrids

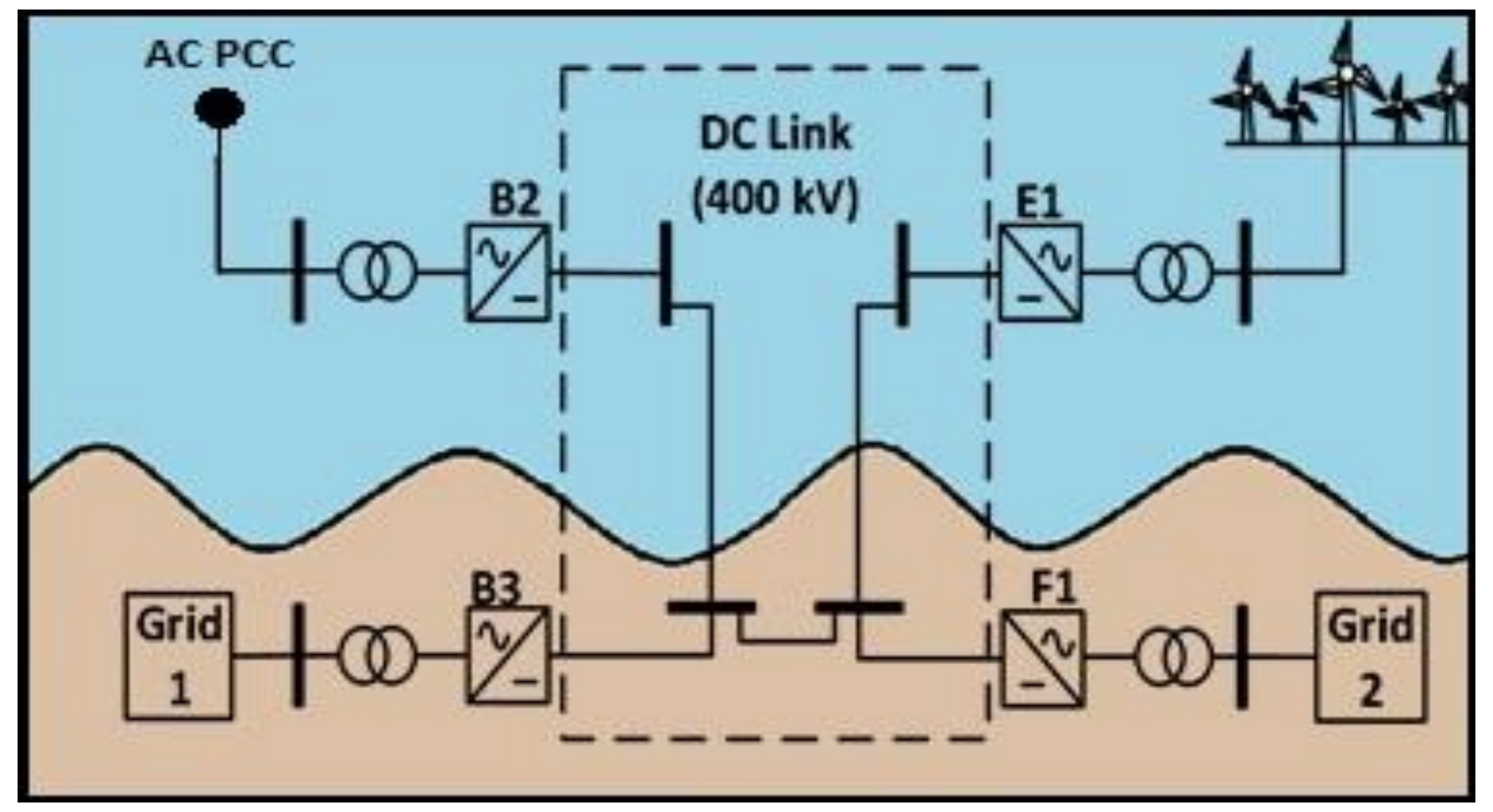


Fig. 2.2.. Four-terminal HVDC system [1]

HVDC System (Fig. 2.2) Description

- 400 kV HVDC grid with a Modular Multilevel Converter (MMC) at each of its 4 terminals
- Converter stations B3 and F1 connected to onshore grids
- E1 connected to offshore windfarm generating 250 MW
- B2 connected to cluster of MGs presented in Fig. 2.1

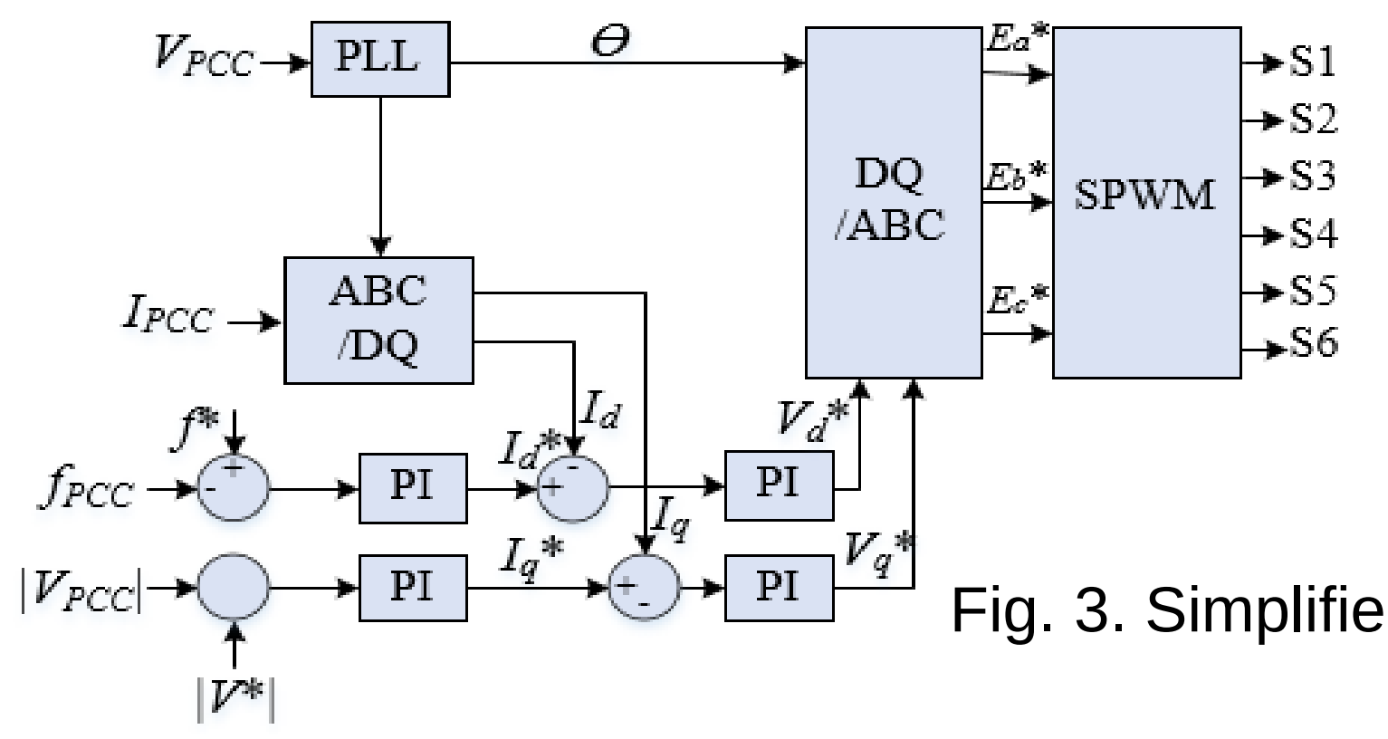
MG Cluster (Fig. 2.1) System Description

- Each of the 3 MGs connected to AC-PCC by sectionalizing breakers BMG1, BMG2 and BMG3; tie-breakers BMG1-2 and BMG2-3 are open
- Each MG has 2 MHKs (rated 1 MW) at 33kV buses, generating 2 MW
- Each MG has 1 battery energy storage (BES) and loads at bus 3 (0.48 kV)
- MG1 and MG3 each has 2.2 MW (1.6 MW essential and 0.6 MW non-essential) load
- MG2 has 1.4 MW essential load

Simulation Case

A simulation case of this test system performed in PSCAD is shown in section 4.

3. Grid-Forming Inverter Control Scheme



- In the absence of grid, the voltage and frequency magnitude is defined, and the stability is maintained by the grid-forming (GFM) inverters in the model
- V-f, PV and Q-V droop, and islanded mode of operations are possible
- V-f control is used for our test case of the islanded system

Fig. 3. Simplified schematic diagram of the controller of the Grid-forming ES-inverter in islanded mode operation [2]

4. Simulation Results

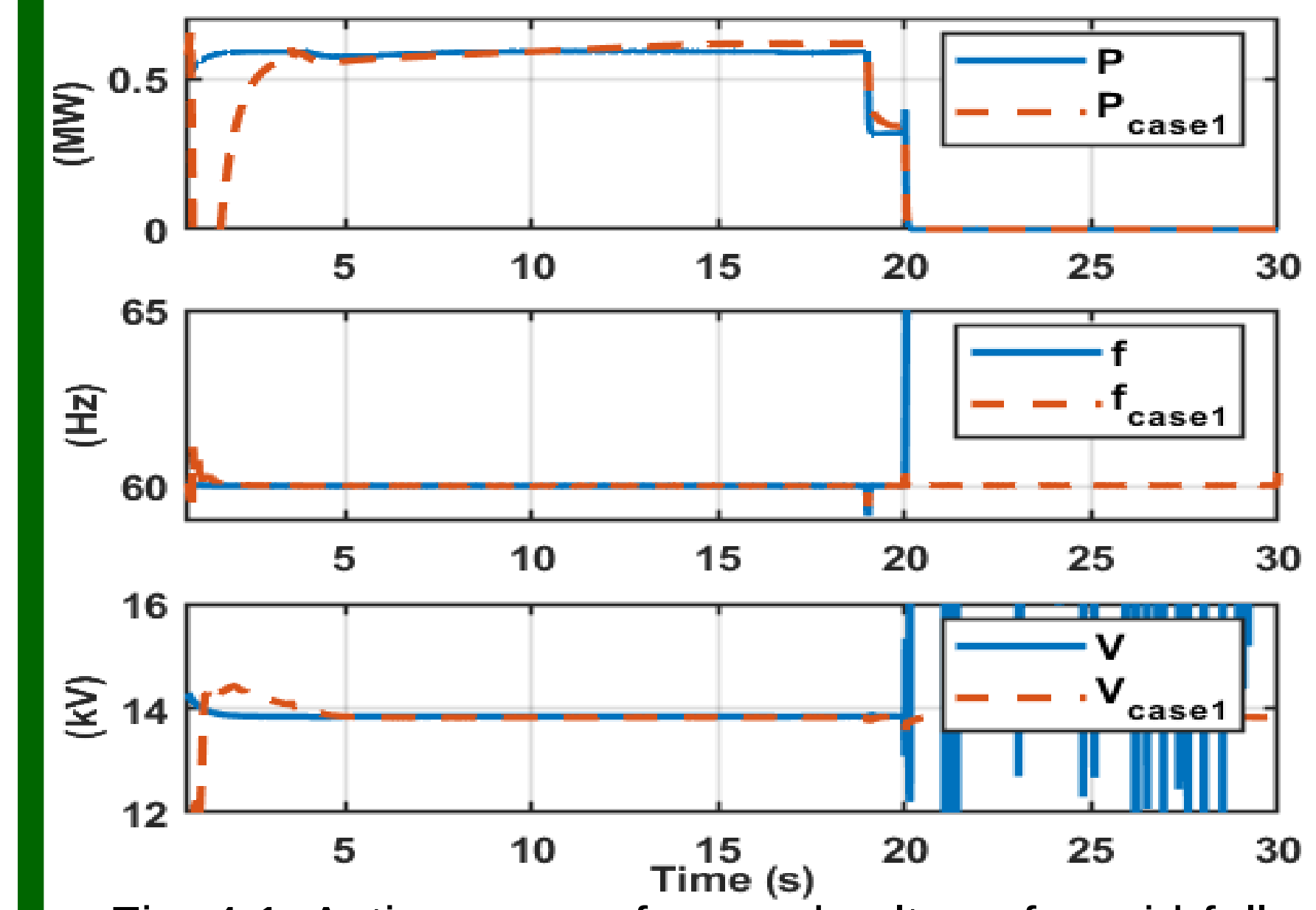


Fig. 4.1. Active power, freq and voltage for grid-following vs grid-forming controller implemented in the MGs

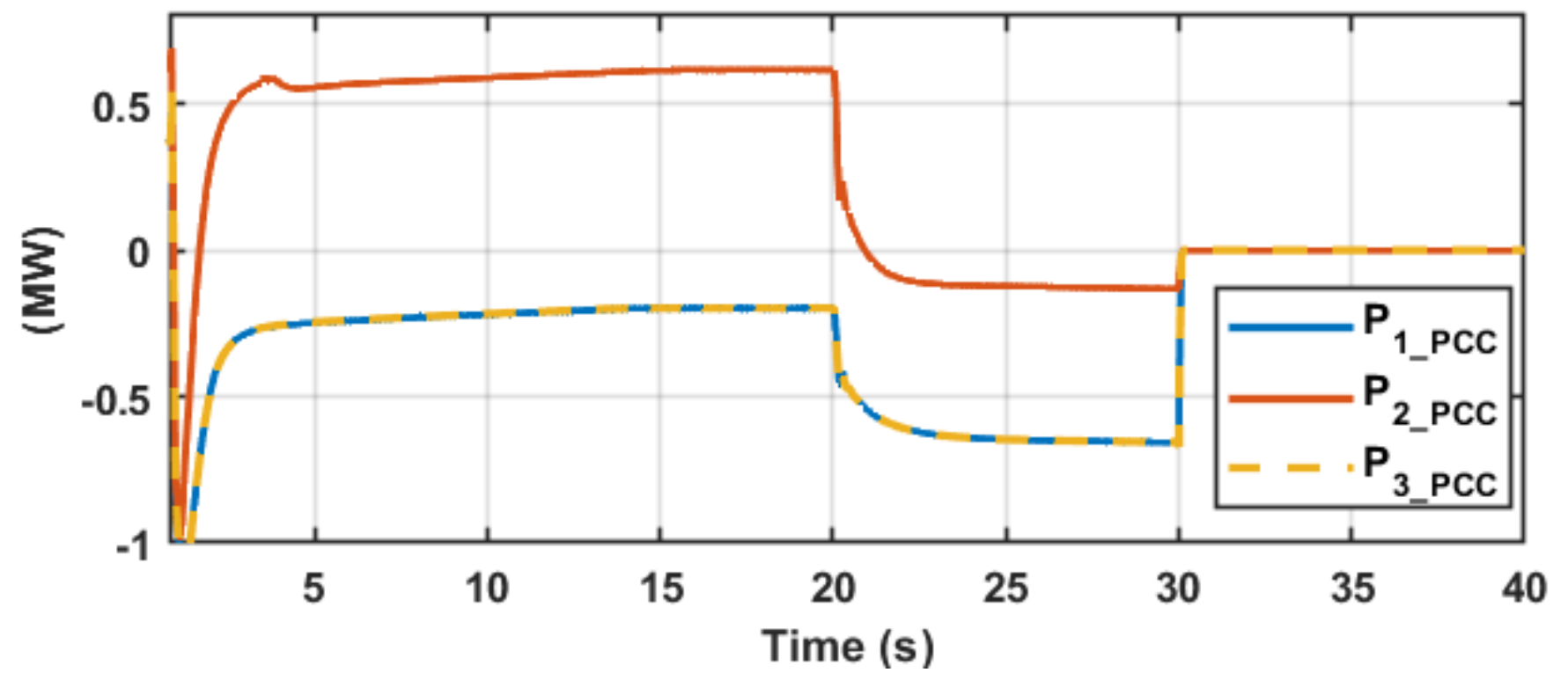


Fig. 4.2. Power flow between MG cluster and the grid

TABLE 4.3. GENERATION & LOAD (MW) IN MGS

Time (s)	MG1/MG3				MG2			
	P_{MHK}	P_{MG}	P_{BES}	P_{LD}	P_{MHK}	P_{MG}	P_{BES}	P_{LD}
0-20	2	0.2	0	2.2	2	-0.6	0	2.4
20-30	1.3	0.6	0	1.9	1.3	0.1	0	1.4
30-40	1.3	0	0.3	1.6	1.3	0	0.1	1.4

- Fig. 4.1 depicts MG system is stable in islanded mode with implemented GFM converter controller
- Fig. 4.2, and Fig. 4.3 depict a case where MHK generation drops at t=20s, and non-essential loads are shed. At t=30s, upon a fault at AC-PCC the MGs are islanded from the grid and remaining non-essential loads are shed. All the notations are in reference to Fig. 2.1

TABLE 4.2. POWER FLOW (MW) AMONG MGS & THE GRID

Time (s)	MG Cluster Status	P_{1_PCC}+P_{3_PCC}	P_{2_PCC}	Power Balance
0-20	Grid tied	-0.5	0.6	0.1 MG2 to grid
20-30	Grid tied; P_{MHK} drops, load drops	-1.2	-0.1	1.3 from grid
30-40	MG islanded, load drops	0	0	Locally

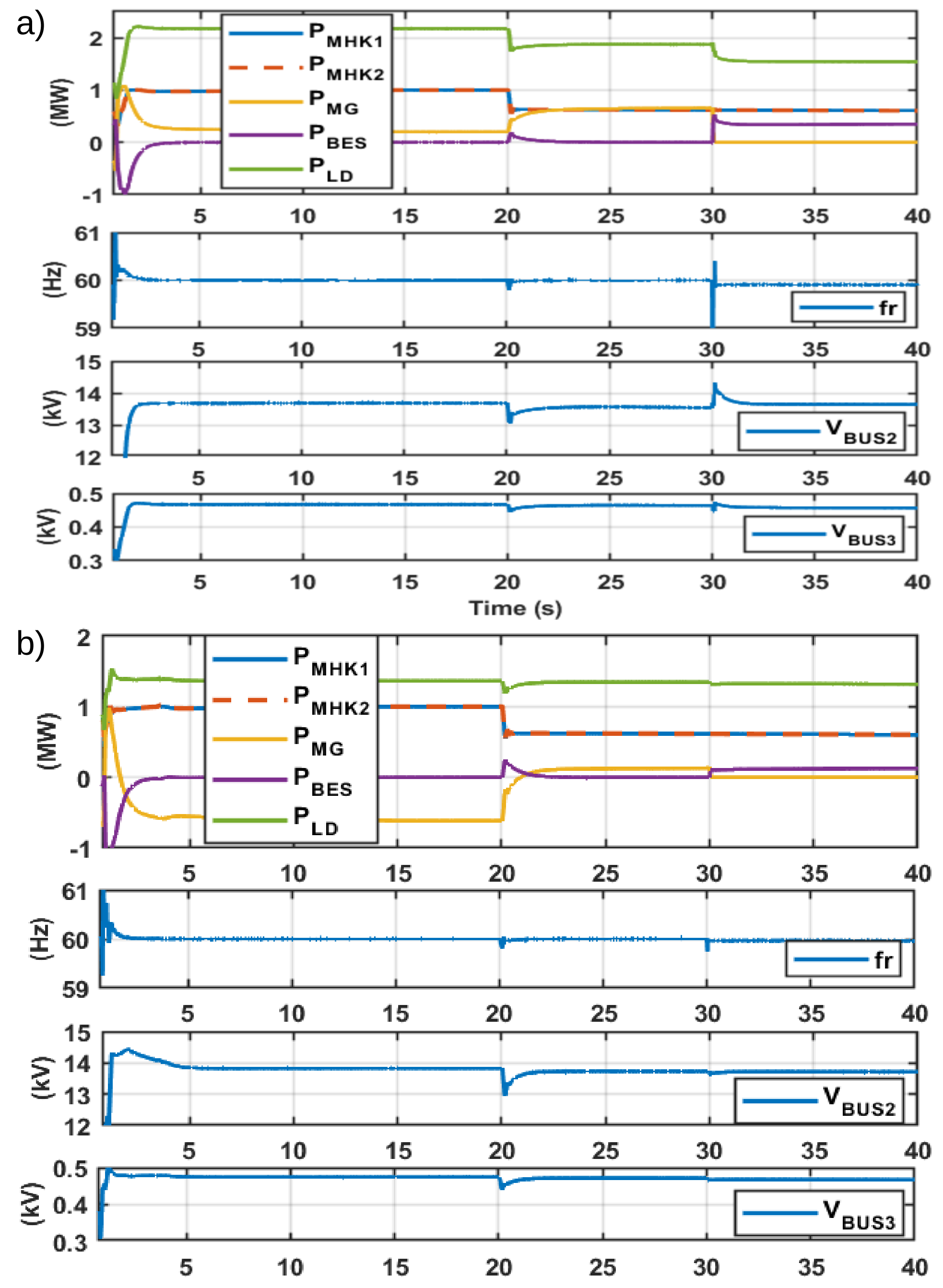


Fig. 4.3. Active power, freq and voltages at Bus 2 and Bus 3 in a) MG1/MG3 and b) MG2

5. Hardware-In-Loop Implementation

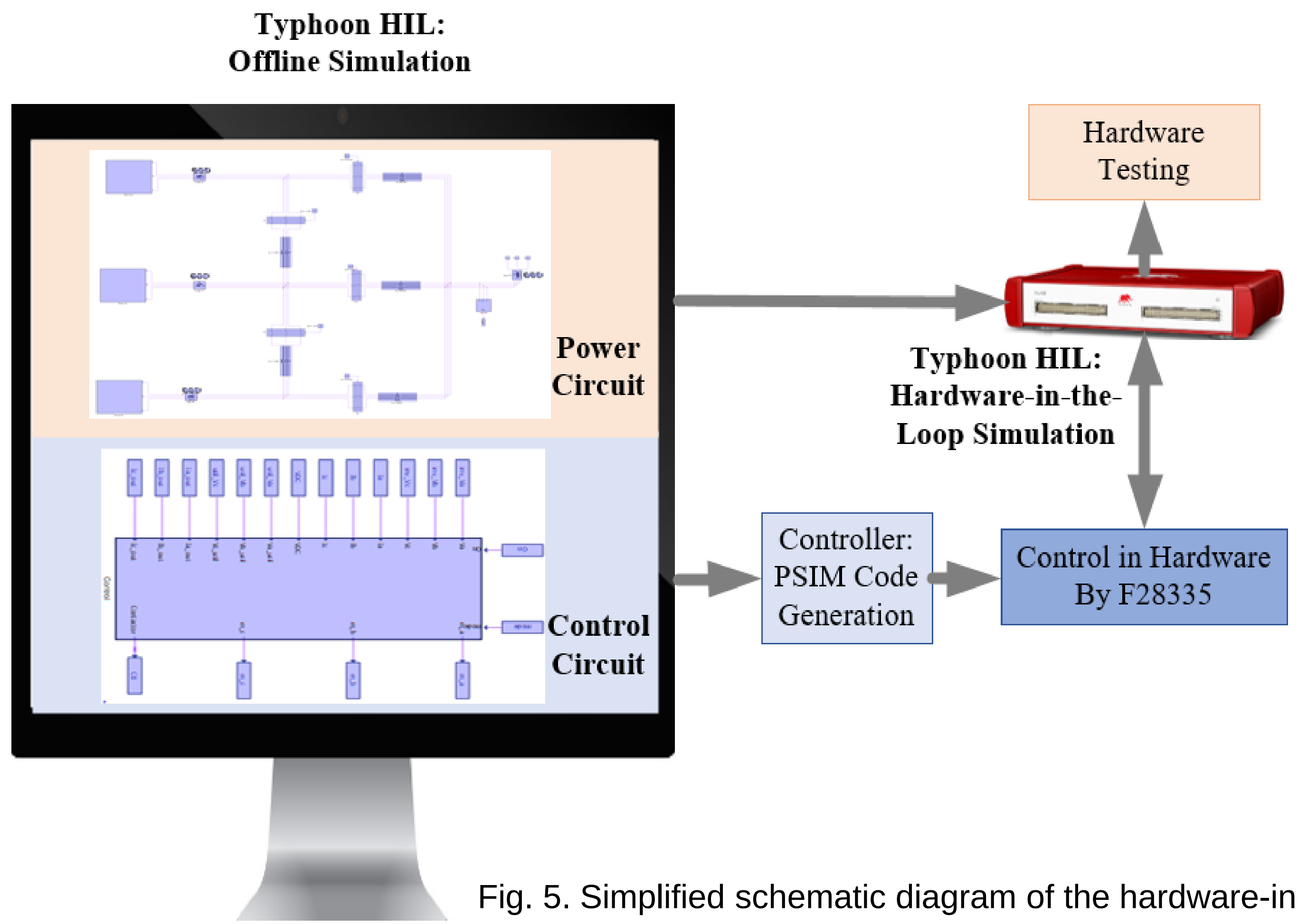


Fig. 5. Simplified schematic diagram of the hardware-in-loop and control in hardware scheme by Typhoon HIL and TI controller (F28335)

- Real time Hardware-In-Loop (HIL) simulation platform provides further insights into the operations of the DER operations in the micrograms
- It also allows the system to interact with other hardware components and test the control algorithm implemented in hardware controller
- The three microgrid cluster with the same rating as in the PSCAD simulation model is constructed in Typhoon HIL and the simulations are underway
- The hardware implementation (by F28335) of the control logic scheme is ongoing

6. Concluding Remarks

- The voltage and frequency stability of an offshore MG cluster is ensured in grid-connected, clustered and islanded condition, considering:
  - Load variation
  - Generation variation
  - Contingencies
- By battery-connected grid-forming inverter control, accurate power sharing is ensured:
  - Among microgrids in the cluster
  - Between offshore MG cluster and onshore grid by establishing HVDC connection
- Energy is harvested from multiple renewable sources (offshore wind and MHK) to balance both offshore and on-shore loads
- In future, the control in hardware is planned with the hardware-in-loop experiment by Typhoon HIL to get a deeper analysis of the operations

7. Acknowledgements

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8. References

[1] F. Kamal, H. M. M. Maruf, B. Chowdhury, M. Manjrekar, "Power Sharing of Offshore Wind Farm and Onshore Grid in Integrated VSC Controlled Multi-Terminal HVDC System", IEEE PESGM, Atlanta, GA, 2019, pp. 1-5.

[2] P. Roy Chowdhury et al., Quality and Stability in a Cluster of Microgrids with Coordinated Power and Energy Management, IEEE Industry Applications Society Annual Meeting, Detroit, MI, USA, 2020, pp. 1-7.