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Unified Power Flow Control Framework for BESS Based Microgrids

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Background and Objectives

- The purpose of this project is to study control framework for BESS under fluctuating energy demands and variations in RES generation within a microgrid (MG).
- In standalone MGs, distributed BESSs operate in grid-forming mode, accurate power sharing becomes important to avoid overloading.
- Centralized power flow control with communication requirements may face interruption during communication failures.
- Meanwhile, reliable control should address some faults automatically, without fault detection and control switching, avoid instability during mode transitions.
- Autonomous and unified control framework is proposed for power sharing and resilient operation of MGs with critical loads.
- Finally, the proposed strategies are validated using hardware-in-the-loop (HIL) testing on Typhoon-HIL platform.

Architecture of Standalone MG with BESS

- From Figure(1), the hybrid MG system is designed to operate in a networked configuration, integrating both AC and DC subsystems. Each MG contains controllable distributed sources (CDSs), while the net load represents the combination of fluctuating renewable energy sources and local demand. The AC and DC sides are interconnected through multiple parallel interlinking converters (ICs), enabling coordinated power exchange across the system.

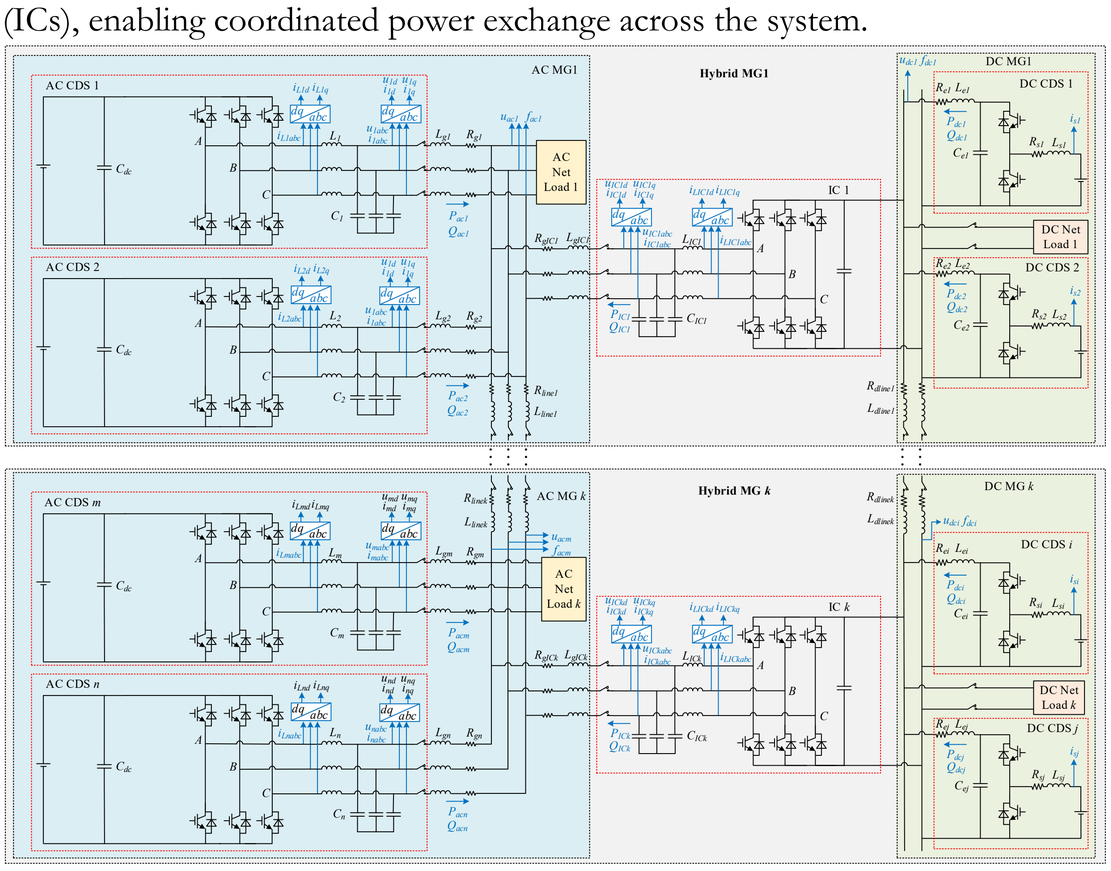

Figure (1) – Architecture of hybrid MGs with distributed BESS.

Proposed Control Strategies

- AC part, DC part and ICs have separate control strategies. AC part and ICs employ droop-based control with virtual impedance and compensation terms. DC part injects a small AC ripple into DC-link voltage, introduce f_{dc} as a global variable to enable autonomous power sharing.

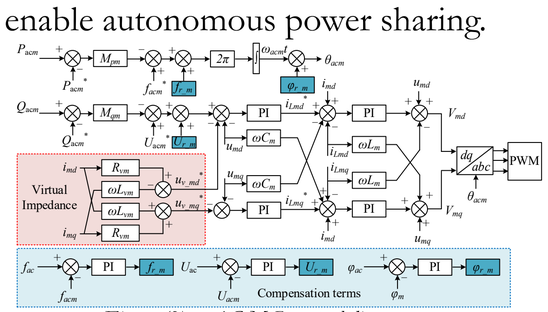

Figure (2) – AC MG control diagram.

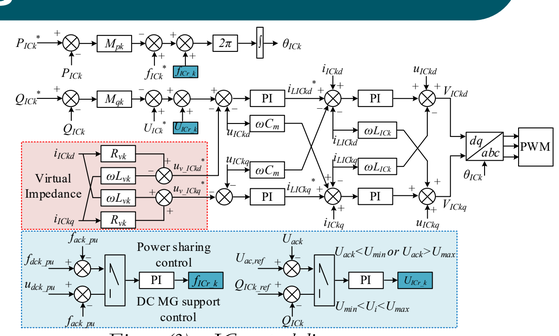

Figure (3) – IC control diagram.

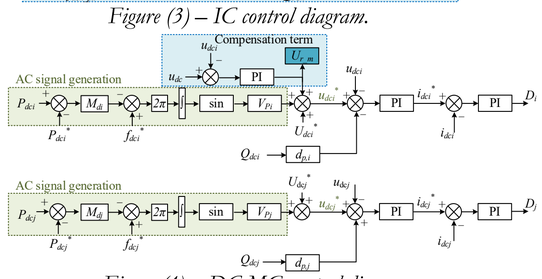

Figure (4) – DC MG control diagram.

Hardware-in-the-Loop Validation

- The Typhoon HIL testbed is used to validate the proposed strategy, and the setup is shown in Figure (5).
- Case 1: normal operation with power sharing and AC voltage support.

  Case 2: operation when AC CDSs fail.

  Case 3: operation when DC CDSs fail.
- Figure (6) shows the performance of autonomous power sharing among BESS in Case 1. Figure (7) and Figure (8) show the effectiveness of fault-tolerant control in Case 2 and Case 3, respectively.

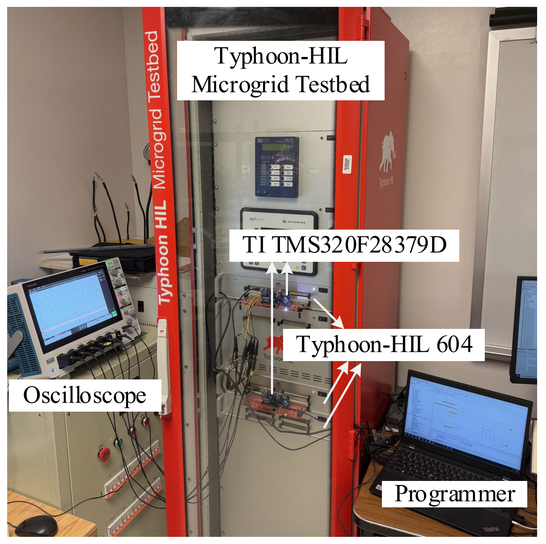

Figure (5) – Typhoon HIL Setup

- As seen in Figure (6). The step-changing net loads represent fluctuating RES and load demand. With the support of ICs, both AC and DC CDSs achieved proportional power sharing despite unequal line impedances. ICs also injected reactive power for dynamic voltage support. System voltages and frequency remained stable throughout.

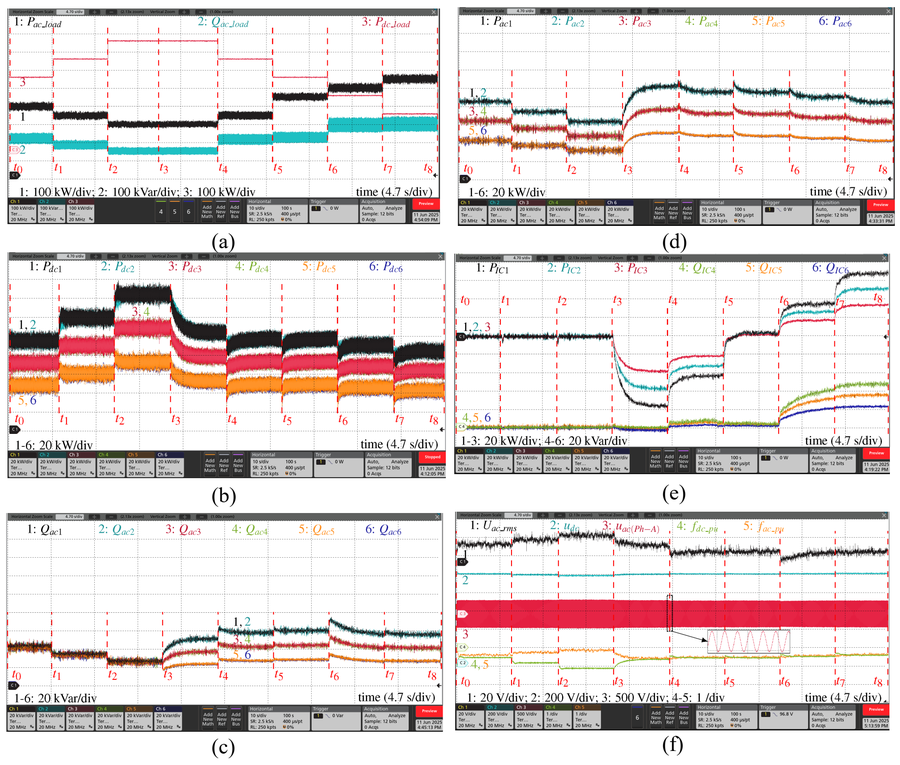

Figure (6) – Experimental waveforms in Case 1. (a) load profile (b) dc CDSs power (c) ac CDSs active power (d) ac CDSs reactive power (e) ICs active and reactive power (f) system voltage and frequency.

- Figure (7) illustrates the voltage stabilization capability when all AC-side CDSs fail, while Figure (8) demonstrates resilient operation in the event of DC-side CDS failures. By examining the voltage and power waveforms, it can be seen that the ICs rapidly support the faulty side, maintaining voltage stability.

Figure (7) – Experimental waveforms in Case 2. (a) system voltage and frequency (b) ICs active and reactive power.

Figure (8) – Experimental waveforms in Case 3.

Conclusions and Future Work

- An autonomous and unified power flow control framework is proposed for a hybrid AC/DC MG to enable accurate power sharing and resilient operation. This framework allows BESSs to participate proportionally in power supply and ensures uninterrupted power delivery during faults.
- HIL experimental results under various MG operating scenarios validate the effectiveness of the proposed approach. The unified control framework successfully supports multiple operating modes without requiring controller reconfiguration.
- The stability analysis and scalability, along with corresponding strategies will be explored to complete design of optimum BESS for critical load in future.

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