VCU College of Engineering

Enhancing Microgrid Resilience to Cyber Attacks

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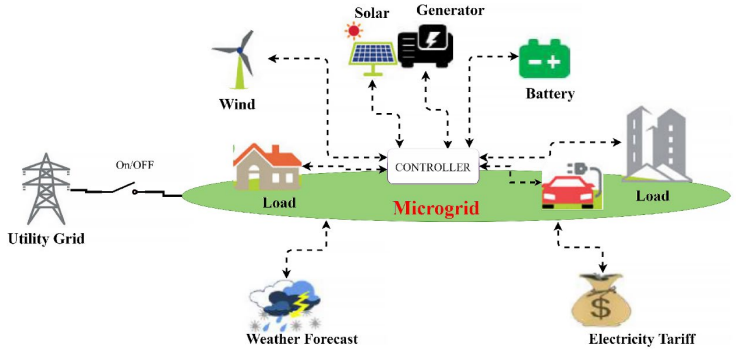
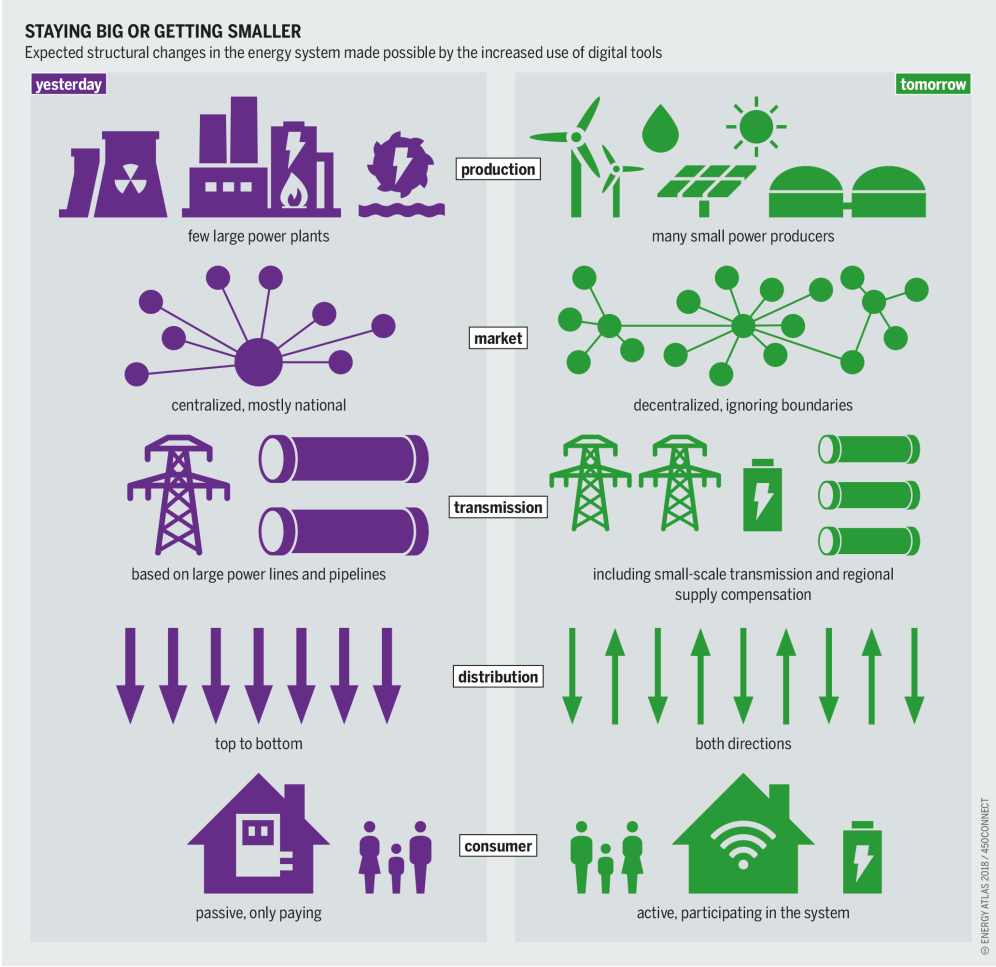
INTERNATIONAL Microgrid SYMPOSIUMS

Motivation

- Transition to decentralized power grid
- Emergence of microgrid
  - Grid modernization
  - Promoting community participation
  - Relies heavily on information
  - Data integrity attack
- Microgrid resilience

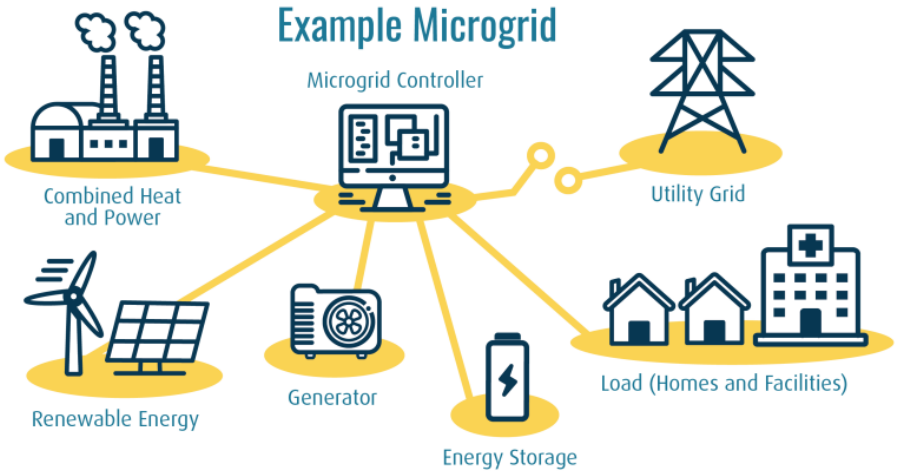




Energy Atlas 2018 - Facts and Figures about Renewables in Europe, (n.d.). https://gef.eu/publication/energy-atlas-2018/

Overview

- Developed a multi-layered microgrid simulation model.
- Integrated an optimization-based energy management system into the model.
- Investigated two critical aspects: data loss and false data injection attacks.
- Explored the impact of these aspects on the optimization and security of microgrid operations.



Microgrid Layout

https://www.naseo.org/issues/electricity/microgrids

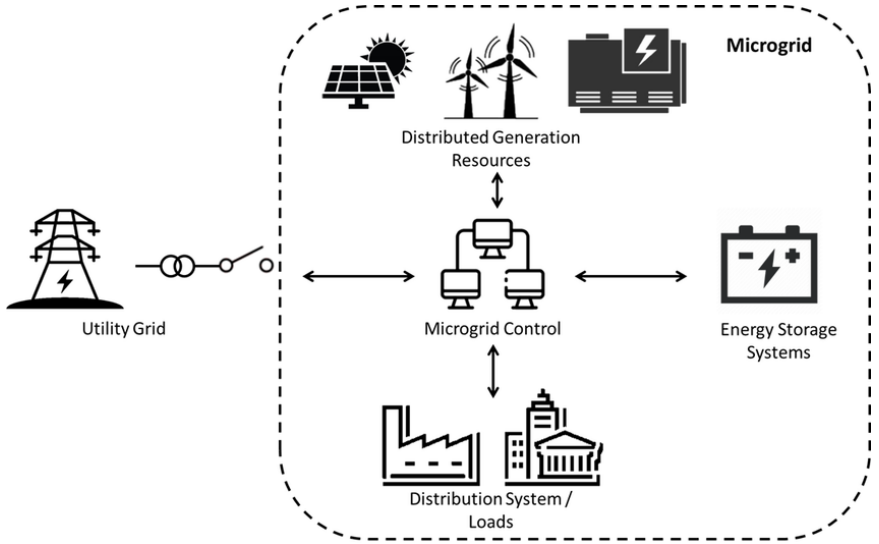
Microgrid: Overview

An interconnection of ESSs, DERs, and loads with defined boundaries that act as a single controllable entity.

Enables two-way flow of both powers for the electrical network and information for the communication network.

Microgrid Component:

- Distributed Energy Resources (DERs)
- Energy Storage System (ESS)
- Loads
- Control and Monitoring System
- Point of Common Coupling (PCC)



Microgrid Components

https://www.researchgate.net/publication/366001011_Experimental_Validation_of_Systems_Engineering_Resilience_Models_for_Islanded_Microgrids_for_Defense_Operations

Energy Management System

An energy management system (EMS) is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation or transmission system.

Objective Function

$$\min\left(\sum_{t=0}^{N}\left(C_{grid}(t)\times P_{grid}(t)\right)\times\Delta t+\sum_{t=0}^{N}\left(P_{gen}(t)\right)\times C_{gen}\times\Delta t+\sum_{t=0}^{N}\left(P_{batt}(t)\right)\times C_{batt}\times\Delta t\right)$$

Constraints

$$P_{pv}(t)+P_{grid}(t)+P_{batt}(t)+P_{gen}(t)=P_{load}(t)$$

$$E_{batt}(t)=E_{batt}(t-1)+P_{batt}(t)\times\Delta t$$

$$X_{min}\leq X\leq X_{max}$$

FDIA Model

Continuous Intensity FDIA Model

$$if\ t_{start} \le t \le t_{end}$$

$$I(t) = random(I_{max}, I_{min})$$

$$D_{att}(t) = D_{act}(t) + \frac{I(t)}{100} \times D_{act}(t)$$

Probabilistic Intermittent FDIA Model

$$if\ t_{start} \le t \le t_{end}$$

$$I(t) = random(I_{max}, I_{min})$$

$$D_{att}(t) = \begin{cases} D_{act}(t) + \frac{I(t)}{100} \times D_{act}(t), if\ random(0,1) < \varepsilon_{attack} \\ D_{act}(t), otherwise \end{cases}$$

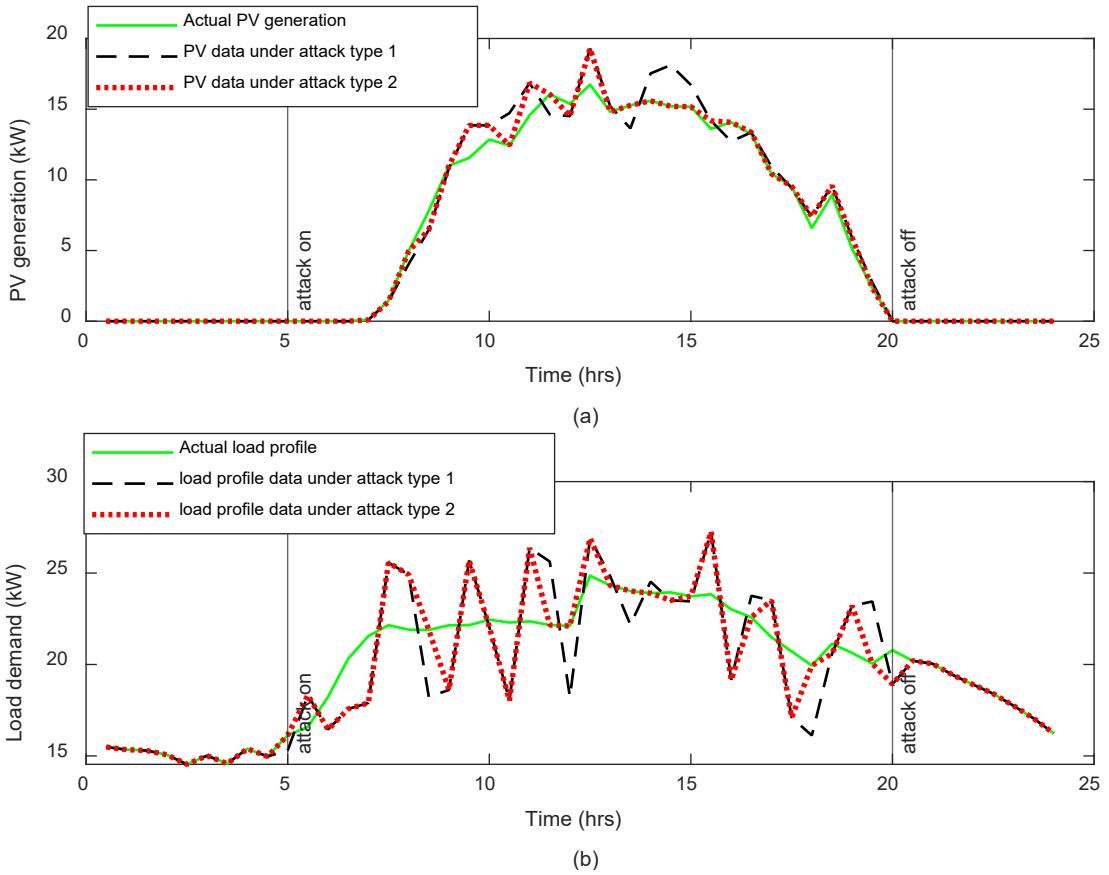


Fig1.(a) PV generation data under 20% FDIA, (b) Load profile data under 20% FDIA

Microgrid Operation: Optimization-based EMS

- Simulation dataset: weather data, customer loads, electricity market datasets.
- EMS inputs: 24-hour RE generation, load profiles, variable electricity prices forecast.
- Optimization-based EMS: Determines optimal battery , load control and dispatch commands.
- Execution: Commands sent to microgrid local controllers for implementation.
- Real-time updates: Sensor data to adjust forecasts and BESS SOC.

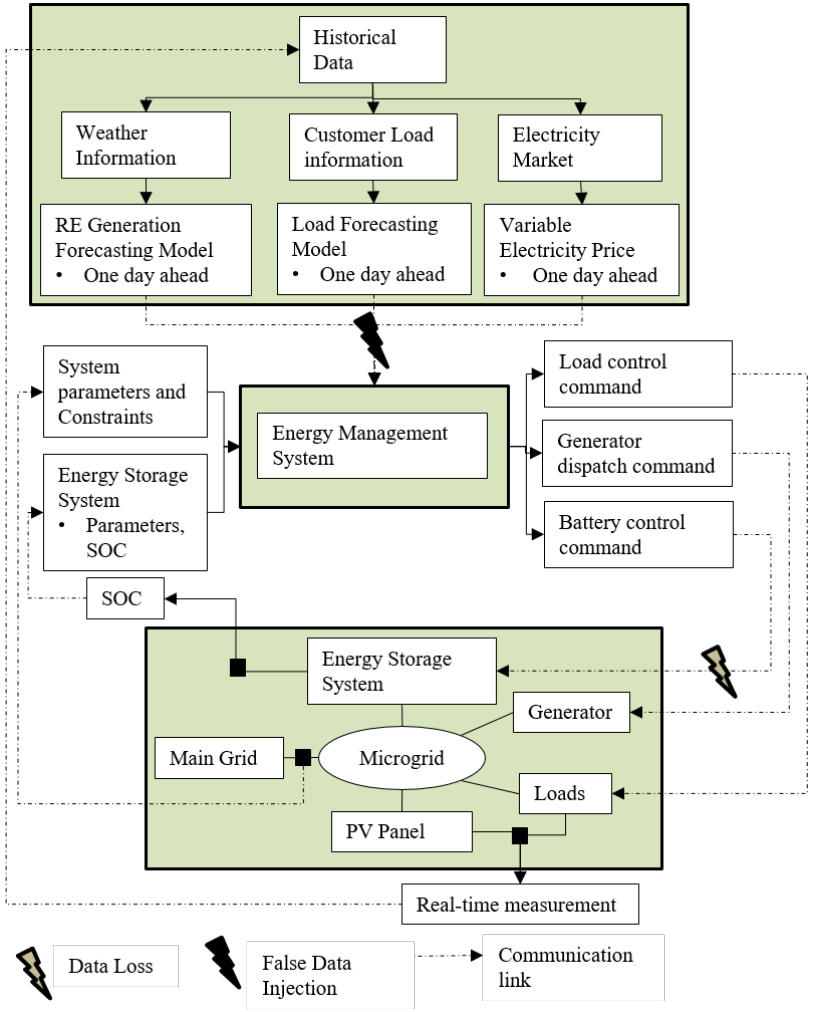


Fig 2. Working flow for the optimization-based EMS

Microgrid Operation Strategy

Simulating Data Loss in Battery Command

- We have simulated probabilistic data loss in battery command to asses the economic impact in the microgrid system with increasing probabilistic data loss.

Simulating FDIA in EMS

- Hybrid EMS: Combining optimization based EMS with adaptive control schemes.
- Optimization-based EMS in normal condition.
- Adaptive control modes activated during islanded operation upon FDIA detection.
- Hybrid approach prioritizing economic efficiency under normal conditions, while ensuring stable microgrid operation in critical conditions by dynamically adjusting objectives based on the situation.

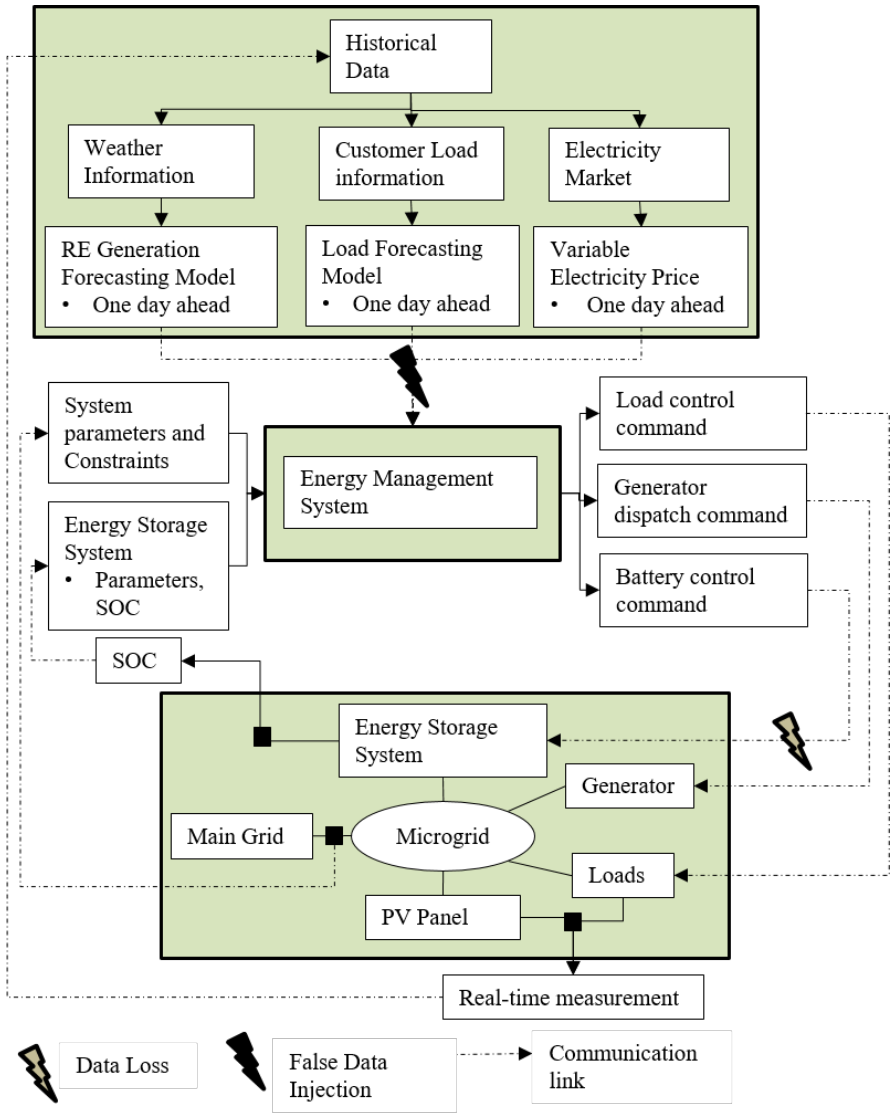


Fig 3. Working flow for the optimization-based EMS

Microgrid Operation: Adaptive Control

- Real-time sensor data, exclusion of 24-hour forecast data. Redundancy measures advised for real-time sensor data in critical systems like microgrids.
- Droop control settings for generators
- Priority of RE sources to meet demand followed by BESS utilization based on SOC.
- Generator cover unmet load
- Predetermined load shed if demand exceeds generation capacity.
- Excess PV generation curtailed to ensure balance.

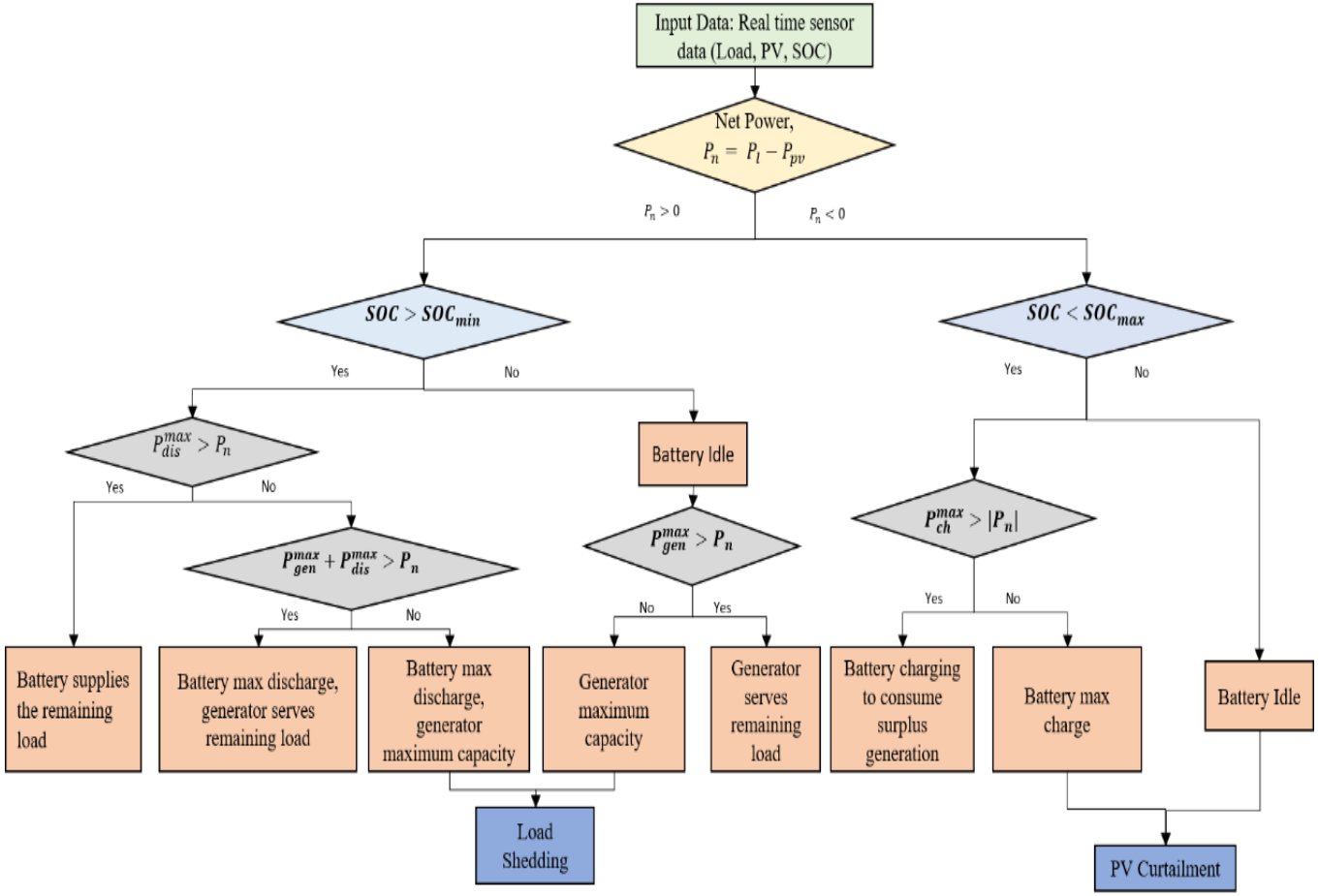


Fig 4. Working diagram for adaptive control schemes for microgrid operation

Simulation Setup: Data Loss Impact

- Peak load 10.2 kW.
- PV system and a battery energy storage system
- PV penetration (10%, 50%, 100%)
- 10% PV penetration, 15kWh battery energy storage system with a maximum charging/discharging rate of 5kW
- 50% and 100% PV penetration, 75kWh battery energy storage system with a maximum charging/discharging rate of 5kW.
- Data loss (0%, 10%, 30%, 50%, 100%)

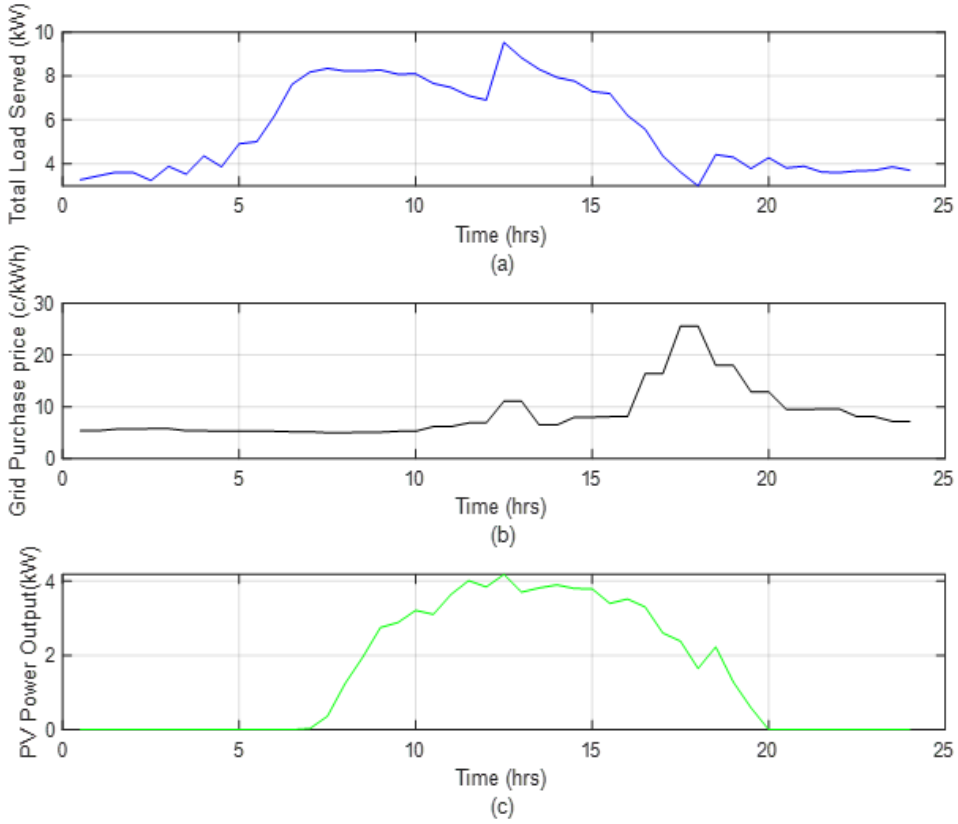
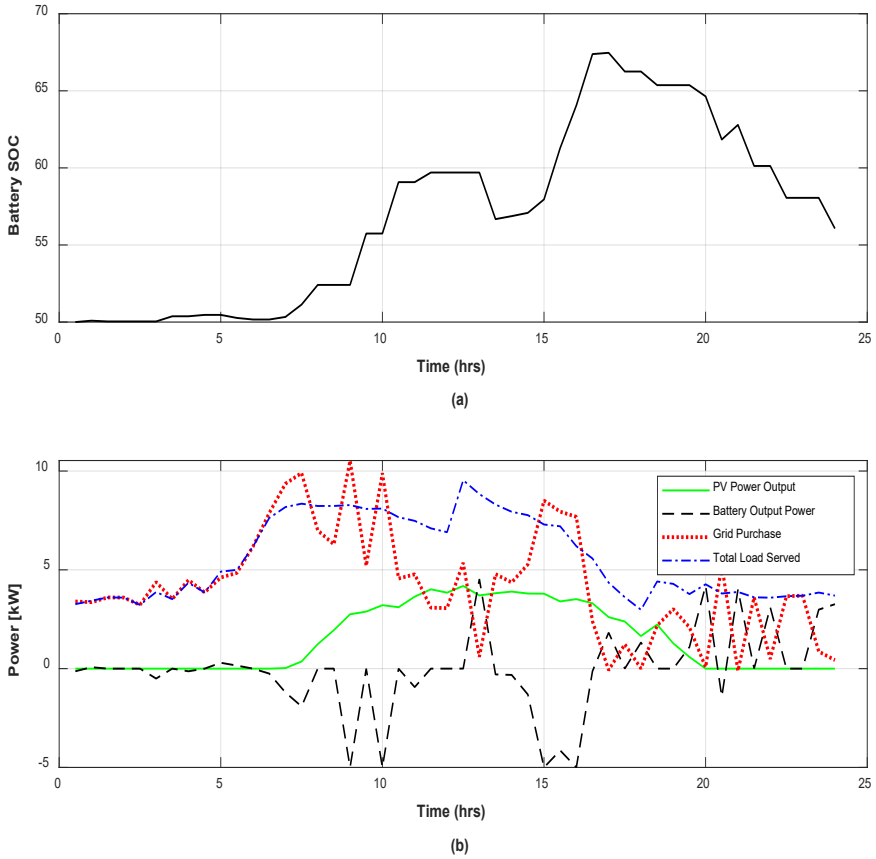


Fig. 5 (a) Actual load profile in the microgrid, (b) Variable grid electricity price, (c) PV generation

Result and Analysis: Data Loss



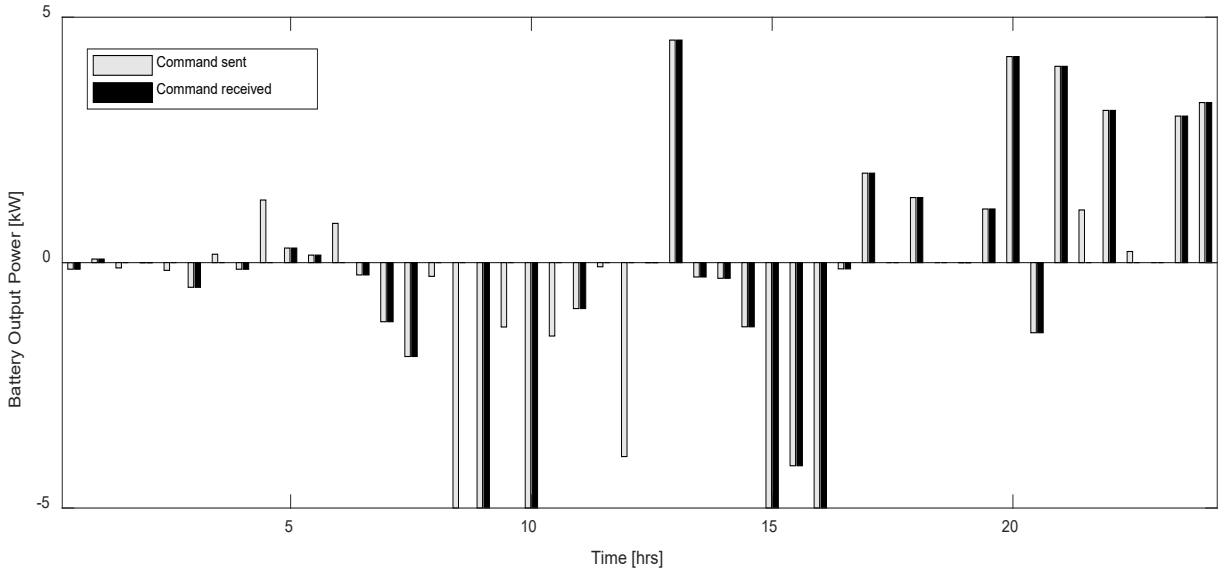


Figure 6: A specific case of 50% PV penetration scenario with 30% data loss in the microgrid (a) State of charge of the BESS, (b) Optimized power profiles of PV generation, battery output, grid electricity, and total load over time, (c) Battery charging/discharging command

Result and Analysis: Data Loss

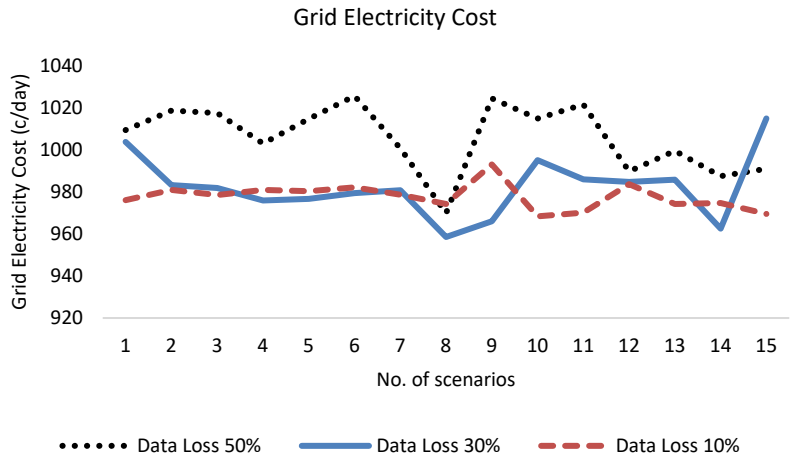


Figure 7: Comparison of grid electricity cost for the microgrid with 10% PV penetration with varied amounts of data loss

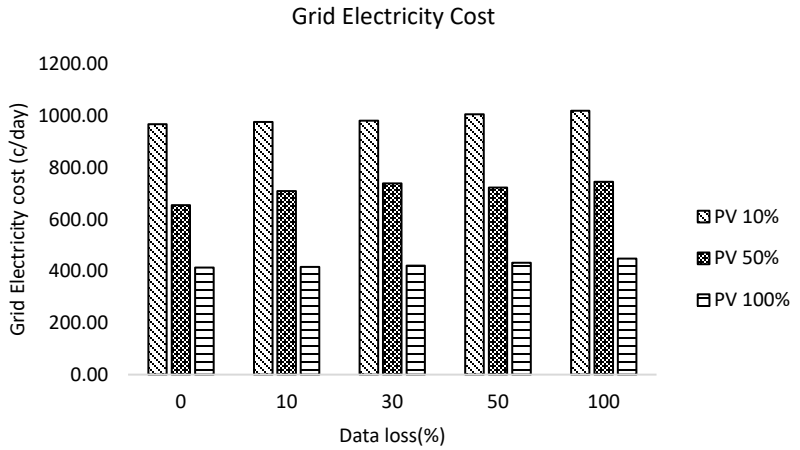


Figure 8: Comparison of average grid electricity cost for varying PV penetration and data loss rate in microgrid

Table . Comparison of average grid electricity cost for varying PV penetration and data loss rate in microgrid

PV % \ Data Loss	Grid Electricity Cost (c/day)				
	0	**10**	**30**	**50**	**100**
10	969.64	977.63	982.33	1007.86	1021.10
50	656.12	710.55	739.41	723.31	746.65
100	414.53	417.04	421.50	432.63	448.88

Simulation Setup: FDIA

- Peak load 25 kW.
- PV system and a battery energy storage system
- Total PV capacity: 16.75 kW
- Diesel Generator capacity 25kW
- 75kWh battery energy storage system with a maximum charging/discharging rate of 5kW (each)

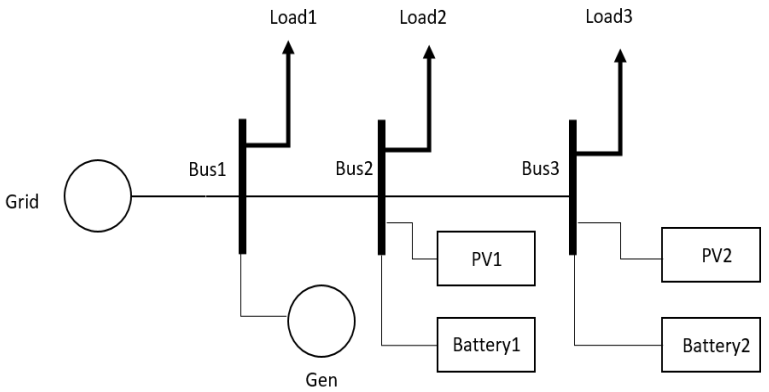


Fig 9. Microgrid Topology

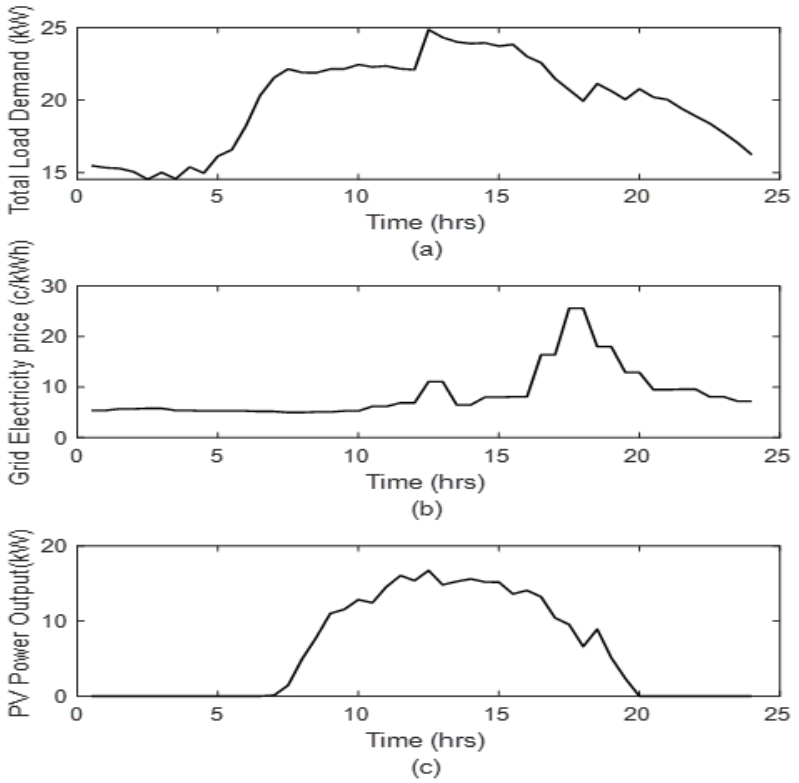


Fig. 10: (a) Actual load profile in the microgrid, (b) Variable grid electricity price, (c) PV generation

Result and Analysis: FDIA

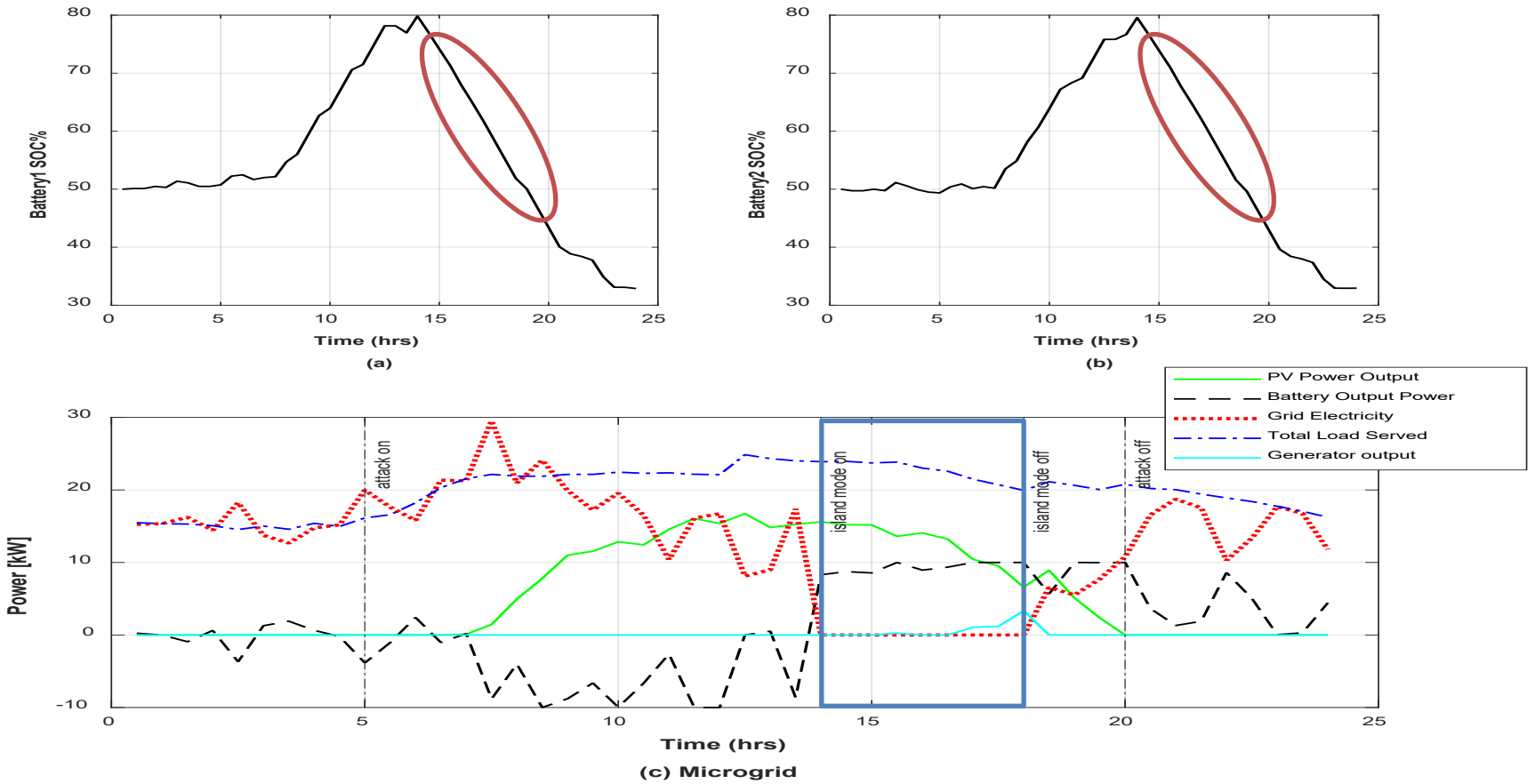


Figure 11: (a) SOC of BESS1, (b) SOC of BESS2, (c) Power profiles of PV generation, battery output, grid electricity, generator output and total load over time using hybrid EMS method under FDIA type 1

Result and Analysis: FDIA

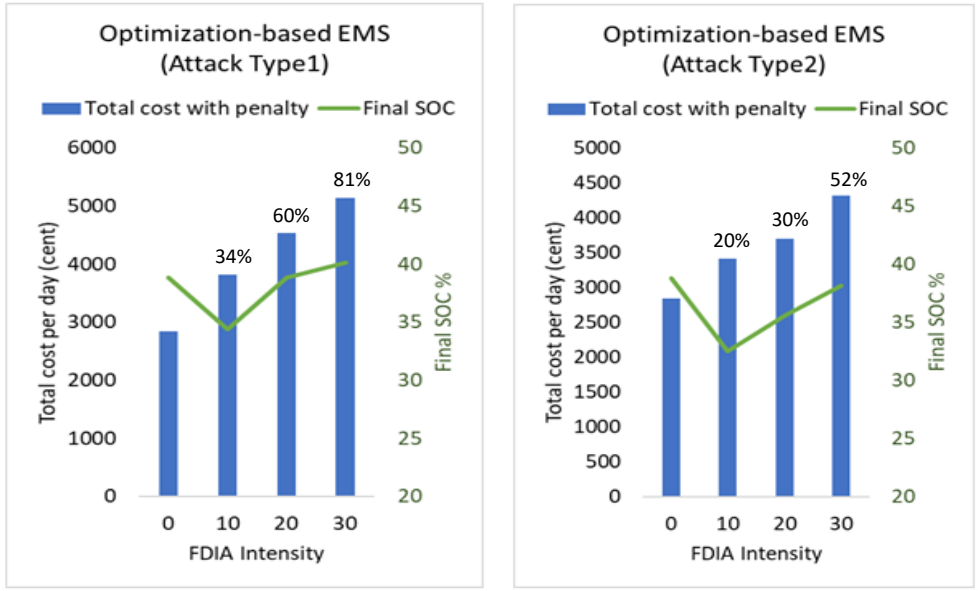


Fig. 12 Total electricity cost* and final SOC with increasing intensity of FDIA type 1 & type 2 in 24-hour microgrid operation for optimization-based EMS

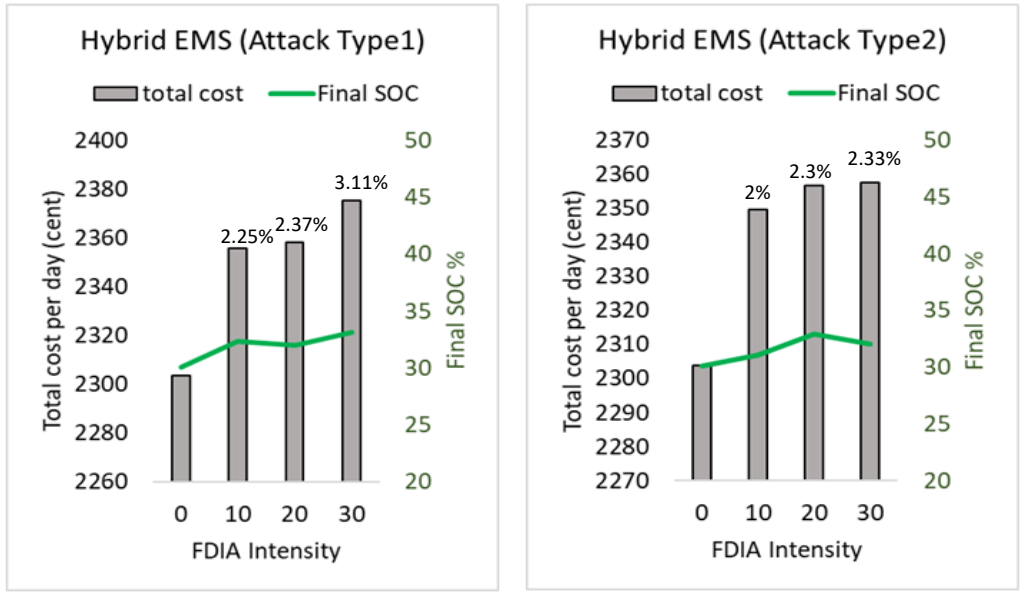


Fig. 13 Total electricity cost and final SOC with increasing intensity of FDIA type 1 & type 2 in 24-hour microgrid operation for hybrid EMS

*In cases of load shedding, a penalty cost is added to the total electricity cost, typically assumed as 240c/kWh according to the literature.

Result and Analysis: FDIA

Table. Summary of Microgrid Operation Under Various FDIA Scenarios

Microgrid Operation Method	FDIA time	FDIA intensity (%)	FDIA type	Islanded mode operation time	Total cost for electricity per day (c/day)	SOC of BESS (%) at the end of the day	Load shedding (%)	Total cost considering penalty for load shedding (c/day)
Optimization based EMS	5:00am – 8:00pm	0	1/2	2:00pm – 6:00pm	2840.02	38.84	0	2840.02
		10	1		2457.88	34.40	1.18	3810.43
		20			2602.97	38.86	1.69	4542.23
		30			2585.11	40.11	2.22	5138.21
		10	2		2449.58	32.54	0.84	3419.93
		20			2502.83	35.62	1.04	3701.47
		30			2593.74	38.18	1.51	4324.38
Hybrid EMS		0	1/2		2303.74	30.11	0	2303.74
		10	1		2355.55	32.31	0	2355.55
		20			2358.37	32.00	0	2358.37
		30			2375.28	33.12	0	2375.28
		10	2		2349.81	31.11	0	2349.81
		20			2356.84	32.94	0	2356.84
		30			2357.51	32.04	0	2357.51

Summary

Designing different layers of microgrid.
Economic optimization of grid utilization using energy management logic factoring variable electricity cost and using efficient energy storage system.
Assessing the impact of variable renewable energy penetration and different levels of data loss on the cost of electricity in the microgrid.
Introducing a hybrid EMS strategy incorporating optimization based EMS along with adaptive control schemes when microgrid under FDIA in island mode operation.
Examining the effects of FDIA on microgrid operation in diverse scenarios
Our findings reveal potential load balance discrepancies during islanded microgrid operation under FDIA, emphasizing the necessity for adaptive control methods.

Thank You