Design and Development of Advanced Controllers for Interconnection of Microgrids

Presented by

Amit Gupta

PhD @Indian Institute of Technology Bhubaneswar

Introduction and Motivation

Energy Transition Challenge

Fossil fuel exploitation and environmental pollution drive the urgent need for renewable energy integration, though intermittent generation poses reliability concerns.

Microgrid Integration

A unified platform that enables seamless integration and coordinated operation of diverse distributed generation sources with different characteristics.

Control Complexity

Traditional controllers are no longer sufficient to handle the increasing complexity and heterogeneous nature of distributed energy resources in modern microgrids.

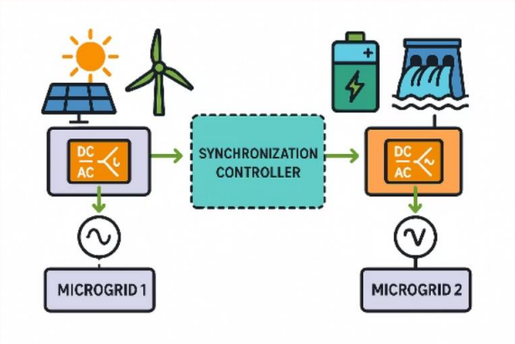
Research Objectives

The doctoral research addresses three critical challenges in microgrid control and interconnection, developing novel solutions for heterogeneous system integration, transient stability enhancement, and reliable power sharing in renewable-dominated environments.

1

Synchronization Controller for Heterogeneous Microgrids

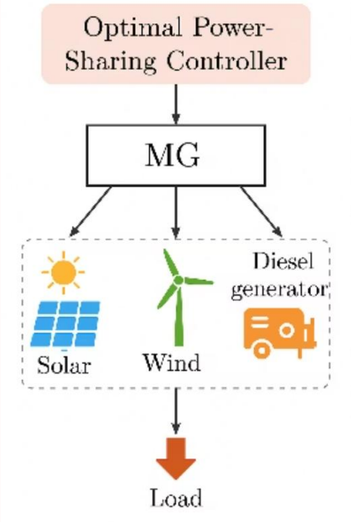
Design of advanced synchronization strategies capable of precisely match the incoming system synchronization parameter. The emphasis is on achieving seamless interconnection irrespective of the underlying generation technologies or control architectures..



2

Transient Stability Enhancement

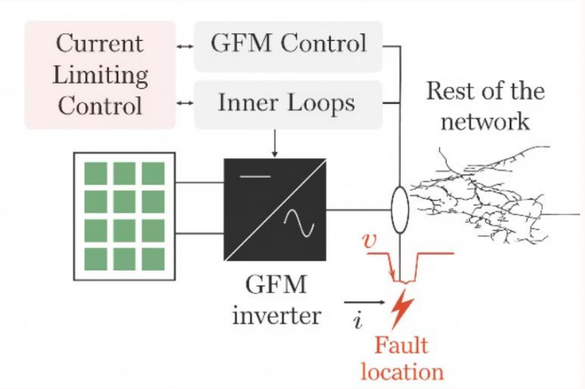
Advanced control strategies for grid-forming converters operating under current-limiting conditions to prevent loss of synchronism during fault events and disturbances.



3

Reliable and optimal Power-Sharing

Innovative droop-based control mechanisms for economical and accurate power distribution among distributed generation units in renewable-rich islanded microgrids.



Key Technical Contributions

01

Unified Synchronization Framework

02

Angle-Based Control with Enhance Transient Stability for GFM

03

Multi-Segment Adaptive Droop for optimal/reliable power sharing

Contribution 1

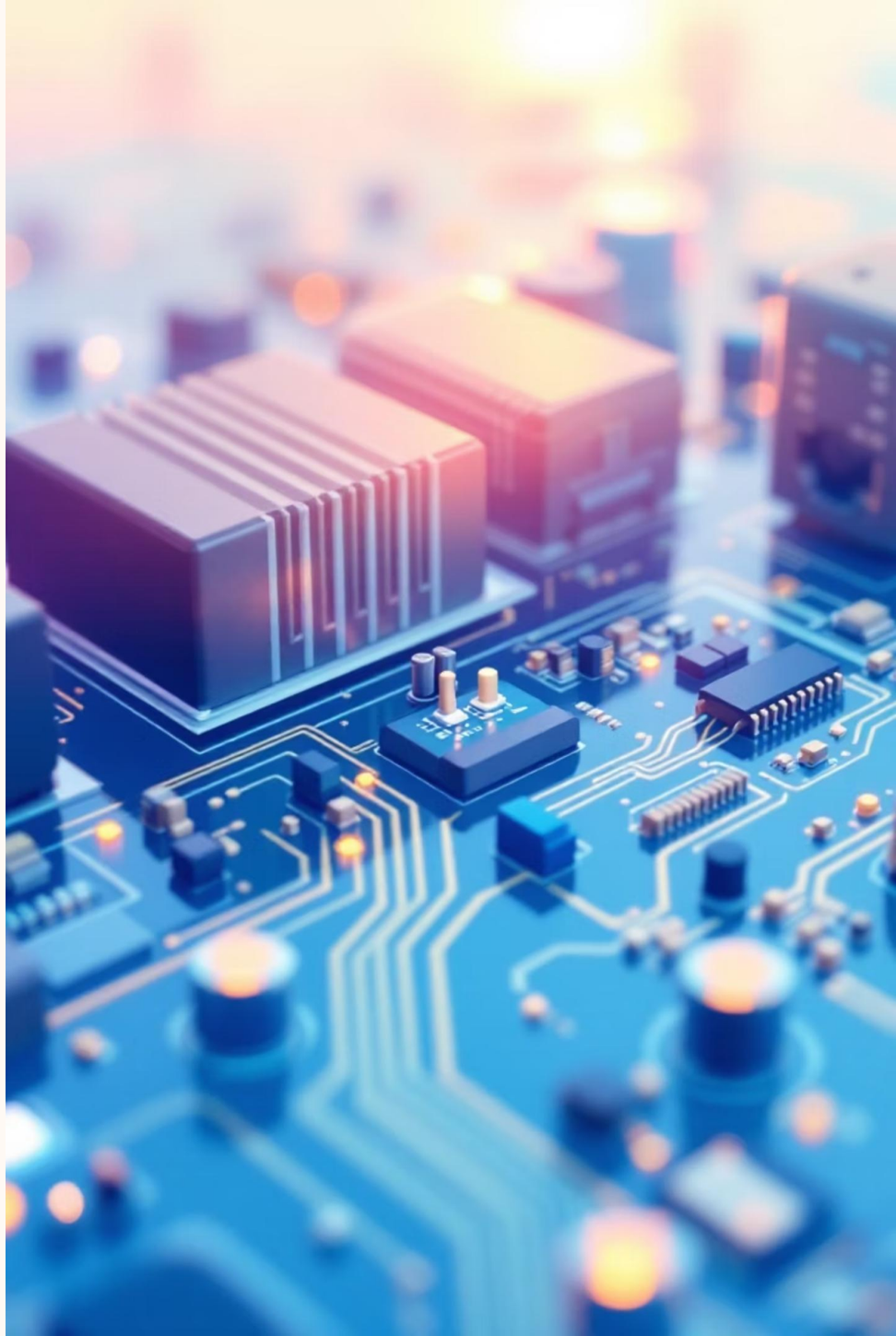
- Single PI controller for heterogeneous MG interconnection with comprehensive system modeling
- Validated through simulations and PHIL experiments for seamless synchronization
- Droop resetting mechanism ensures stable operation and optimal power sharing post-interconnection

Contribution 2

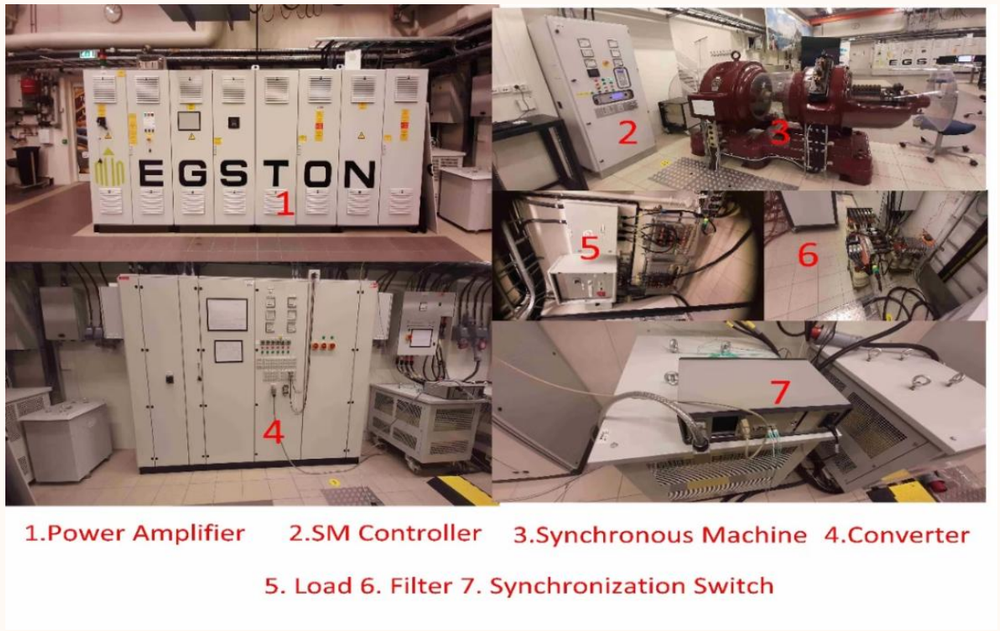
- Virtual power introduction in droop control activates during disturbances only
- Enhanced phase tracking prevents synchronism loss during current-limiting operation
- Addresses both Type 1 and Type 2 instability mechanisms in GFM inverters

Contribution 3

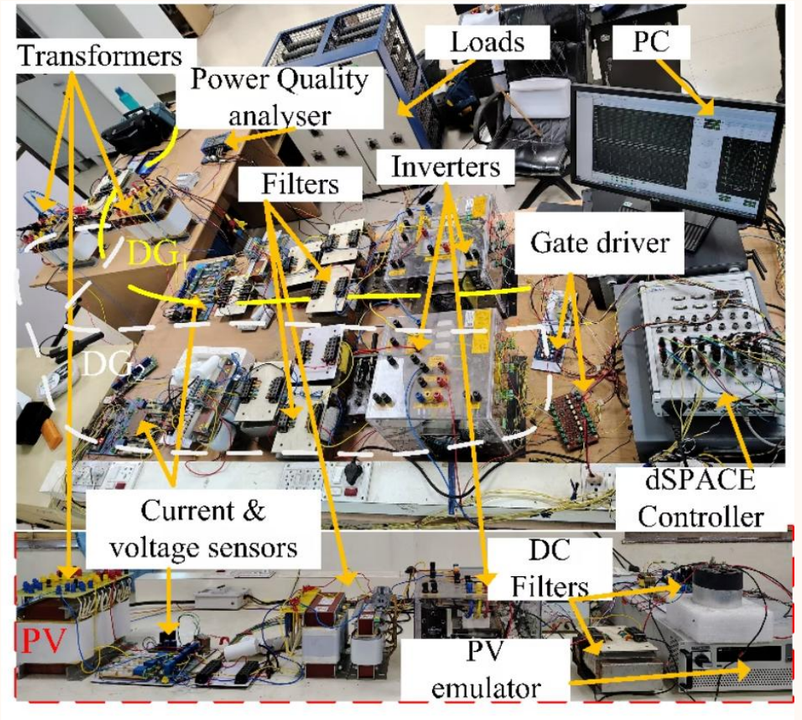
- Dynamic droop adjustment based on priority and cost for accurate economic dispatch
- Fuzzy logic adaptive gradient controller maintains stability within DG capacity limits
- Small-signal modeling framework enables systematic parameter tuning for robust performance



Experimental Validation Infrastructure



Power Hardware-in-the-Loop (PHIL) experimental setup at Norwegian University of Science and Technology (NTNU), Norway



Microgrid experimental testbed at Indian Institute of Technology Bhubaneswar (IITBBS), India

Real-Time Simulation

Experience in Power-hardware-in-loop to validate the system for bigger setup

Multi-DG Configuration

Development of a 20 kW hardware prototype.

- 2 constant voltage source based DG
- PV based DG
- Diesel based generator

Testing

Comprehensive disturbance analysis, including voltage sags, frequency deviations, and topology changes.

Research Dissemination and Impact

Journals

- **A. Gupta**, P.C. Sekhar, "A Droop Based Unified Synchronization Scheme with Adaptive Phase and Frequency Loop Integration for Interconnection of Heterogeneous Microgrids". (1st revision completed in *IEEE Transaction in Power Electronics*)
- **A. Gupta**, P.C. Sekhar, M.Z. Degefa, S. D'Arco' "A Unified Controller for Interconnection of Heterogeneous, Multi-DG Mini/Microgrids with Varying Dynamic Characteristics". (1st revision completed in *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*)
- **A. Gupta**, P.C. Sekhar, "Enhanced Transient Stability Strategy for Grid-Forming Inverters Operating in Current Limiting Mode". (Communicated in IEEE Transaction in Power Electronics).
- **A. Gupta**, P.C. Sekhar, "A Multi-Segment Adaptive Droop Control Strategy for Optimal Power Sharing in Renewable Dominated Islanded Microgrids". (To be submitted)

Conferences

- **A. Gupta** and P. C. Sekhar,"A Sliding Mode-based Negative Sequence Compensation for Seamless Interconnection of Microgrids under Unbalanced Condition", 2025 *International Conference on Power Electronics and Energy (ICPEE)*, Bhubaneswar, India, 2025, pp. 1-6.
- **A. Gupta** and P. C. Sekhar,"Dynamic Droop Control for Optimal Power Sharing in Renewable Rich Hybrid Islanded Microgrids", 2024 *IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, Mangalore, India, 2024, pp. 1-6.
- **A. Gupta**, P. C. Sekhar, M. Z. Degefa, K. Jonatan R. A. and S. D'Arco, "Synchronization Controller for Seamless Interconnection of Mirogrids with Heterogeneous Sources," 2022 *22nd National Power Systems Conference (NPSC)*, New Delhi, India, 2022, pp. 344-349.
- **A. Gupta** and P. C. Sekhar, "A Review of Control Strategies for Operation of Distributed Resources Under Grid Faults," 2022 *IEEE PES Innovative Smart Grid Technologies – Asia (ISGT Asia)*, Singapore, Singapore, 2022, pp. 200-204.
- M. Z. Degefa, J. R. A. Klemets, S. D'Arco, P. C. Sekhar and **A.Gupta**, "Review of Grid Interconnection Requirements and Synchronization Controllers for Dispersed Minigrids," *2021 IEEE PES/IAS Power Africa*, Nairobi, Kenya, 2021, pp. 1-5.
- **A. Gupta** and A. R. Saxena, "An Isolated Dual-Input Dual-Output DC-DC Converter with Bi-directional Feature for Low Voltage DC Grids," 2020 *IEEE First International Conference on Smart Technologies for Power, Energy and Control (STPEC)*, Nagpur, India, 2020, pp. 1-6

Thank You

Amit Gupta, PhD CandidateIndian Institute of Technology Bhubaneswar