A Templated Modelica Model for Decoupling Physical System and Control in Resilient Community Energy Systems

Juan Diego Flores Garcia[1], Tahiya Hossain[1], Viswanathan Ganesh[1], Wangda Zuo[1,2]

[1]Architectural Engineering, Pennsylvania State University, University Park, PA, USA

[2]National Laboratory of the Rockies, Golden, CO, USA

PennState College of Engineering

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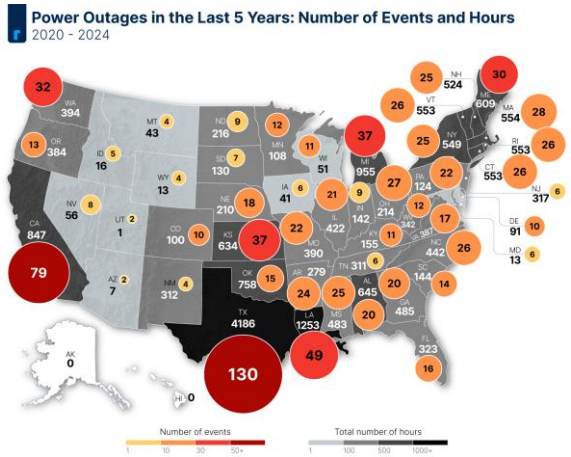
A Widening Resilience Gap

No longer a question of if the community will lose the grid, but how it keeps critical services running when it does.



~60 yrs

average age of U.S. transmission infrastructure — nearing or exceeding design life [1]



520M

customer-hours without power annually across the U.S. [2]



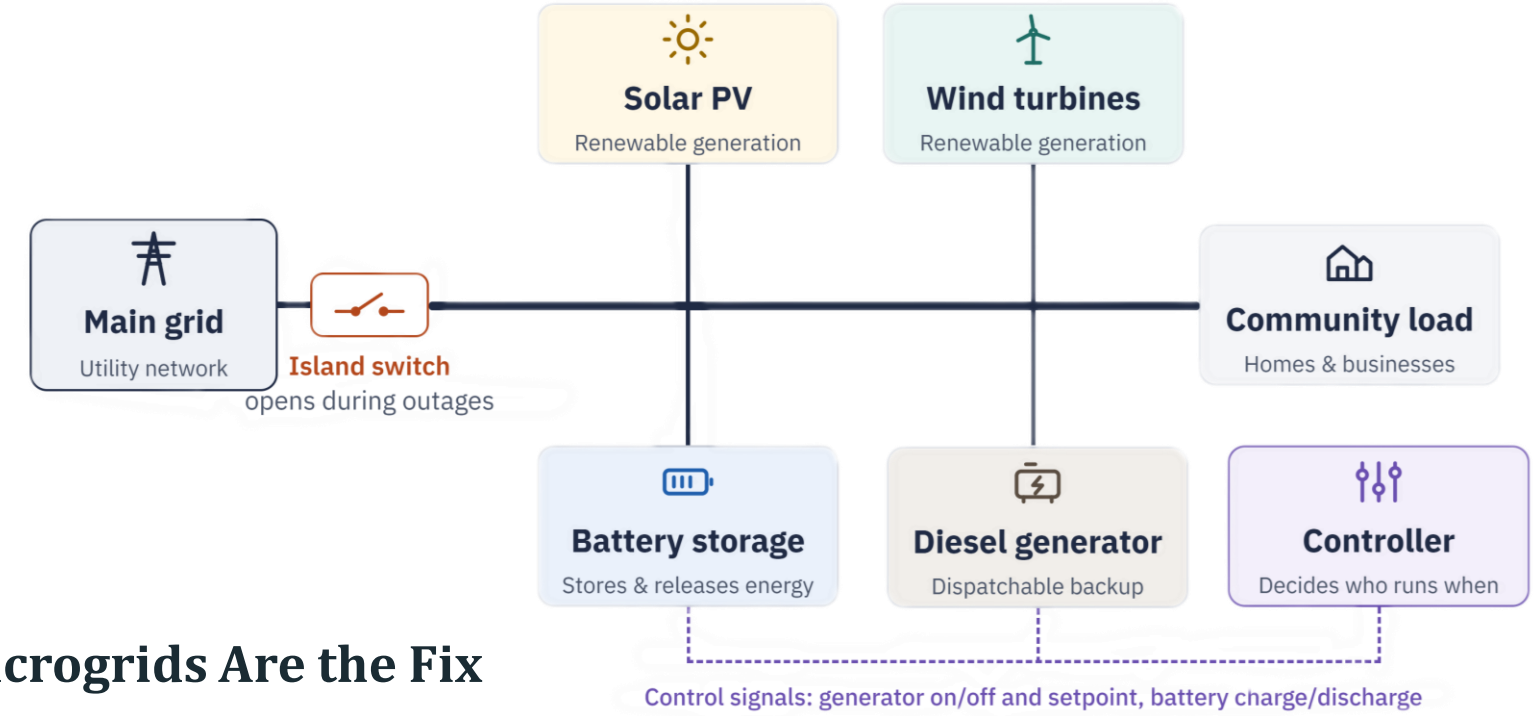
2 weeks

20,000 people in Gary, IN without power after August 2026 storms [3]

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Microgrids

A microgrid combines local generation and smart controls to power a community, with or without the main grid.



The catch

Microgrids Are the Fix

- Islanding capability sustains critical loads during prolonged grid outages [4,5]
- Hybrid distributed energy systems (DER) replace inefficient, high-emission diesel-only backup
- Can also shave peak demand under normal operation to prevent localized blackouts [6]

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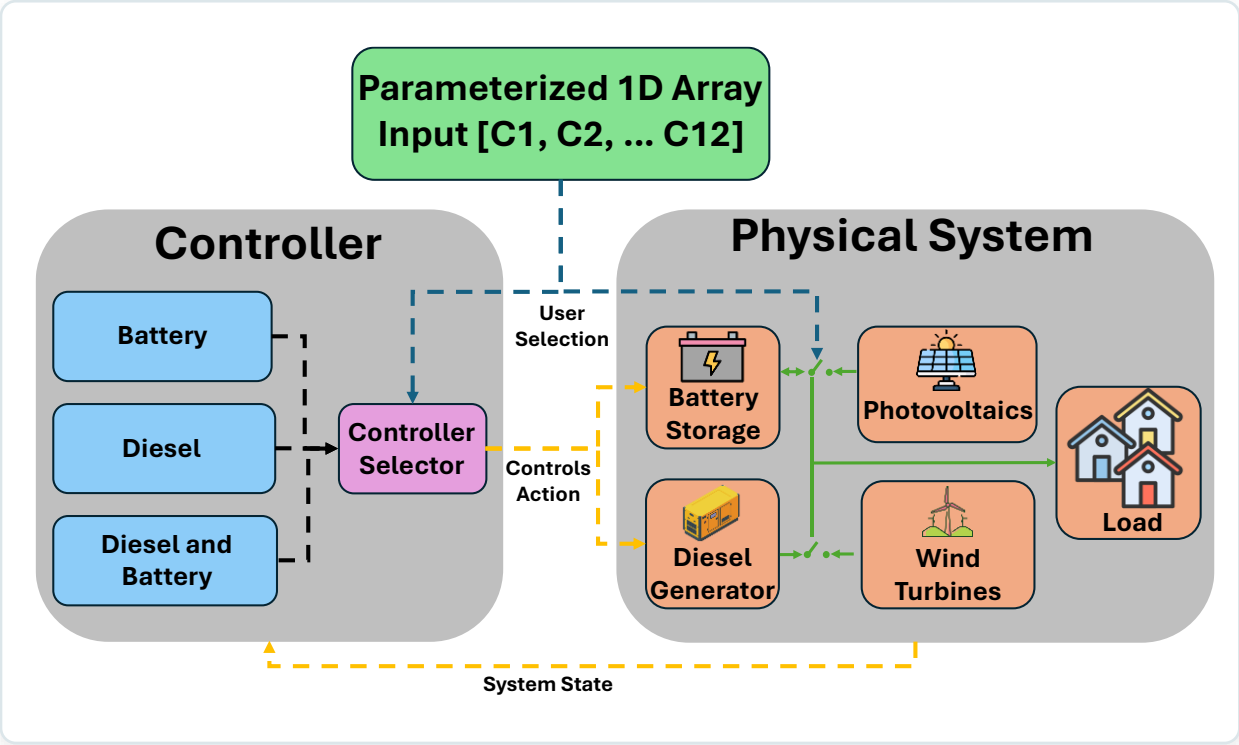
A Modular, Decoupled Template Framework

Core Contribution:

A parameterized 1D array switches the active physical configuration AND auto-links it to the matching baseline controller: 12 topologies, zero manual rewiring.

Two interoperable sub-models:

- Controller
- Physical System
- Communication via standardized data buses



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Twelve Distinct Microgrid Configurations

Table: Microgrid Configurations and Active Control Strategies

Config ID	Included Components	Controlled Asset(s)
1	DG only	DG
2	BESS only	BESS
3	DG + Wind	DG
4	DG + BESS	DG + BESS
5	DG + PV	DG
6	Wind + BESS	BESS
7	BESS + PV	BESS
8	DG + Wind + BESS	DG + BESS
9	DG + Wind + PV	DG
10	DG + BESS + PV	DG + BESS
11	Wind + BESS + PV	BESS
12	DG + Wind + BESS + PV	DG + BESS

Design Constraint

12 configs from 4 asset types:

- Diesel Generator (DG)
- Battery energy storage system (BESS)
- Photovoltaic panels (PV)
- Wind turbines (Wind)

Every configuration retains at least one dispatchable unit (DG or BESS) to guarantee resilience during islanded operation.

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Structurally Decoupled Sub-Models

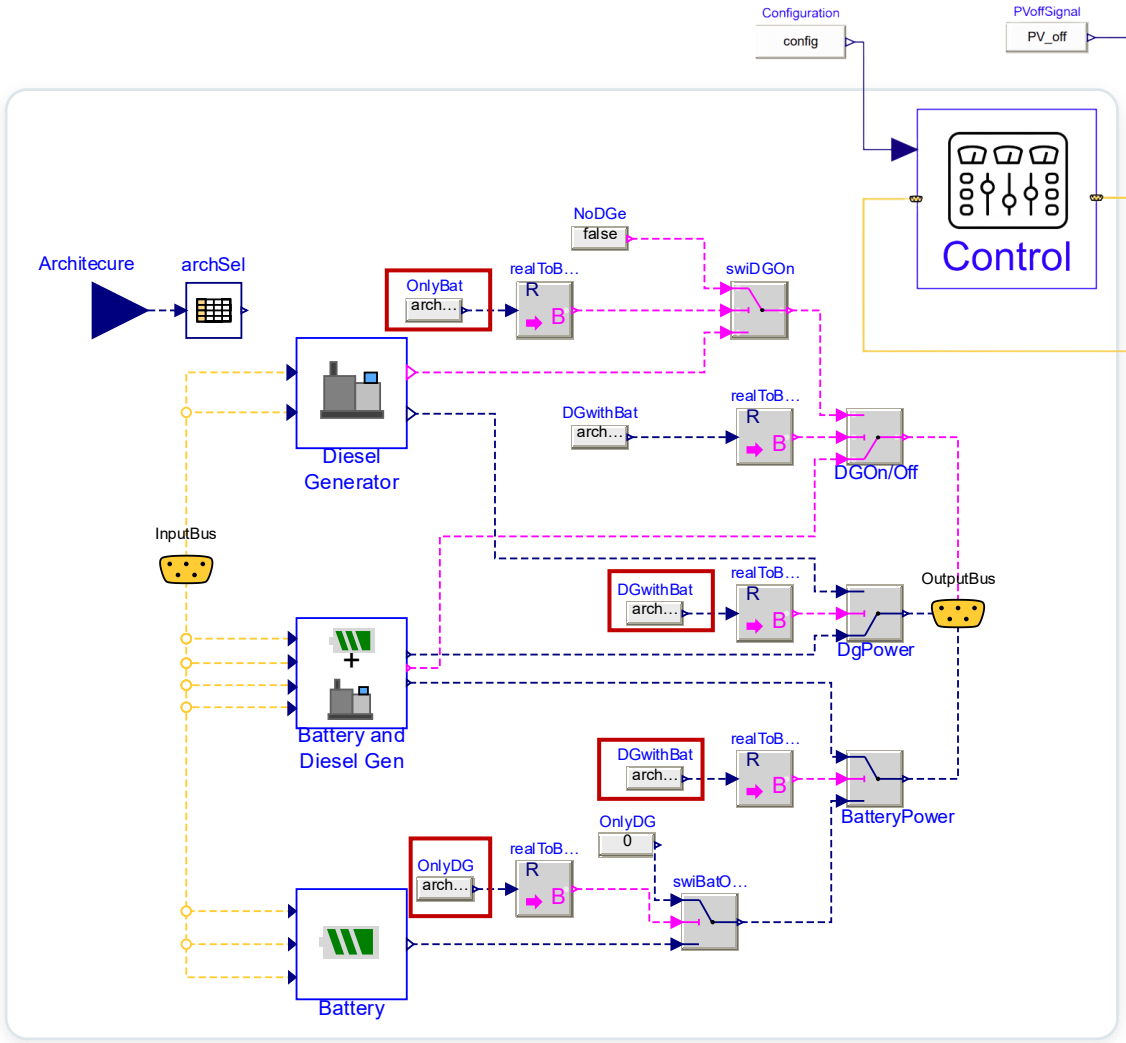


Figure: Controller & switching mechanism

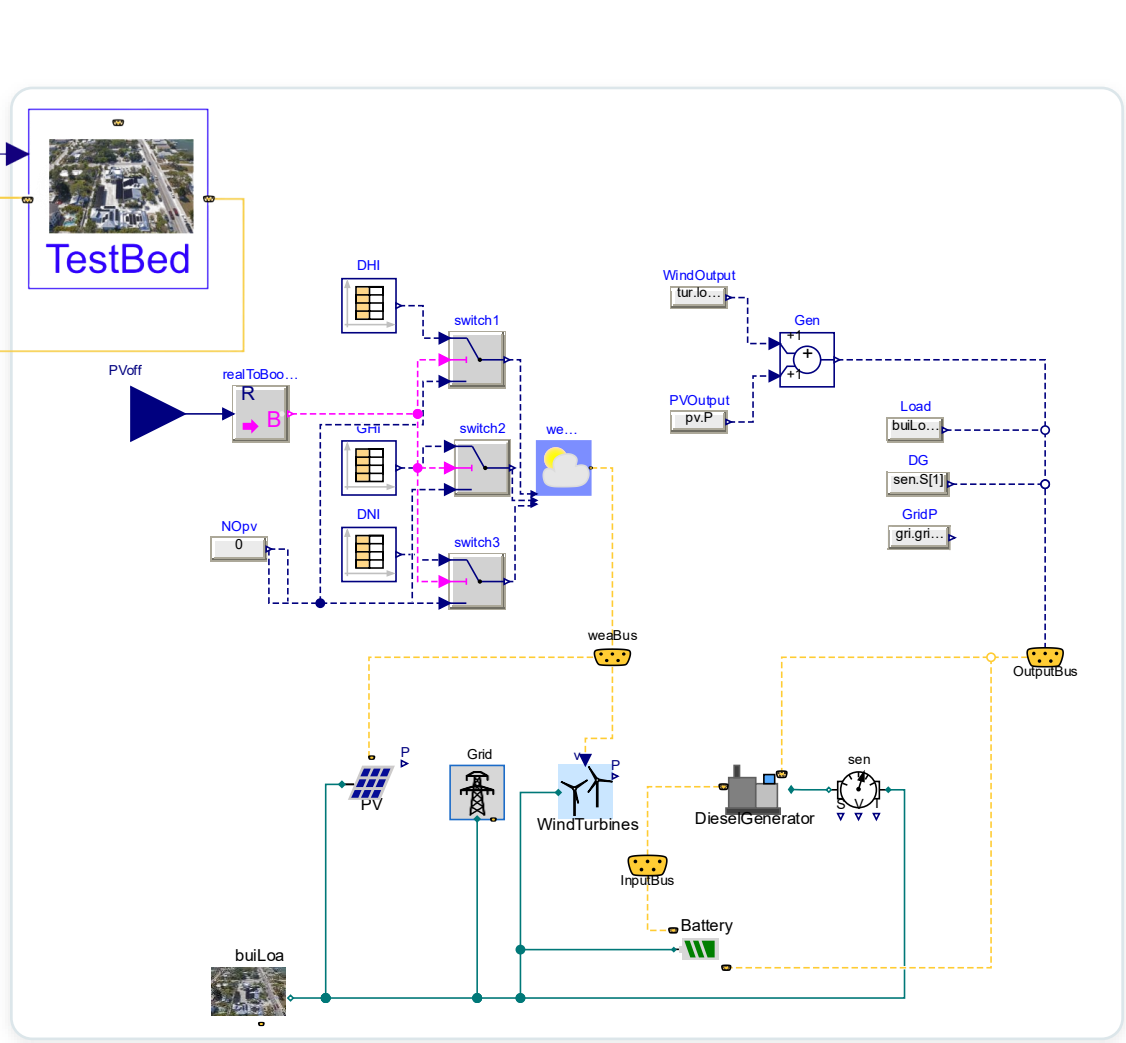
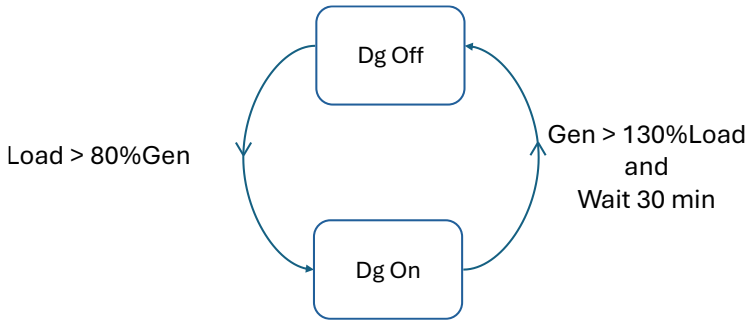


Figure: Physical System (TestBed)

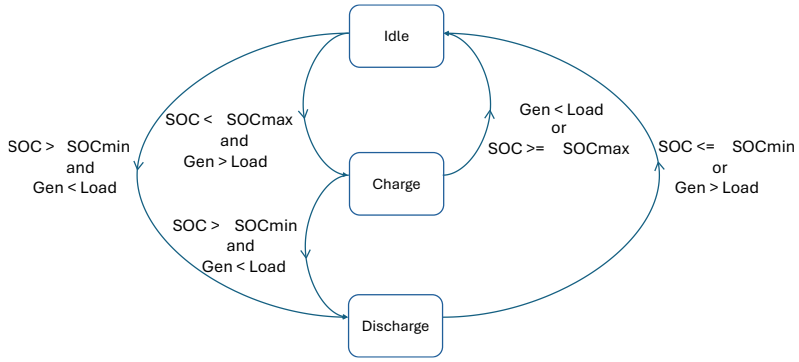
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Controller: Three Auto-Selected Control Strategies



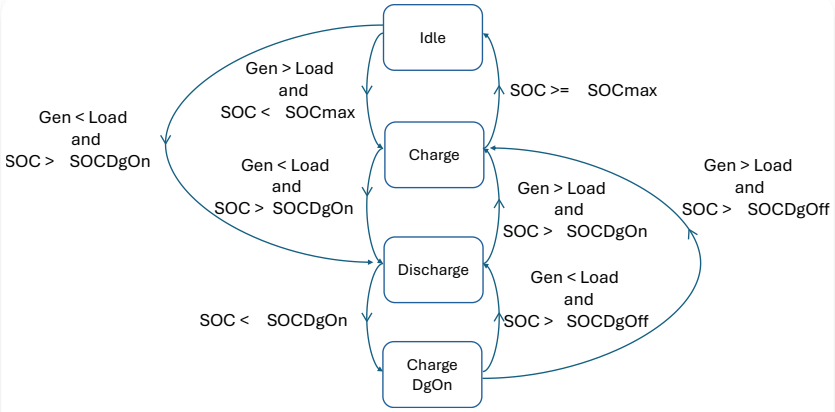
DG-only

Load-following: ON above 80% load, OFF only after generation exceeds 130% for a sustained 30-min window



BESS-only

3-state idle / charge / discharge tracks state of charge (SOC) vs. net load, maximizing renewable self-consumption



DG + BESS

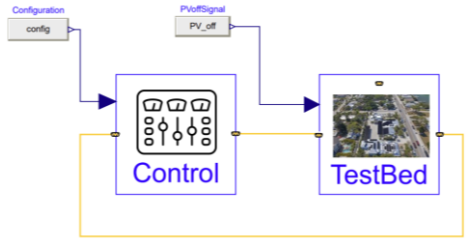
4-state logic: DG activates only when SOC drops below a critical threshold, stands down once recharged

Complexity of controller

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From Modelica Model to Automated Simulation

1 · BUILD ONCE
Modelica template



Single top-level model: Configuration → Control ⇄ TestBed

Decoupled: physics and control logic in separate blocks

2 · PACKAGE
FMU export

One FMU

Control.fmu
Supervisory dispatch: DG on/off & setpoint, BESS charge/discharge

signal bus

TestBed.fmu
Physical system: PV, wind, DG, BESS, community load

3 · RUN MANY
Python orchestration

1. **Select Config ID**
   1–12 topologies
2. **Set parameters before init**
   active assets → target size
3. **Simulate the FMU**
   Control and TestBed over the desired period
4. **Record outcomes**
   load served · fuel · CO_2 · Cost

repeat: every topology × sizing

No manual re-wiring between topologies

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Testing the Template Model by Sizing the Energy System for a Community

Site: Historic Green Village

- 2,776 m² mixed-use community near Tampa, FL: 1 commercial office, 2 retail, 2 residential buildings [11]
- Wind was excluded from the sizing selection for this site, but all 12 topologies were still run to evaluate the templating mechanism itself



3,669.4
total kWh critical energy / week

31.5 kW
peak critical demand

524.2
avg. kWh / day

168 hr
simulated outage

Scenario

- Deterministic 168-hour (7-day) outage, Aug 20–27

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Baseline Sizing & Exhaustive Search Space

Component	Sizing	Basis
DG (baseline)	Fixed at 40 kW	Peak load + 20% engineering margin

Legend

DG	Diesel generator
BESS	Battery energy storage system
PV	Photovoltaic (solar) panels

Included Components
DG only

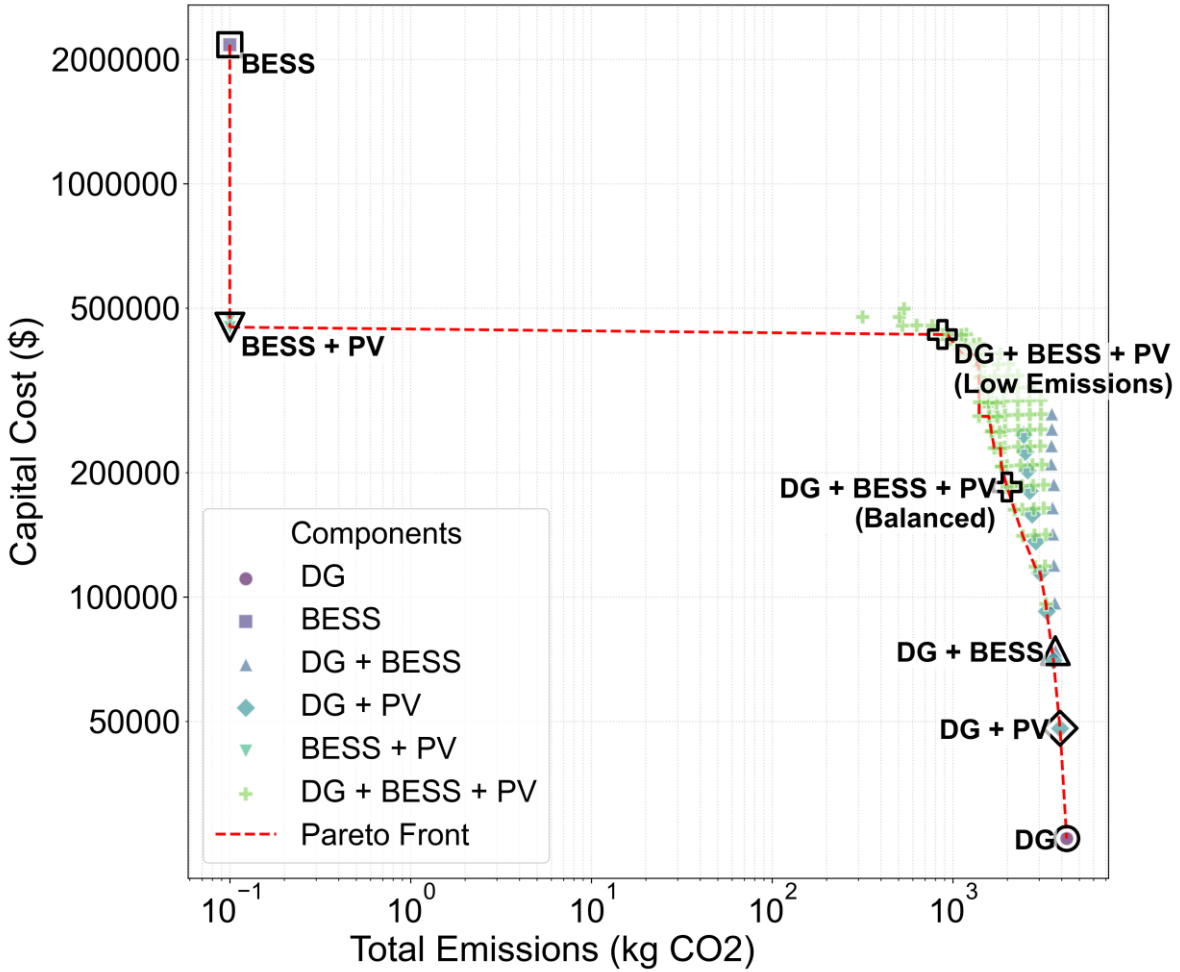


222
sizing combinations evaluated

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Mapping the Cost–Emissions Pareto Frontier

- Only configurations that sustained the full 168-hr critical load are plotted
- Narrows 124 simulations to 26 representative Pareto-optimal configurations
- Frontier spans low cost, high emissions (DG-only) to high cost, low emissions (BESS-only), with hybrids filling the middle



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Verifying Dynamics

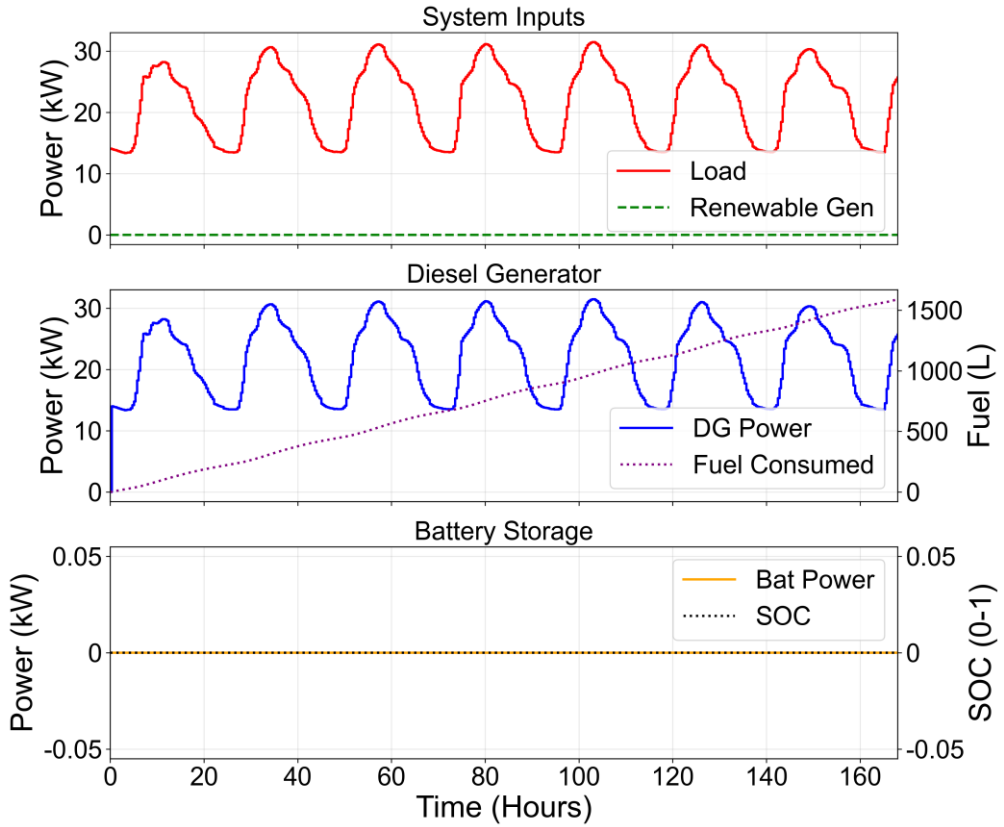


Figure: DG-only

1,600 L fuel consumed over the week

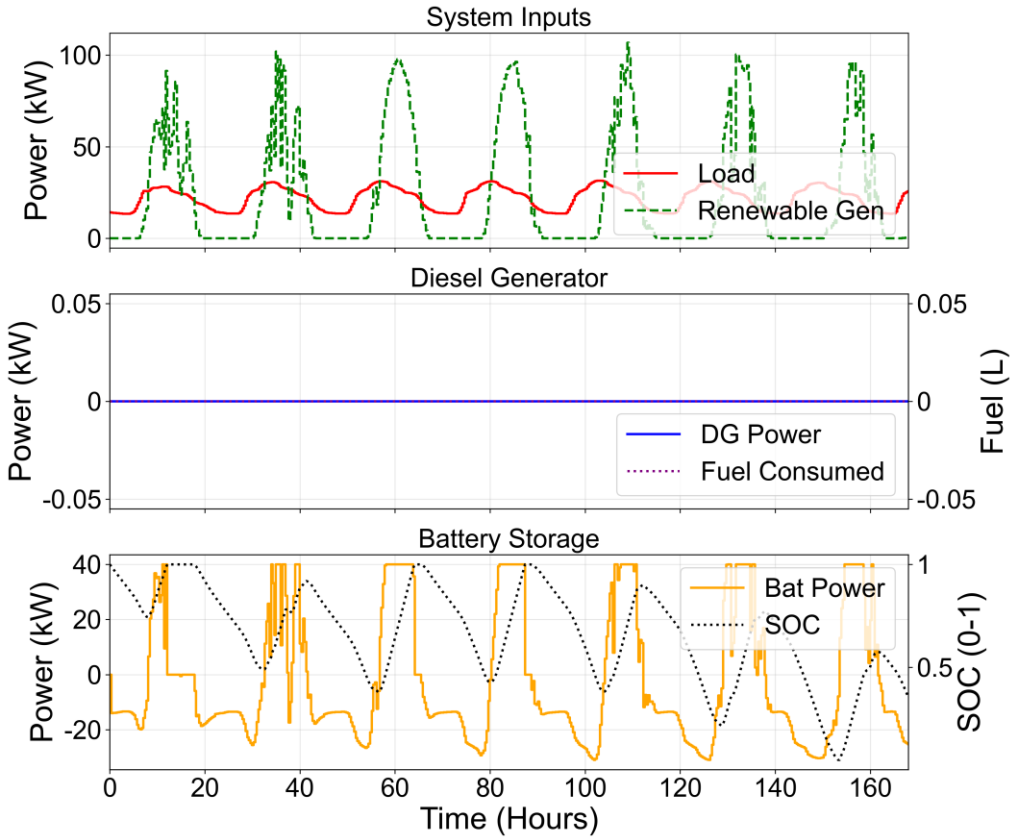


Figure: Purely renewable PV + BESS

BESS absorbs daytime PV surplus, discharges overnight

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Verifying Dynamics: DG+BESS+PV

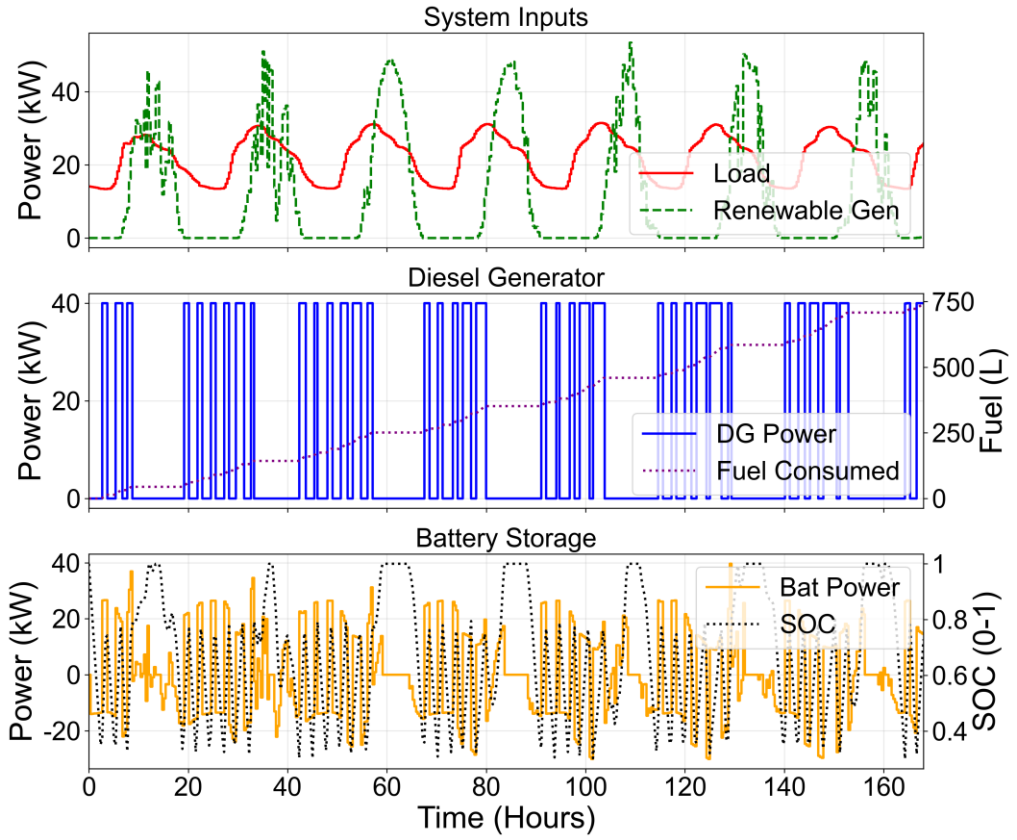


Figure: DG+BESS+PV (Balanced)

Smaller battery (50 kWh) cycles 30–80% SOC repeatedly, forcing frequent DG starts

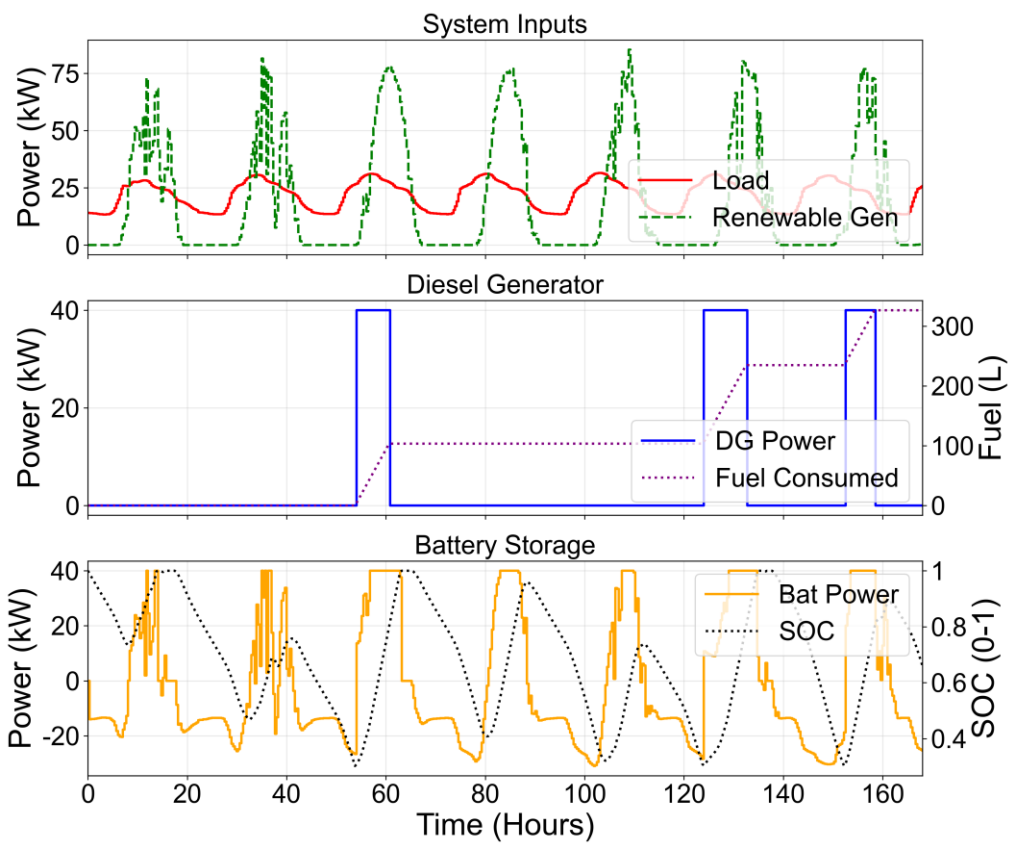


Figure: DG+BESS+PV (Low Emissions)

Larger battery (400 kWh), fewer cycles, better long-term battery health

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Seven Selected Pareto-Optimal Configurations

Configuration	PV (kW)	BESS (kWh)	DG (kW)	Capital Cost	Emissions (kg CO_2)
DG	0	0	40	$26,000	4,262
BESS	0	4,748	0	$2,171,853	0
DG + BESS	0	50	40	$74,086	3,689
DG + PV	10	0	40	$48,080	3,916
BESS + PV	100	450	0	$449,686	0
DG + BESS + PV (Balanced)	50	50	40	$184,486	1,993
DG + BESS + PV (Low Emissions)	80	400	40	$431,526	875

Selection depends on stakeholder priorities:

- "Balanced“: smaller battery, moderate cost & emissions
- "Low Emissions“: larger battery + PV, highest hybrid cost but fewer emissions

Legend

DG	Diesel generator
BESS	Battery energy storage system
PV	Photovoltaic (solar) panels

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Conclusion

- A modular Modelica template decouples physical assets from control logic
- In a 168-hr outage case study, it mapped the cost–emissions Pareto front of 222 designs with the correct controller selected automatically and no manual rewiring.
- As outages grow longer, communities need microgrids verified to survive them before they're built, where we can utilize our Template to evaluate them.

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Juan Diego Flores Garcia
Email: jdf5775@psu.edu

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