A Resilient Energy Management Framework Design For Community Microgrid Assisted Load Restoration

Presentation for NCSU FREEDM Annual Symposium 2023

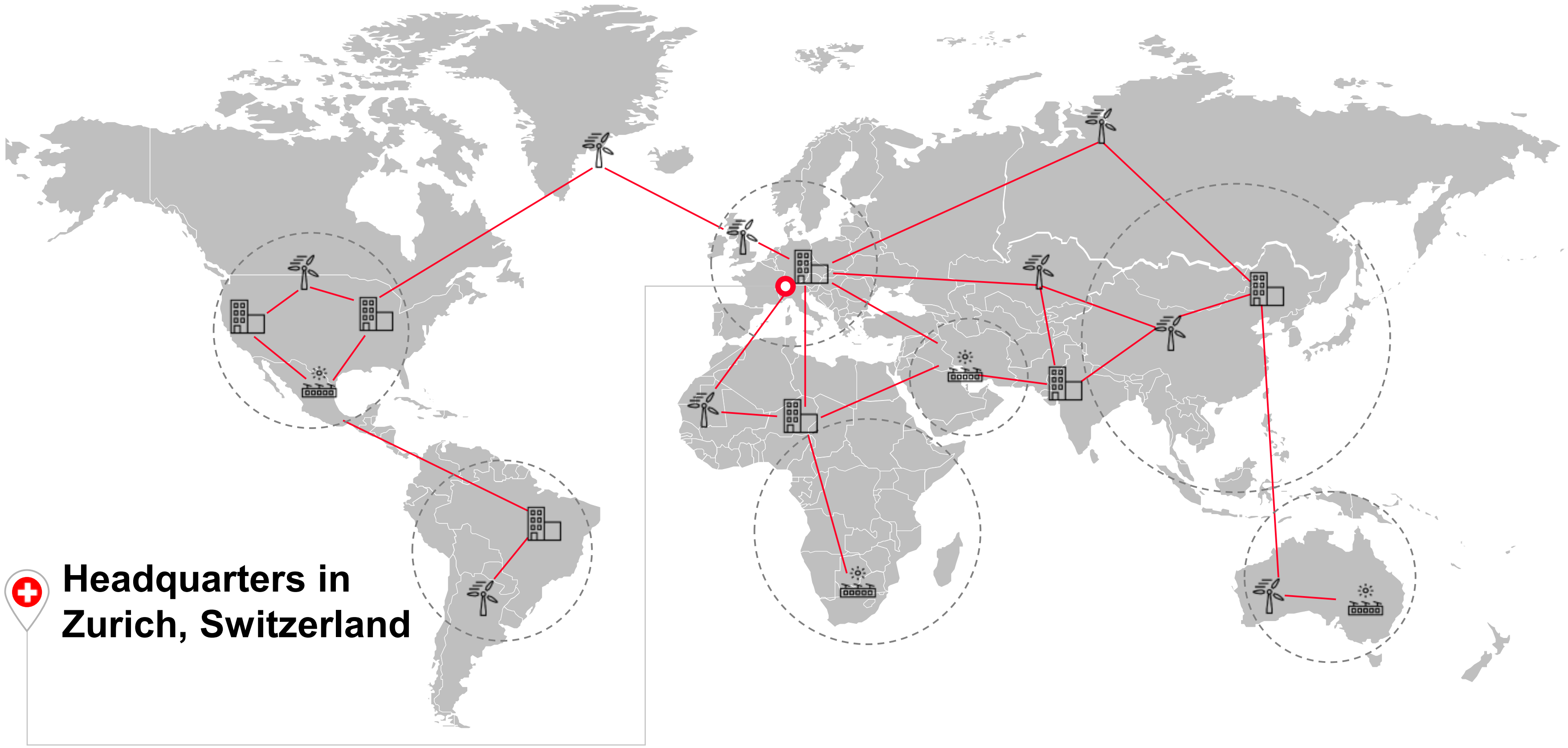
Hitachi Energy Research

Ashwin Shirsat, Scientist

2023-02-20

About Hitachi Energy

HITACHI
Inspire the Next



38,000 employees

90+
countries with 200 offices

~250
years' heritage combined

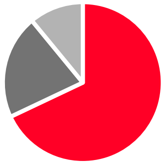
5,500
sales employees & field engineers

2,000
engineers & scientists in R&D

Four Business Units

Grid Automation	**High Voltage Products**
Grid Integration	**Transformers**

Customers



- Transport & Infrastructure
- Industry
- Utilities

Offering

- Services
- Software & Automation
- Systems
- Products

Geographies

- Asia, Middle East & Africa
- Americas
- Europe

Public

Hitachi Energy

One global R&D organization

Our R&D team is present in **20+ countries** and we have Research Centers in **seven countries**

2000+ R&D experts	**>60%** work in software development	**~200** researchers	**>80%** researchers have PhDs

Hitachi Energy Research – We are Hiring!

HITACHI
Inspire the Next

Researcher on Power Systems and Protection

DER Management and Microgrid Controls Scientist

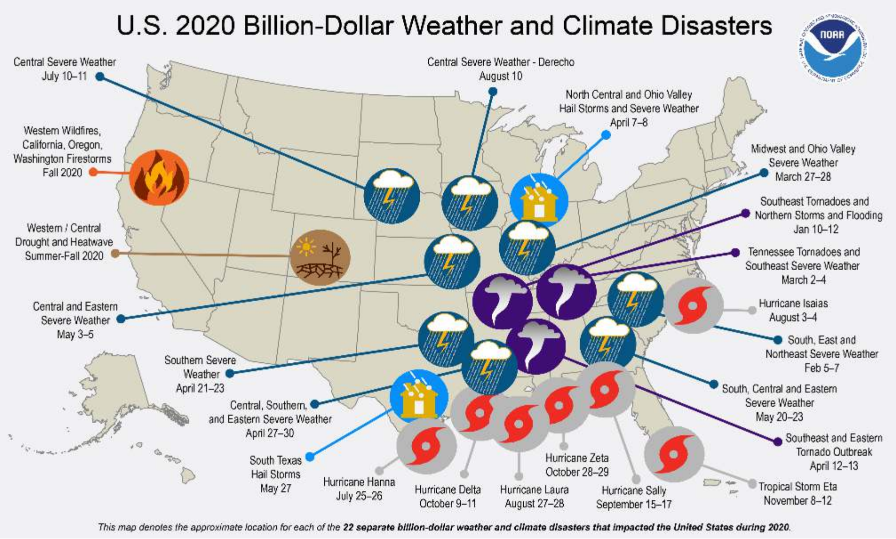
Hitachi Energy

A Resilient Energy Management Framework Design For Community Microgrid Assisted Load Restoration

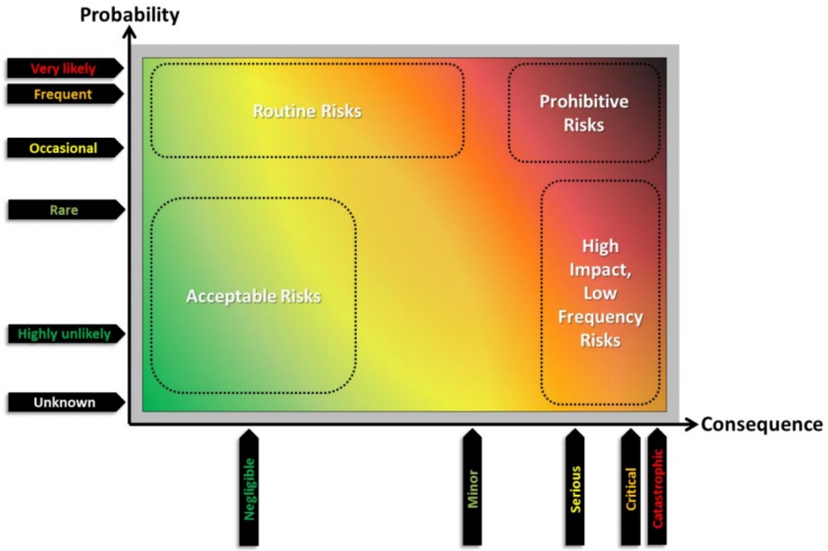
Presentation for NCSU FREEDM Annual Symposium 2023

Extended Duration Power Outages – An Increasing Likelihood Event

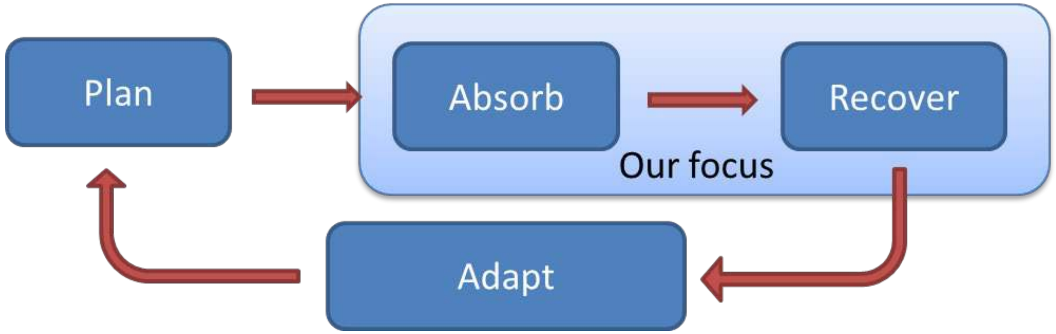
- Frequency and likelihood of extended duration outages is increasing due to climate change and cyber-security threats.



(Source: NOAA)



(Source: US DOE)

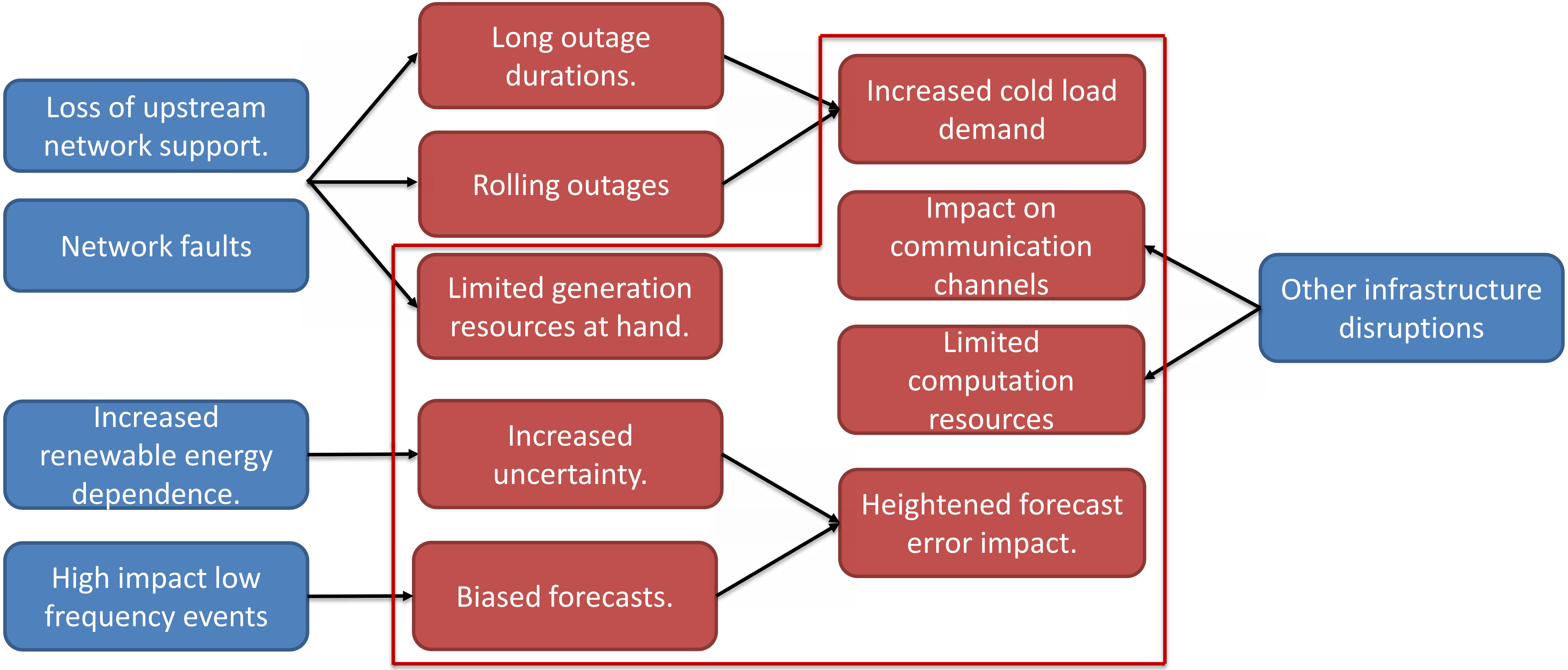


Goal

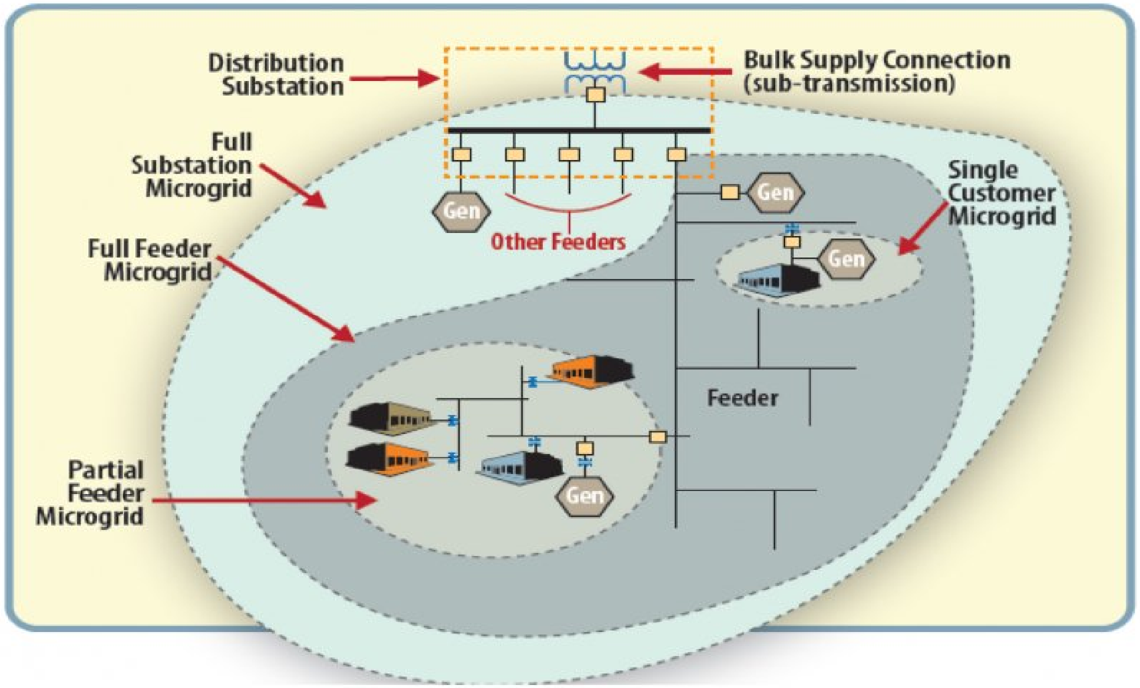
With minimum network reinforcements, improve the network ability to absorb and recover from impacts caused by extreme events.

Challenges Faced while Operating During Extreme Events

- Operating the electric grid under extreme weather events or cyber-attacks comes with numerous challenges.



Motivation



(Source: US DOE)

- Microgrid is a group of interconnected distributed generation resources and loads that operate within defined electrical boundaries.

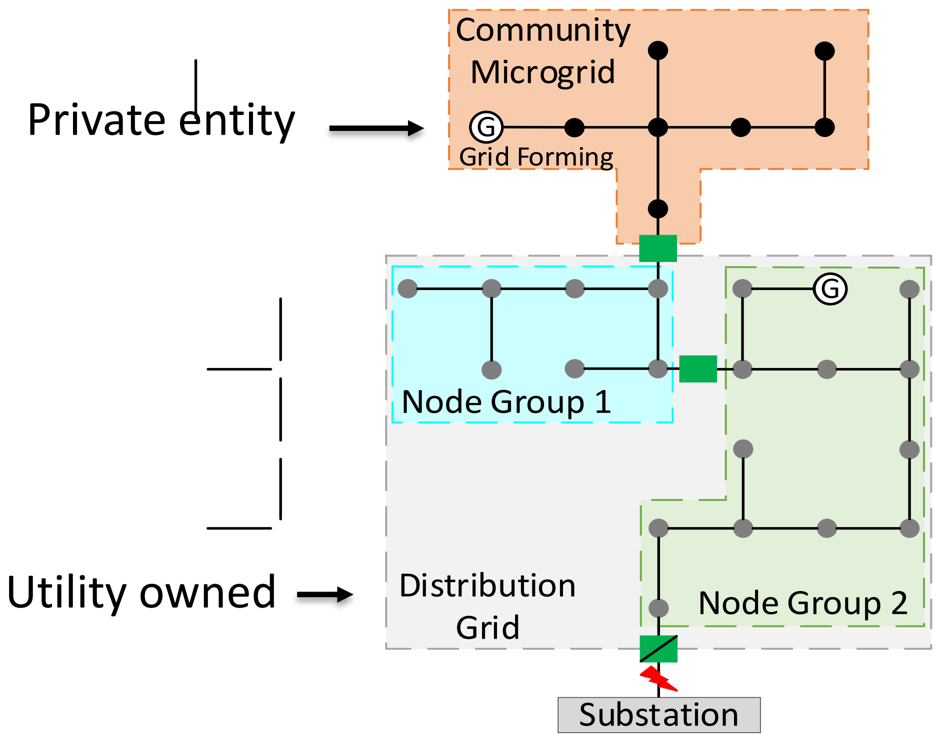
- Advantages:
  1. Enhance local reliability and power quality.
  2. Energy surety during emergency conditions.
  3. Grid support functionality provision.
  4. Smoothing of intermittent and volatile resources.

Objective

- Secure operation for extended duration using microgrid.
- Maximize load served (priority to critical load).
- Minimize renewable generation curtailment.
- Robust against uncertainties.

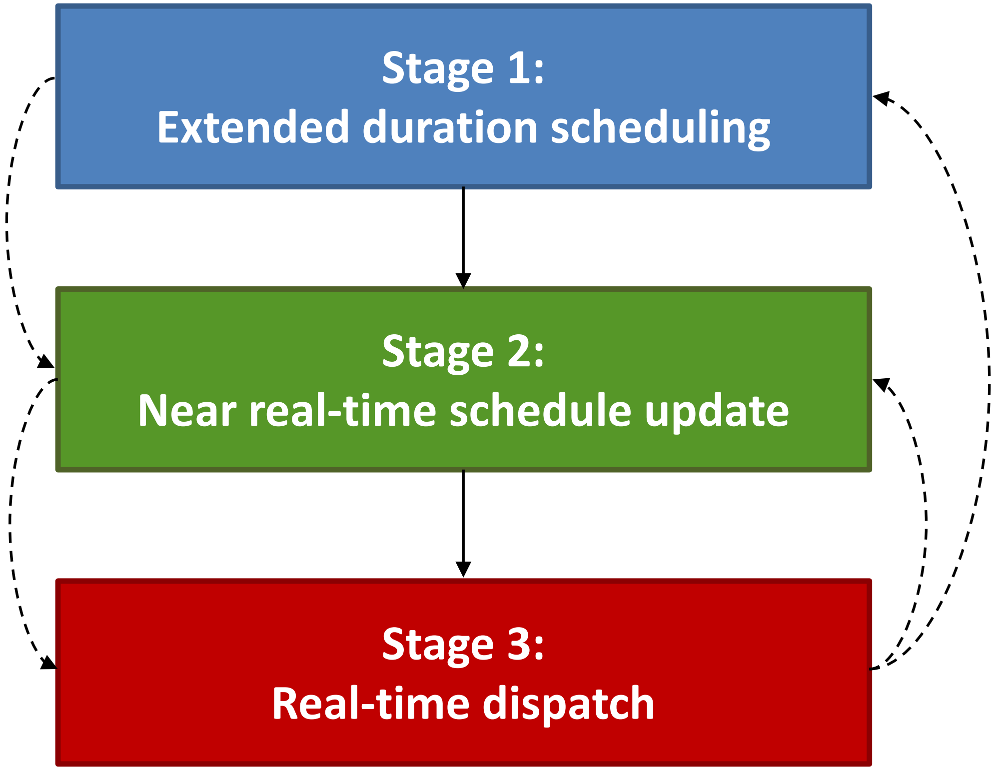
Resilient Operation of Power Distribution Systems

System Level Uniqueness



Community microgrid setting + **Coverage maximization using dynamic boundary**

Algorithm Level Uniqueness



Secure and adaptive hierarchical multi-timescale framework (SA-HMTS)

Kang, Ning, Wang, Jianhui, Singh, Ravindra, and Lu, Xiaonan. Interconnection, Integration, and Interactive Impact Analysis of Microgrids and Distribution Systems. United States: N. p., 2017.

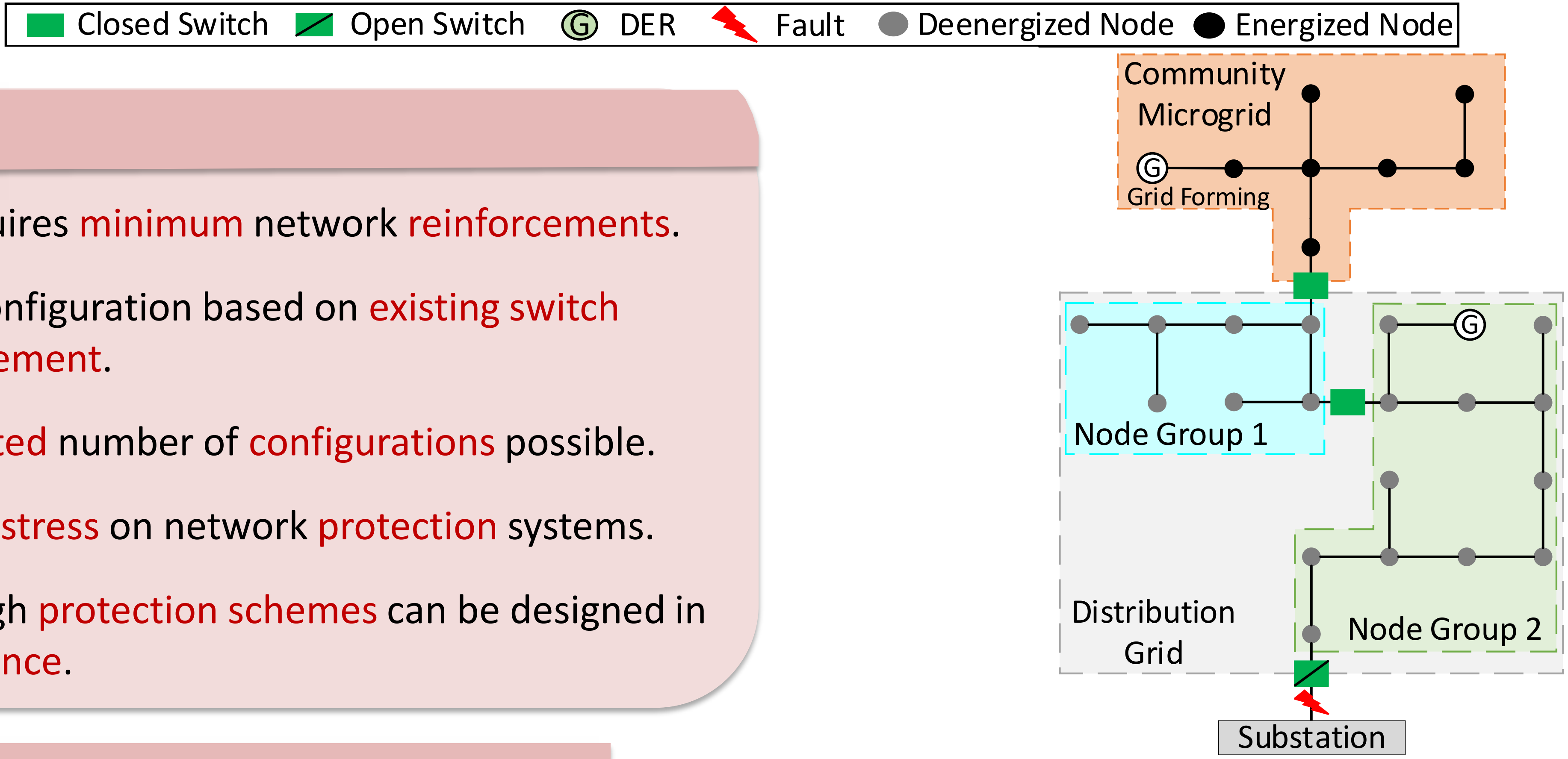
Resilient Operation of Power Distribution Systems

- Concept of dynamically changing CMG boundary:

Closed Switch Open Switch G DER Fault Deenergized Node Energized Node

Resilient Operation of Power Distribution Systems

- Concept of dynamically changing CMG boundary:

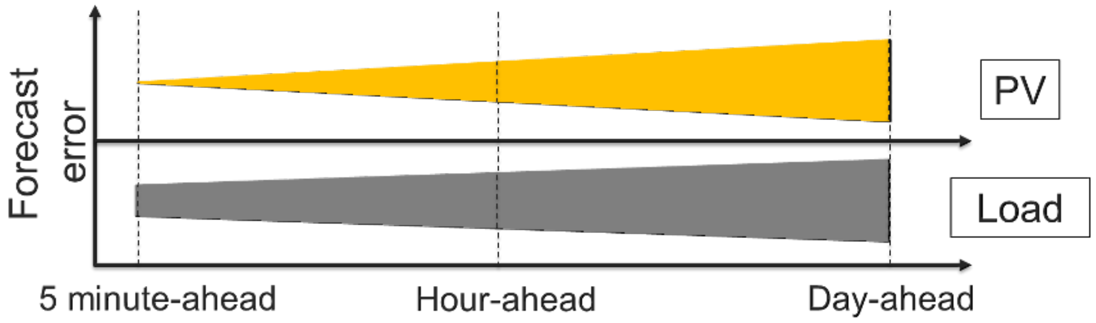


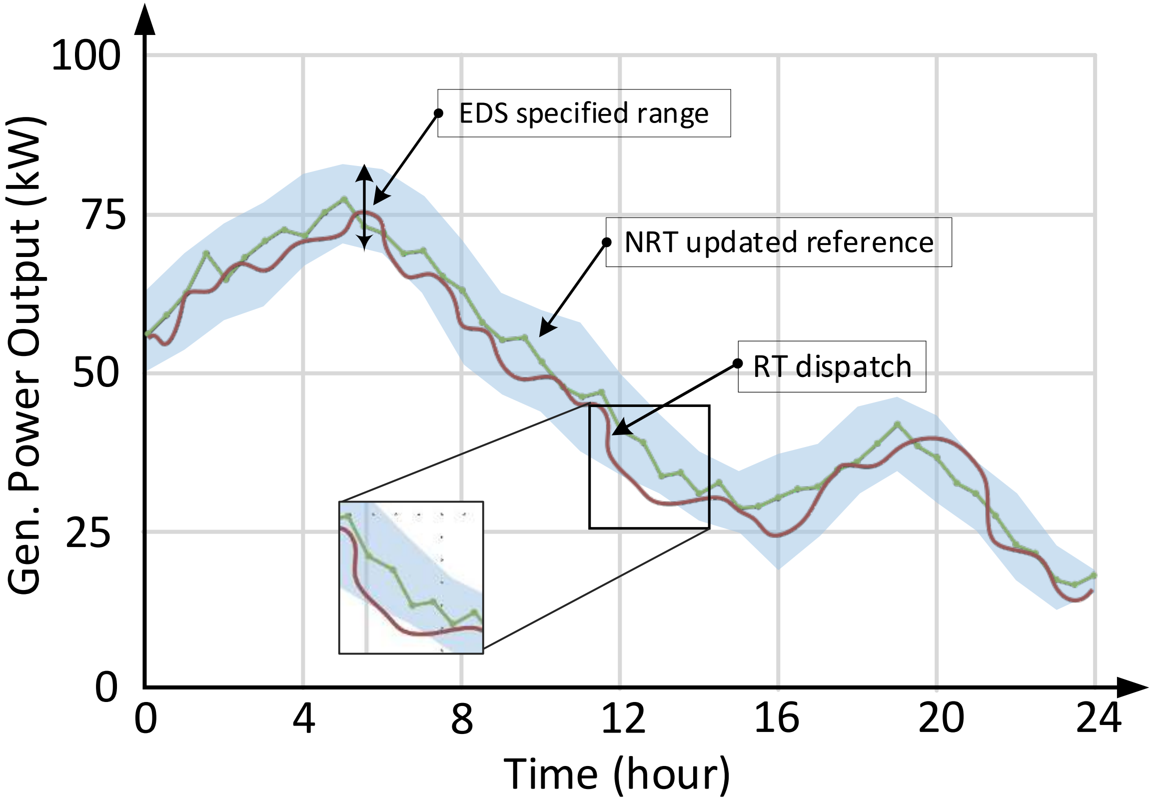
Benefits

- Requires minimum network reinforcements.
- Reconfiguration based on existing switch placement.
- Limited number of configurations possible.
- Less stress on network protection systems.
- Rough protection schemes can be designed in advance.

Microgrid-as-a-Service (MaaS)

Proposed Energy Management System Design





Extended duration scheduling (EDS)

- Long-term **hourly generation allocation**.
- **Dynamic boundary** decision.
- Receding horizon **stochastic** optimization.

Objective: Maximize weighted load supplied.

Near real-time schedule update (NRT)

- Fine tune generation allocation for one hour.
- Fix slow responding generator setpoints.
- Demand response decisions.
- Deterministic optimization.

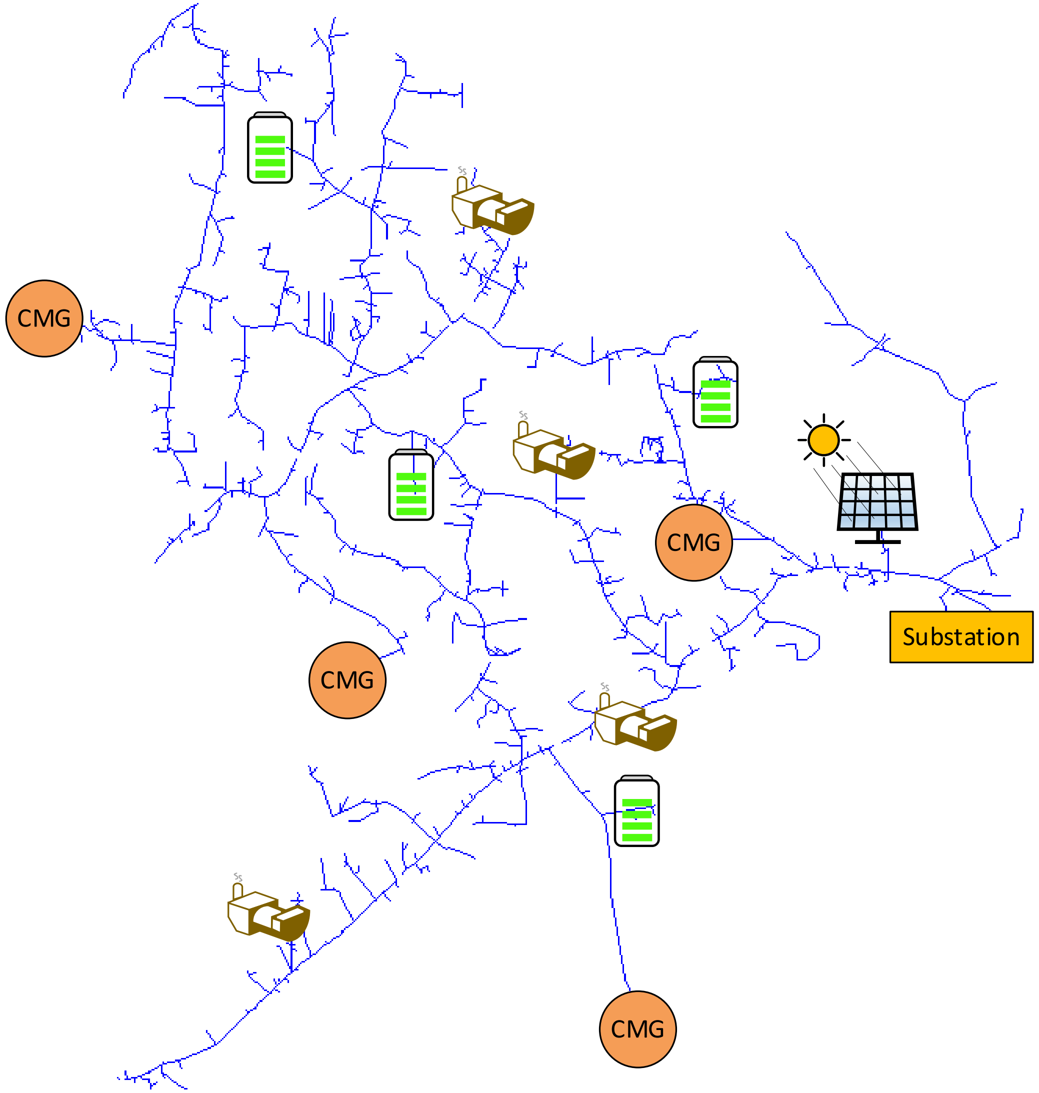
Objective: Minimize deviation from EDS reference.

Real-time dispatch (RT)

- Fine tune fast-responding generation output for 5 mins.
- Deterministic optimization.

Objective: Minimize PV curtailment.

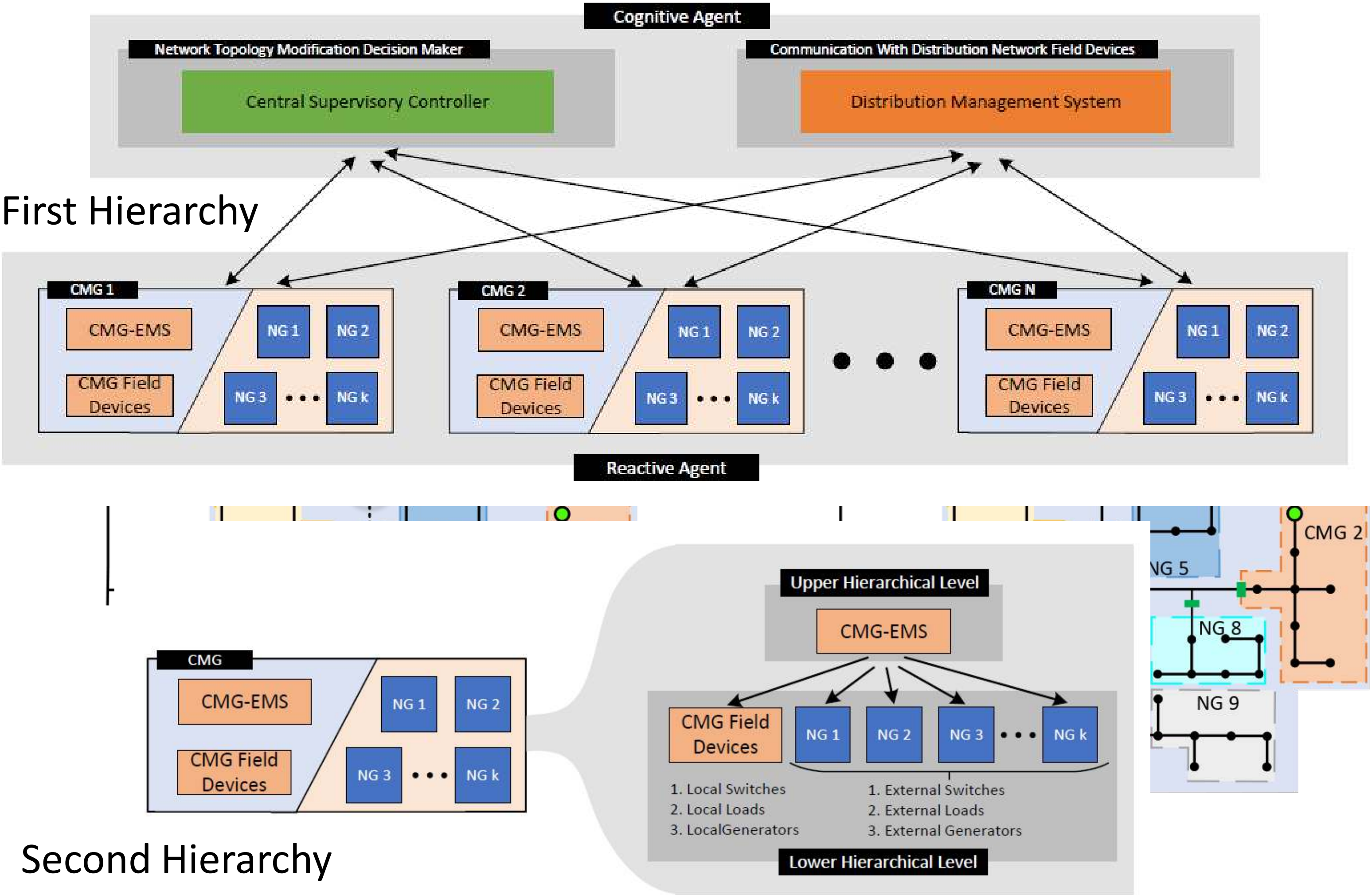
Multi-Feeder Resilient Load Restoration and Energy Management



- Until now, the emphasis was on the operation of a single community microgrid (CMG).
- Real world systems consist of multiple CMGs scattered over multiple feeders.
- Each CMG can have a different approach for energy management and load restoration.
- How to scale the proposed EMS system to perform restoration over large scale heterogenous networks?

Scalability and Modularity

Hierarchical Multi-Agent Approach



Hierarchical Multi-Agent Framework

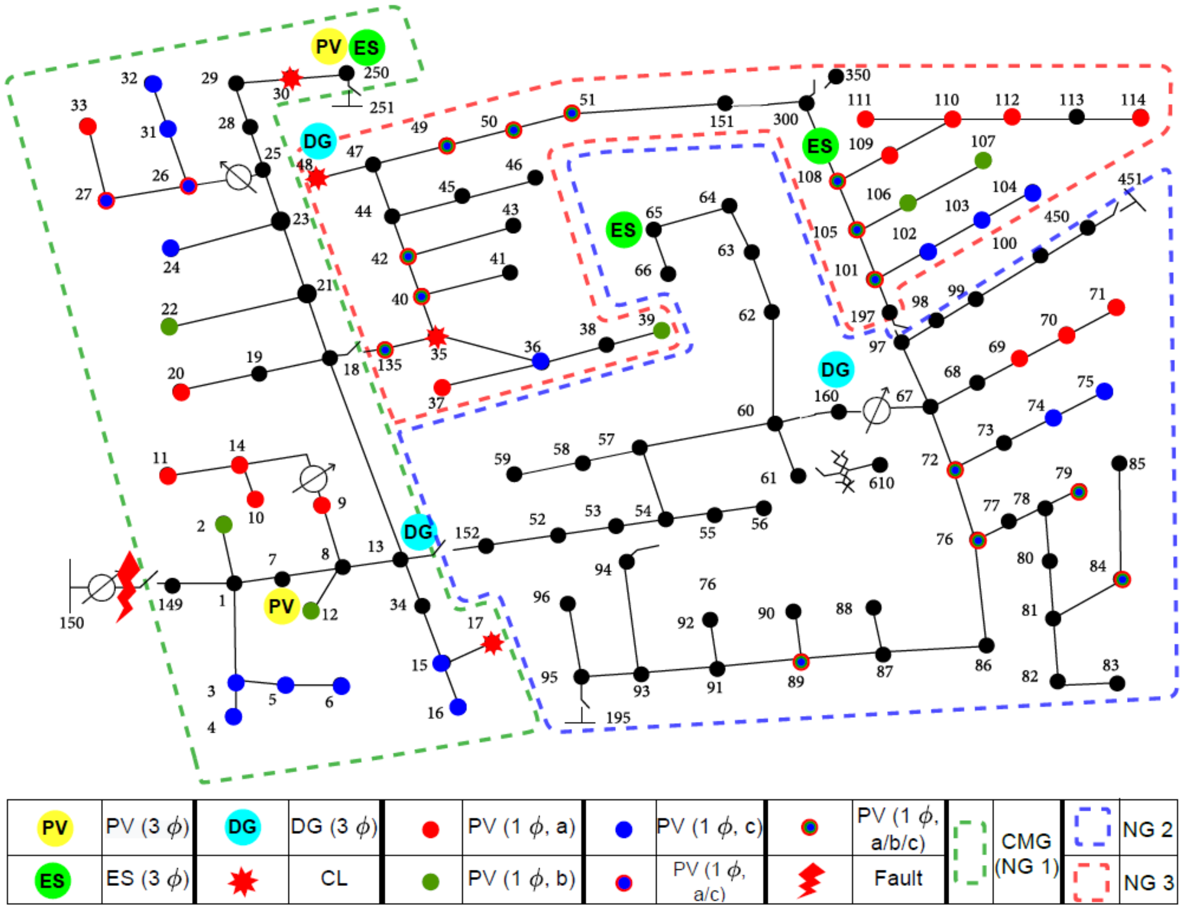
First Hierarchy

- Central supervisory controller ➔ cognitive agent coordinating load sharing between CMGs.
- CMG ➔ reactive agent responding to load sharing and implementing locally computed decisions.

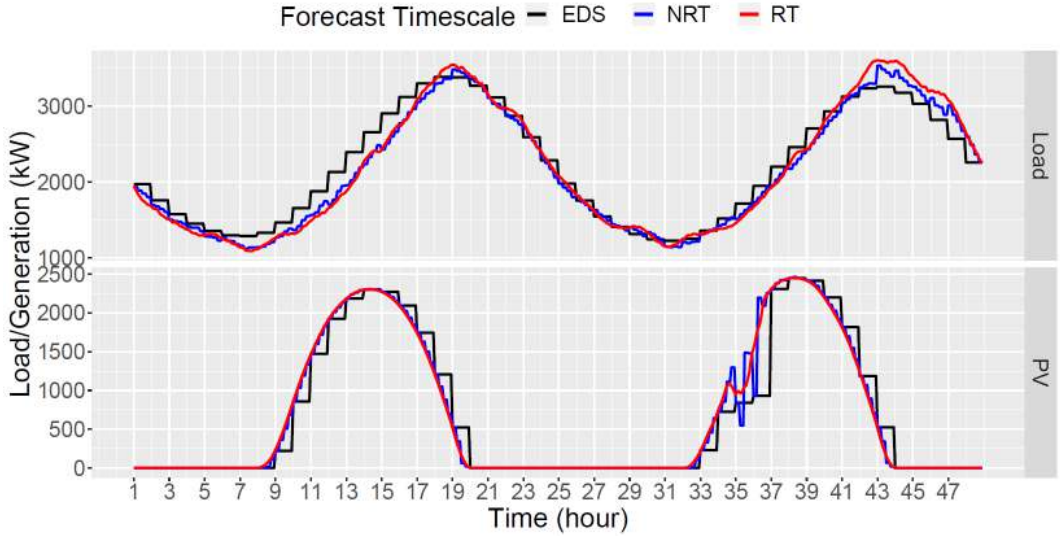
Second Hierarchy

- CMG-EMS ➔ cognitive agent that computes the energy management decisions.
- Field devices ➔ reactive agents responding to the instructions of the CMG-EMS.

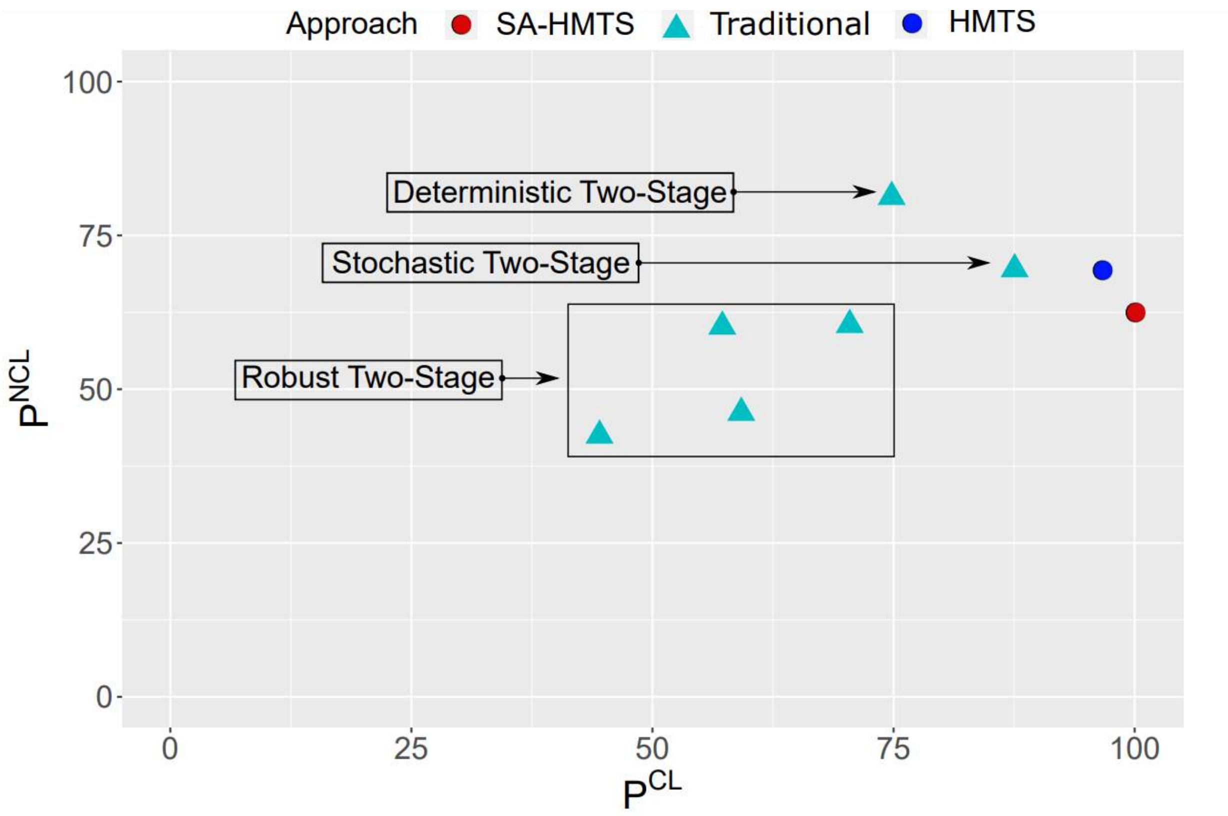
Simulation Setup

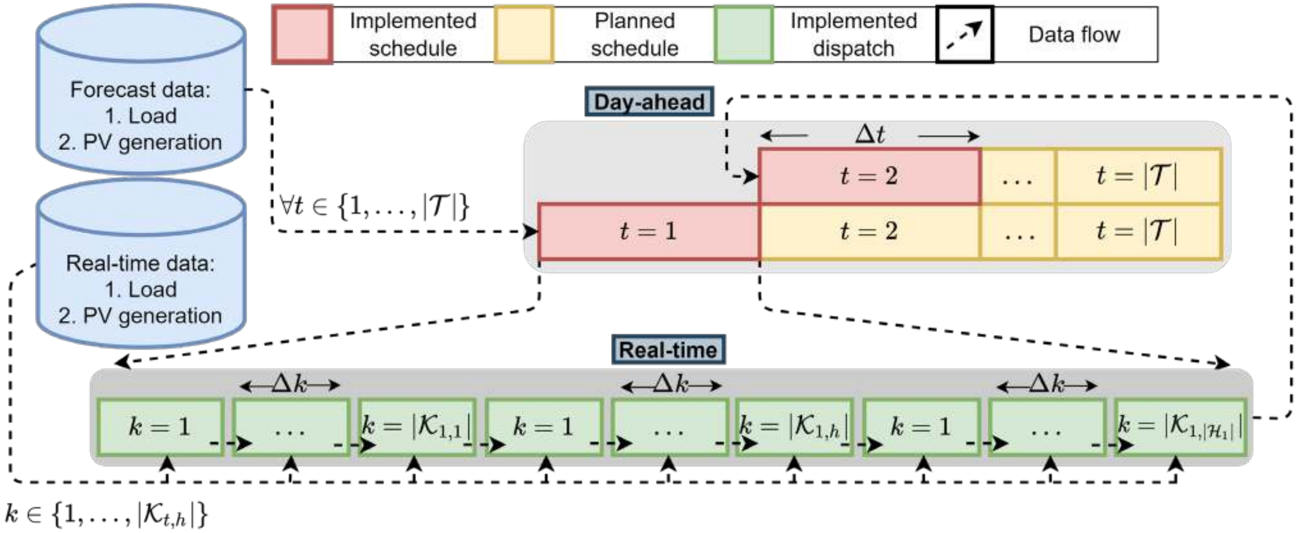


Generator	Generator node	Rating (kW/kWh)	Initial Fuel/SOC
DG*	13 48 160	900 kW 450 kW 900 kW	12000 Liter 6000 Liter 6000 Liter
PV*	7, 250	750 kW, 750 kW	-
ES*	65 108 250	500 kW/1000 kWh 500 kW/1000 kWh 2750 kW/5500 kWh	75% 75% 75%
BTM PV#	See Figure	3 to 15 kW	-



OpenDSS Simulation Results – Base Case



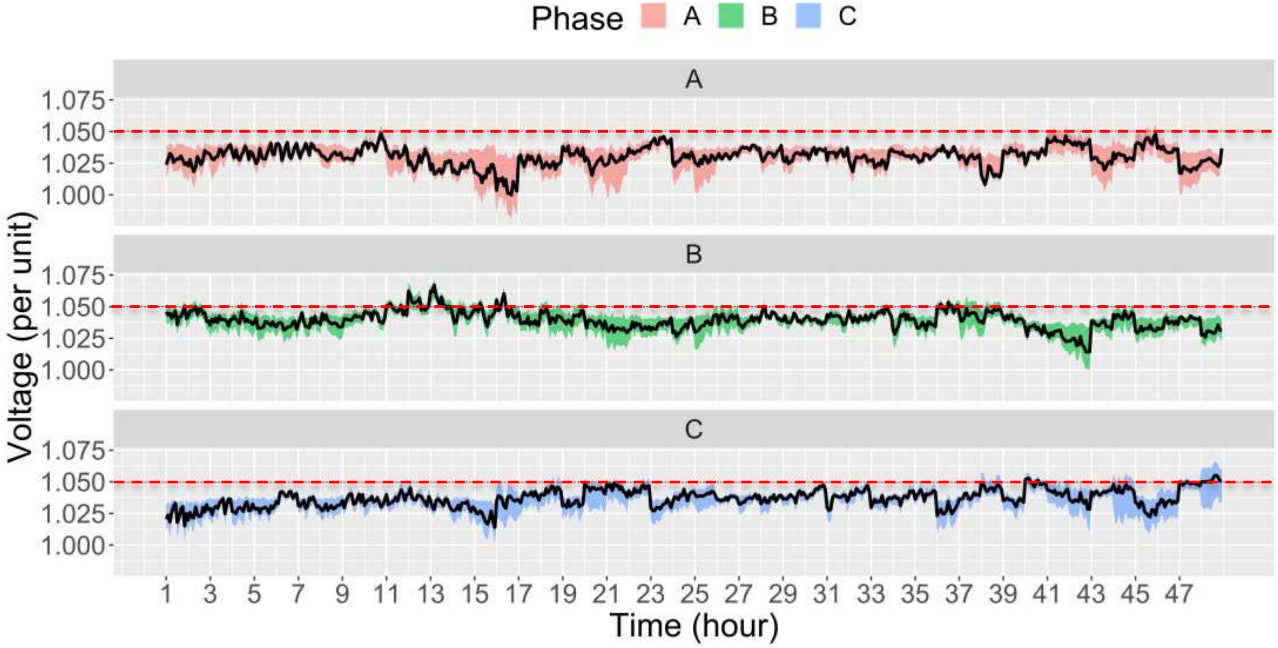


Key takeaways

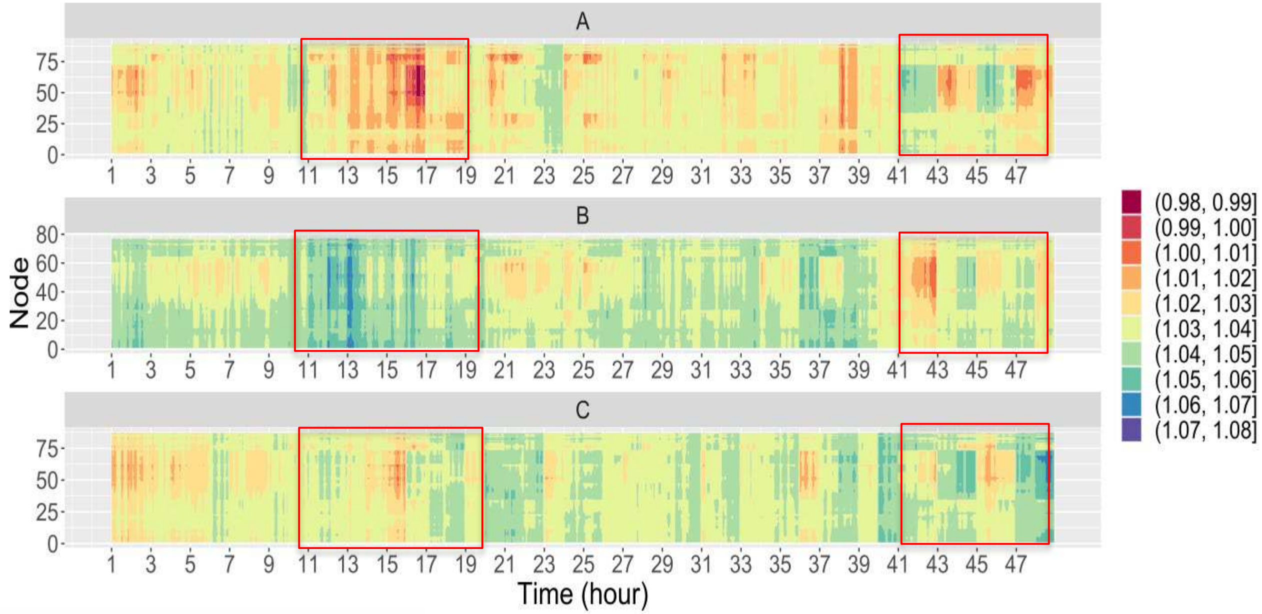
- Deterministic optimization ➔ unable to perform well due to forecast errors + computationally light.
- Robust optimization ➔ conservative + computationally heavy.
- Stochastic optimization ➔ balanced performance but affected by forecast error.

Hardware-In-Loop Simulation Results – Base Case

Node voltage variation vs. time



Node voltage vs. time



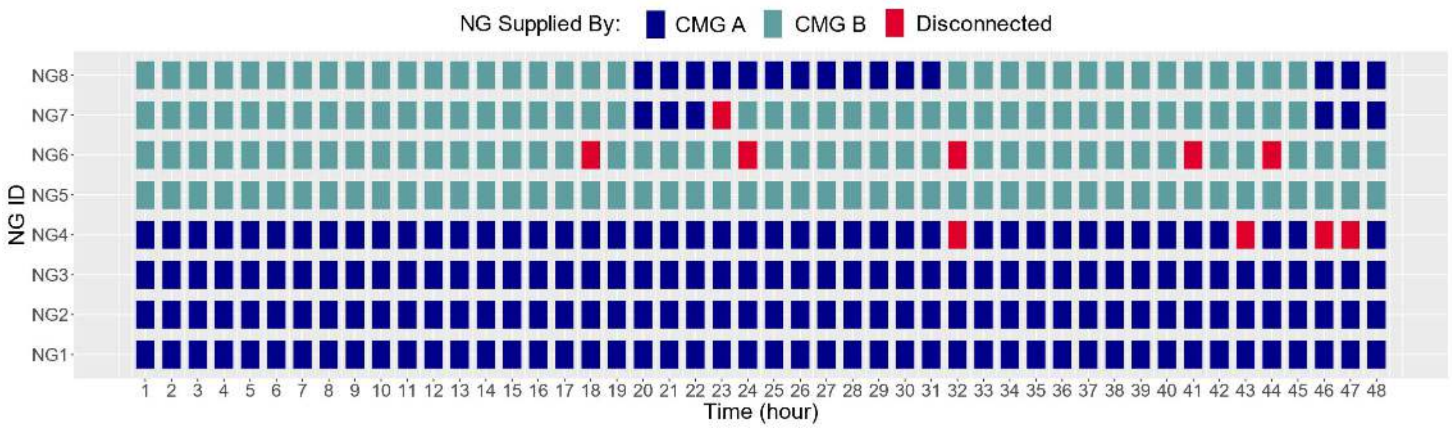
- PCC voltage reference ➔ 1.04 p.u.
- Line plot shows phase wise average voltage and voltage range across all nodes for different time intervals.
- Heatmap shows actual node voltage w.r.t. time.

Key takeaways

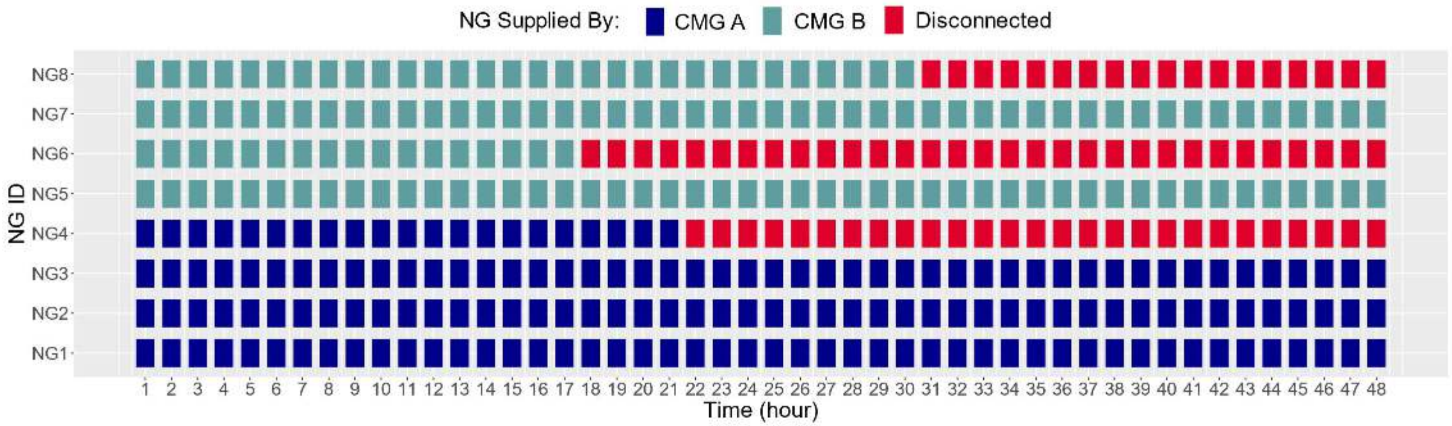
- Voltage ➔ mainly stays within the specified ANSI limits.
- Momentary voltage variations ➔ cause no severe operating limit violations.

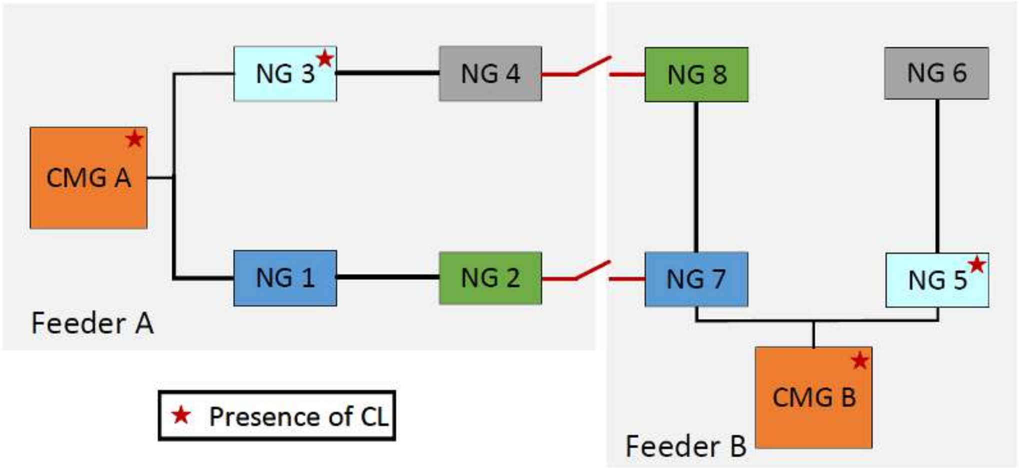
Multi-Agent Multi-Microgrid Approach for Resilient Energy Management

With NG Reallocation



Without NG Reallocation

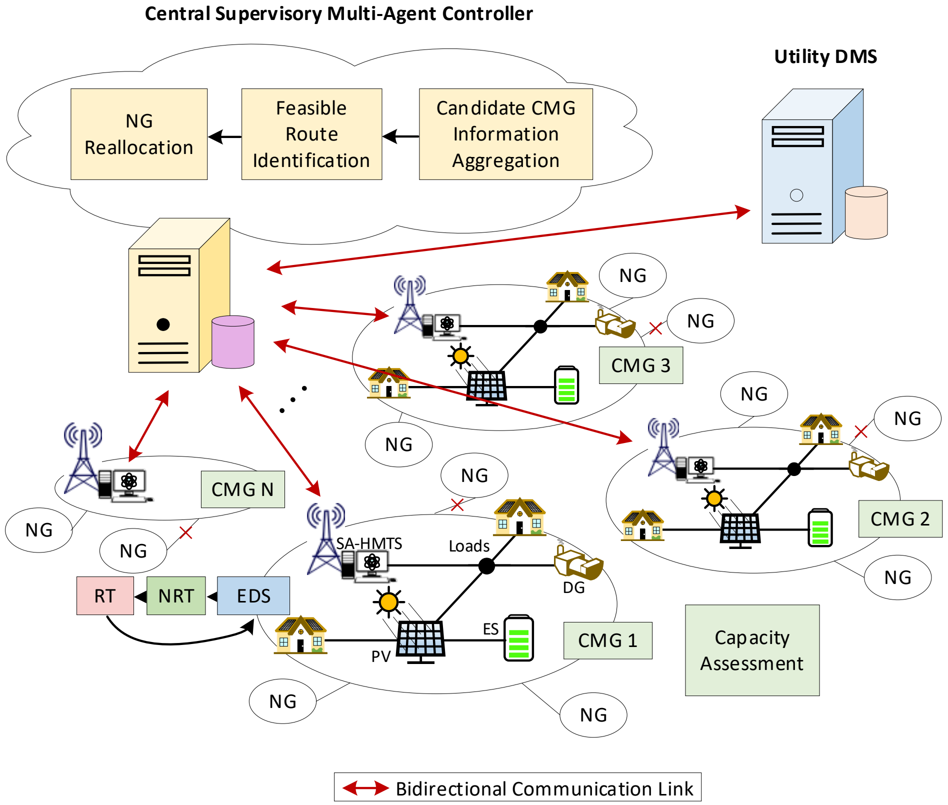




Key Takeaways

- Exchange of NGs from energy deficient CMG to energy rich CMG.
- 17.19% increase in average NG connectivity duration.
- Having avenue for reallocating NGs ➔ increase served load.

Summary



Features

- Minimum network reinforcements
- Dynamic MG Coverage Maximization
- Uncertainty-awareness
- Proactive load curtailment
- Computationally efficient
- Spatio-temporal generalizable
- Scalable design
- Simplistic adaptable design
- Timely decision dispatch
- Equitable access to electricity
- Extended duration resource allocation
- Resilient operation
- Secure operation
- Privacy preservation

Thank You!
Any questions?

1. A. Shirsat, et al., "Hierarchical Multi-timescale Framework For Operation of Dynamic Community Microgrid," *2021 IEEE Power & Energy Society General Meeting (PESGM)*, 2021. [Online]. Available: https://arxiv.org/abs/2011.10087

2. A. Shirsat et al., “SA-HMTS: A secure and adaptive hierarchical multi-timescale framework for resilient load restoration using a community microgrid,” 2022. Accepted for publication in IEEE Transactions on Sustainable Energy. [Online]. Available: https://arxiv.org/abs/2202.05252