Personal Background

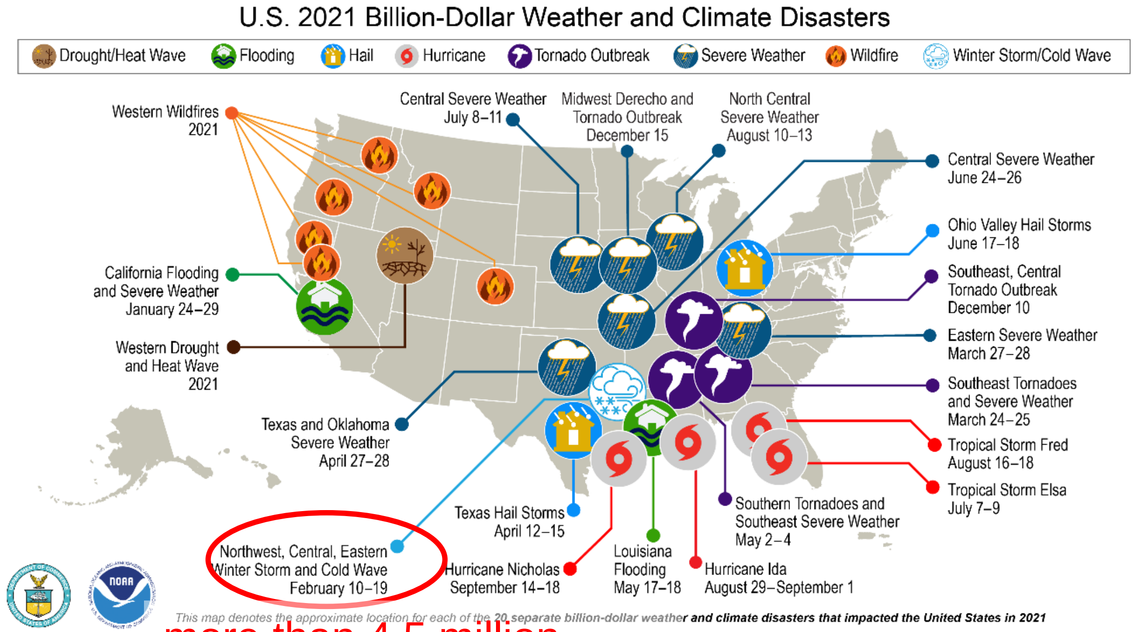
- **PhD, North Carolina State University (NCSU), FREEDM System Center**
  - Electrical engineering, 2019.08 - 2023.12
  - *Advisor*: **Dr. Ning Lu (IEEE Fellow)**
  - *Dissertation*: Energy Management System of Renewable-powered Microgrids for Resilience Service in Distribution System
  - **Internship, Pacific Northwest National Laboratory (PNNL)**
    - Optimization and Control Group, 2021.07 – 2021.10
    - *Mentor*: **Dr. Di Wu**
    - *Project*: Avista’s Shared Energy Economy Model Pilot: A Techno-economic Assessment
- **Electrical Engineer, China Southern Power Grid Co., Ltd.**
  - Operation and maintenance for 110-500kV power systems
- **Master, South China University of Technology (SCUT)**
  - Power System and Its Automation, 2013.09 - 2016.06
  - *Thesis*: Capacity Configuration Optimization for Islanded Microgrid Considering Demand Response
- **Bachelor, South China University of Technology (SCUT)**
  - Electrical Engineering, 2009.09 - 2013.06

Outlines

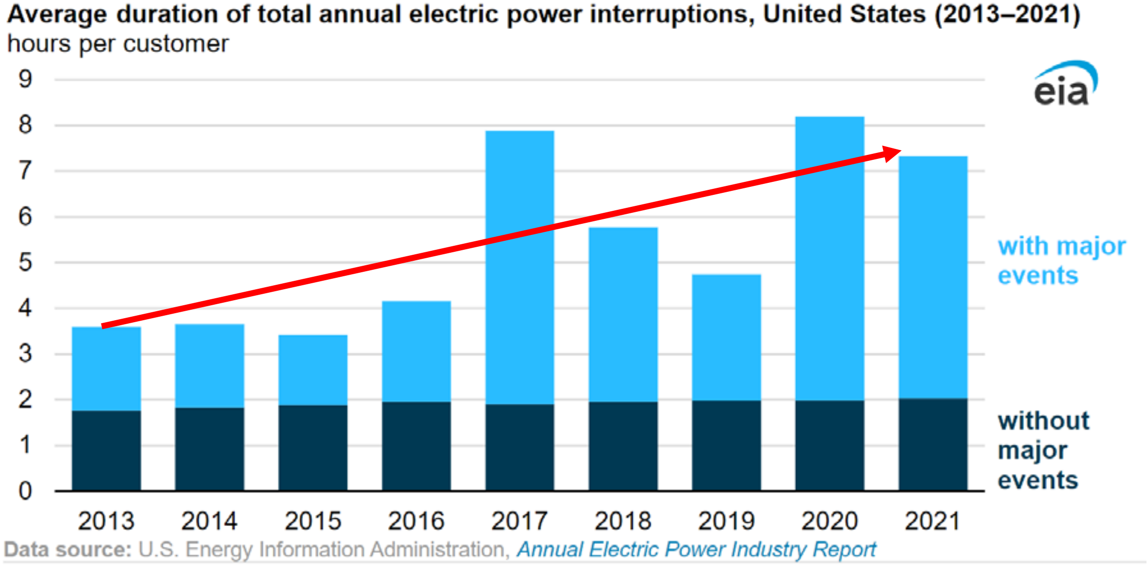
- **Energy Management System of Renewable-powered Microgrids for Resilience Service in Distribution System (Proj-1)**
  - Research Background and the Project
  - Energy Management System(EMS) Design
    - Overview
    - Flexible topology control
    - Adaptive cold load pickup model
- Other Projects
  - Energy Storage Application Analytics (Proj-2)
  - Avista's Shared Energy Economy Model Pilot (Proj-3)
  - Coordinated Real-time Sub-Transmission Volt-Var Control Tool (Proj-4)
- Ongoing Work and Future Work

Background

- **Surging Extreme Weather Events[1]**
  - Large scale, long-duration, high loss disasters
  - Doubled weather event related power outage in the last 10 years
  - Resilience service needs



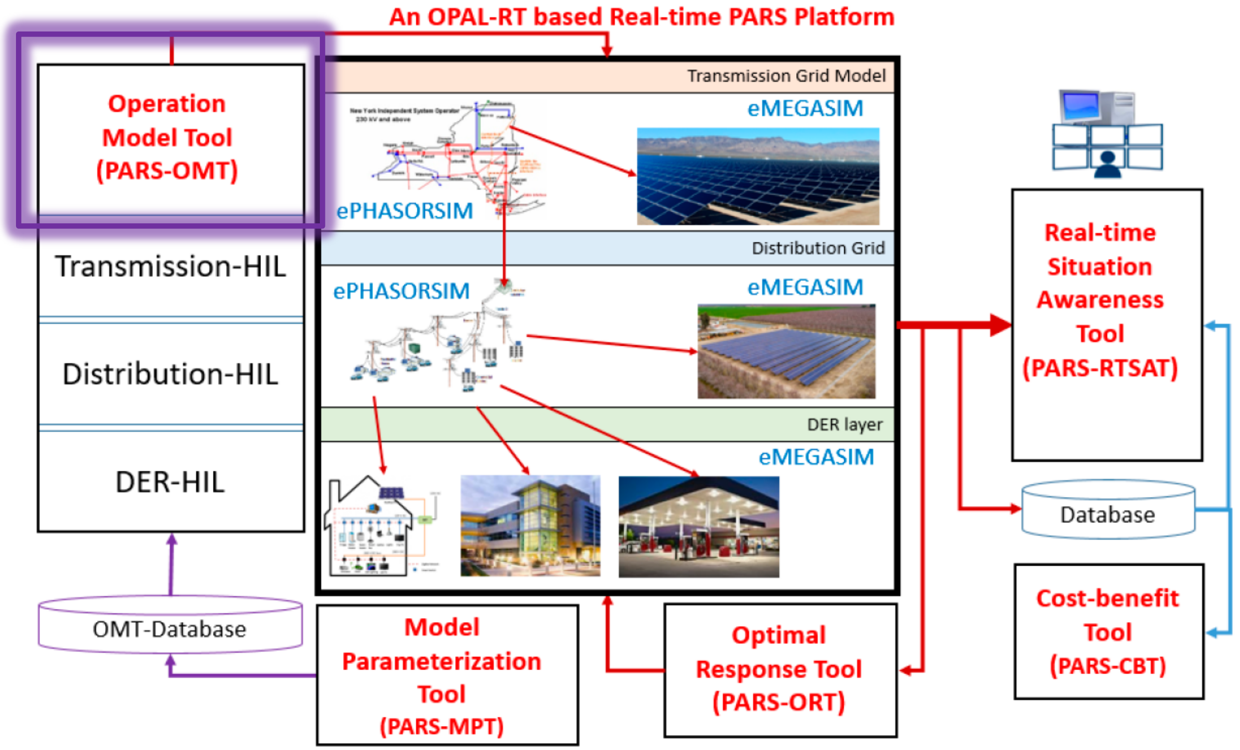
more than 4.5 million
homes lost power

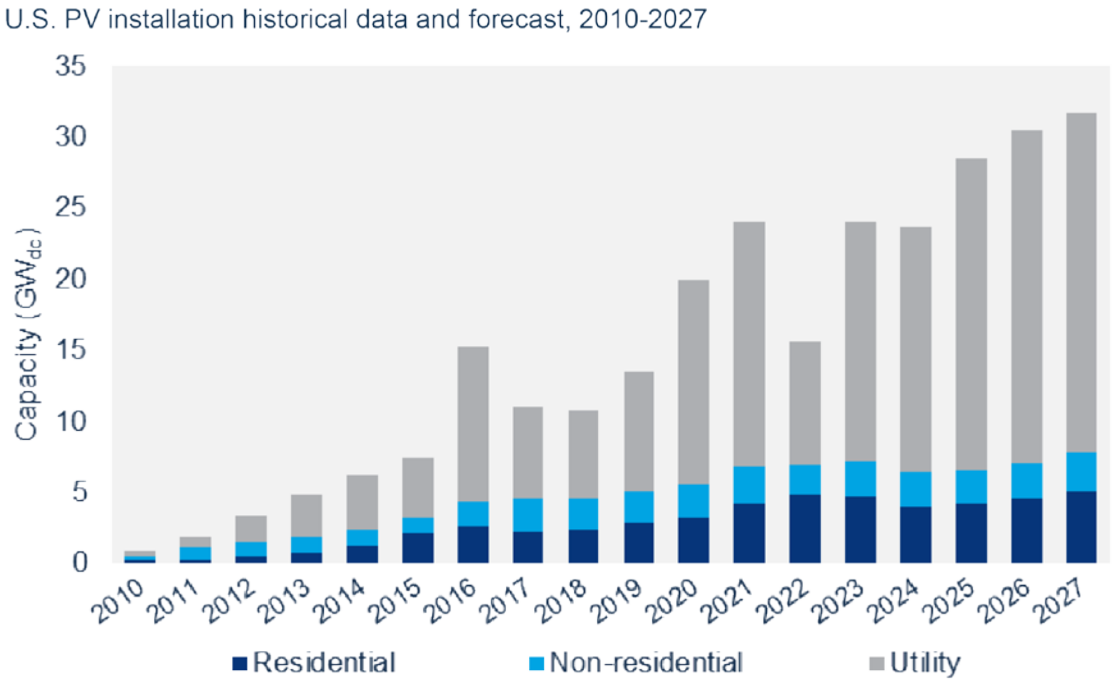


[1] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022)", accessed on Nov. 14, 2022. [Online]. Available: https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73

Project Overview

- **Photovoltaic Analysis and Response Support Platform for Solar Situational Awareness and Resiliency Services (ASSIST)[1-2]**
  - Department of Energy, $3.1 M, 2019.12 - 2023.12
  - Mainly focuses on resiliency service in the distribution system
    - Cases: 1) **Utility MW-level PV plant**; 2) Commercial community-level; 3) residential/rooftop-level





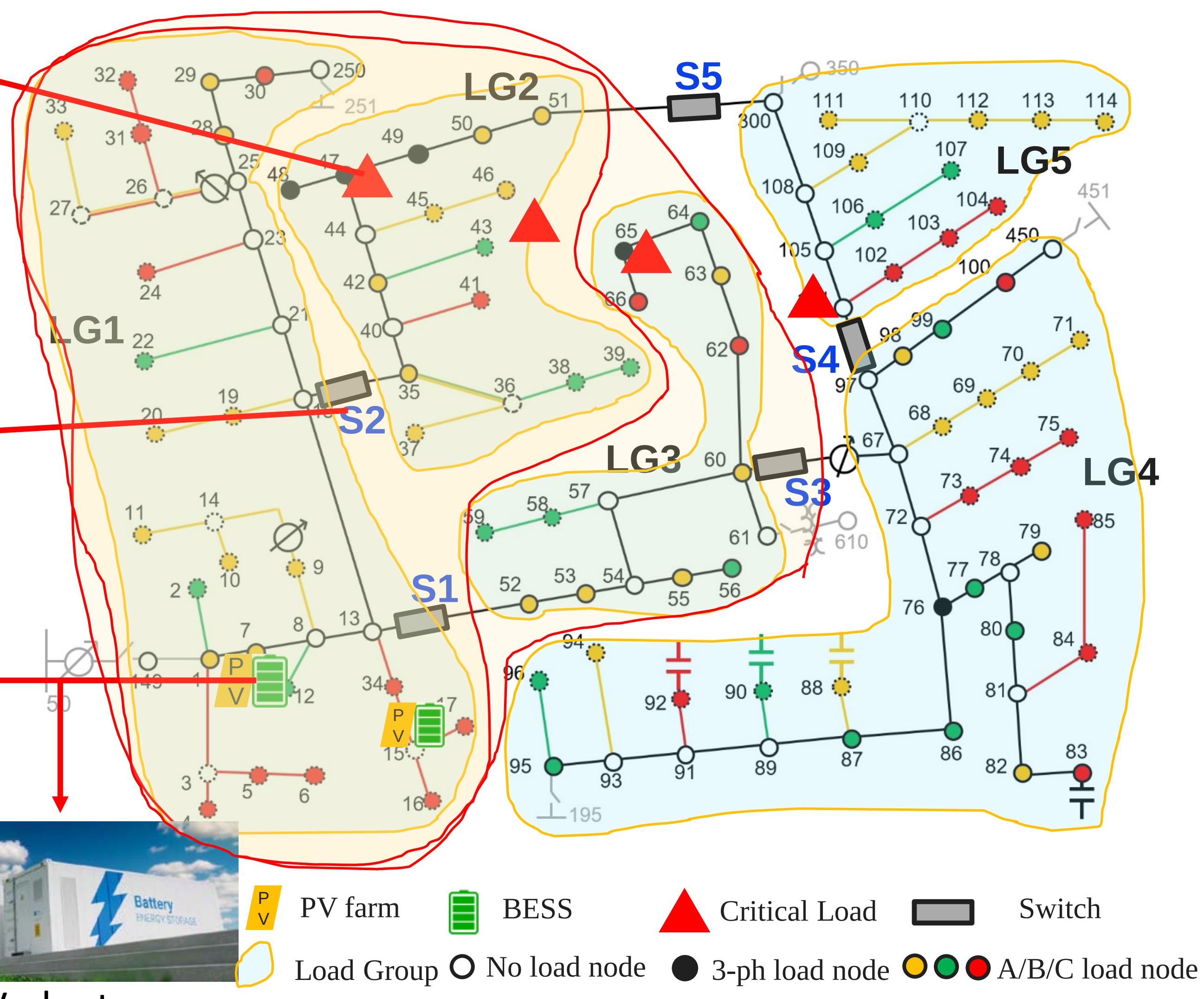
[1] https://sites.google.com/a/ncsu.edu/ninglu/pars-platform
[2] final report https://www.osti.gov/biblio/2349508

Microgrid Energy Management System(EMS) Design

Critical load

Smart switch

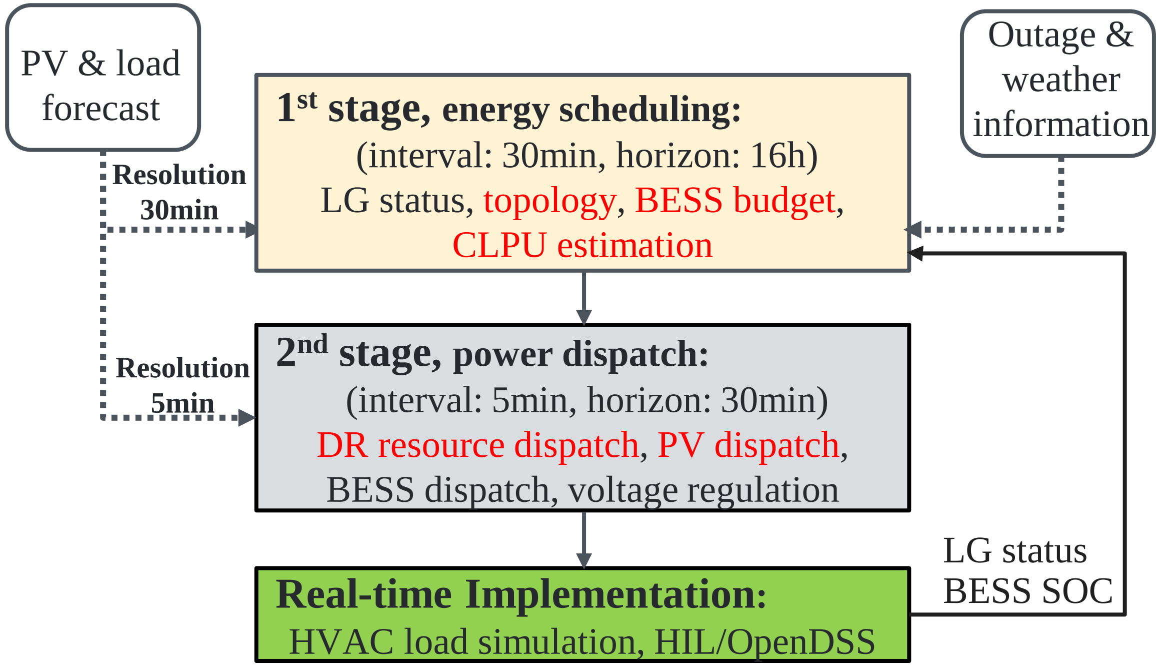
Hybrid PV plant



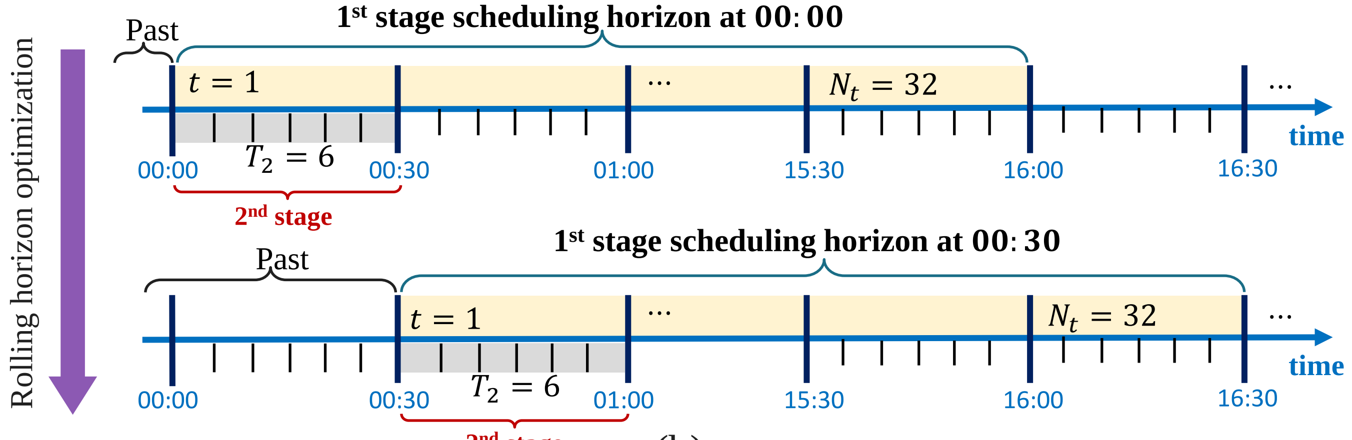
EMS design

- Resilience service via temporary microgrid
  - Amount of **served loads**
- Main Design Considerations
  - Long duration: up to days
  - Radial topology control
  - **Dynamic microgrid boundary**
  - **Customer comfort**
  - **Cold Load Pickup**
  - **Phase Load imbalance**

Two-stage Rolling Scheduling



(a)



(b)

- **1st stage: energy scheduling**

$$\max. \sum_{t=1}^{N_t} \sum_{m=1}^{N^{G}} \sum_{p\in\{a,b,c\}} U_{m,t}^{G} w_t^{\text{pref}} w_{m,p}^{\text{crit}} P_{m,p,t}^{\text{load}} \Delta t - c_1^{\text{PV}} f_1^{\text{PVcurt}}$$

Amount of weighted served load **PV curtailment**

$$- f_1^{\text{CLPU}}$$

CLPU penalty

- **2nd stage: power dispatch**

$$\min. \sum_{t'=1}^{T_2} \sum_{i=1}^{N^{\text{Node}}} \sum_{p=1}^{3} U_{i,p,t'}^{\text{DR}} P_{i,p,t'} \Delta t' + c_2^{\text{low}} \Delta E^{-} + c_2^{\text{PV}} f_2^{\text{PVcurt}}$$

Amount of load shedding **BESS deviation (< the setpoint)**

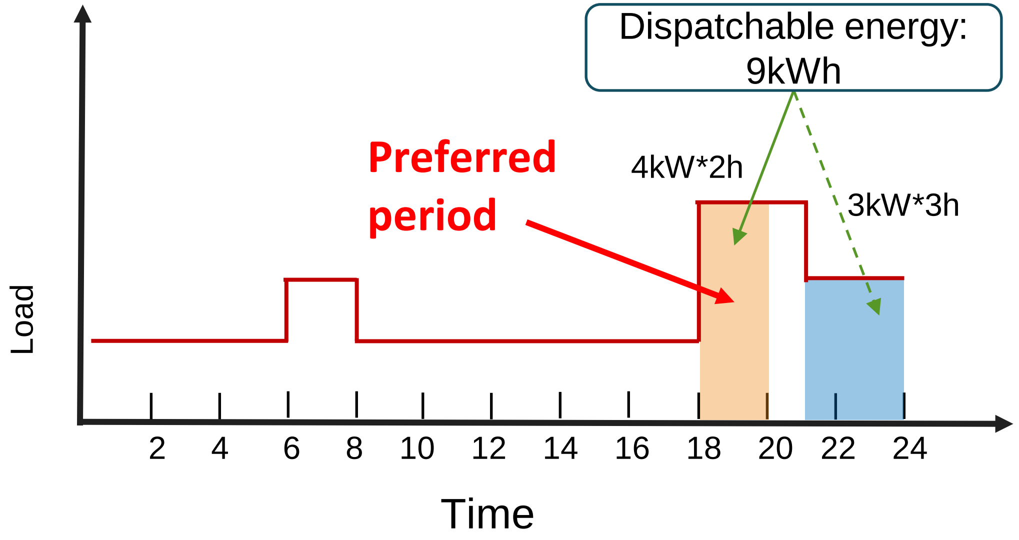
Valuable Service

- **Customer comfort consideration**
  - Critical load
  - Minimum service duration (MSD)
  - Preferred service period

$$\max.\sum_{t=1}^{N_t}\sum_{m=1}^{N^{\mathrm{G}}}\sum_{p\in\{a,b,c\}} U_{m,t}^{\mathrm{G}}\boldsymbol{w}_t^{\mathbf{pref}}\boldsymbol{w}_{\boldsymbol{m},\boldsymbol{p}}^{\mathbf{crit}}P_{m,p,t}^{\mathrm{load}}\Delta t-c_1^{\mathrm{PV}}f_1^{\mathrm{PVcurt}}-\boldsymbol{f}_1^{\mathrm{CLPU}}$$

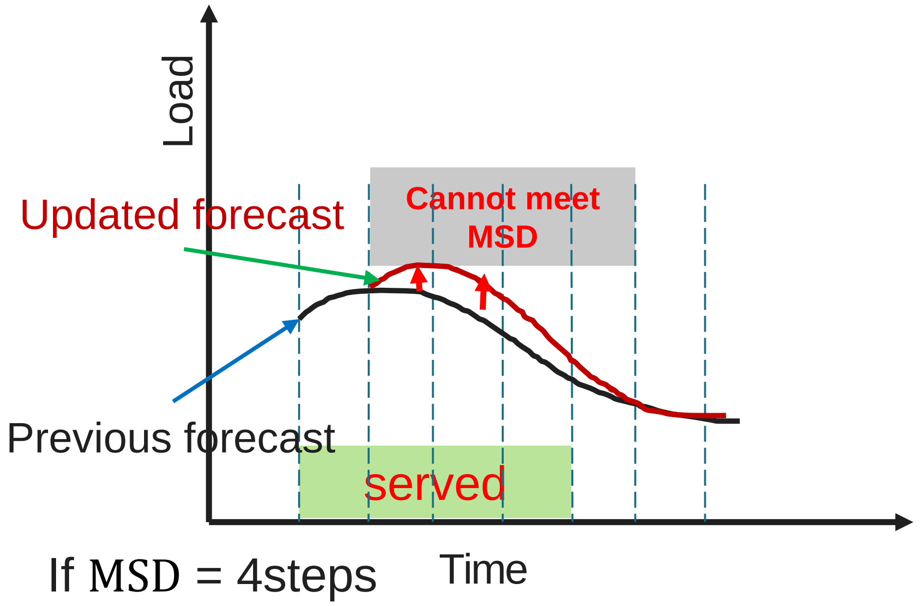
Frequent interruptions

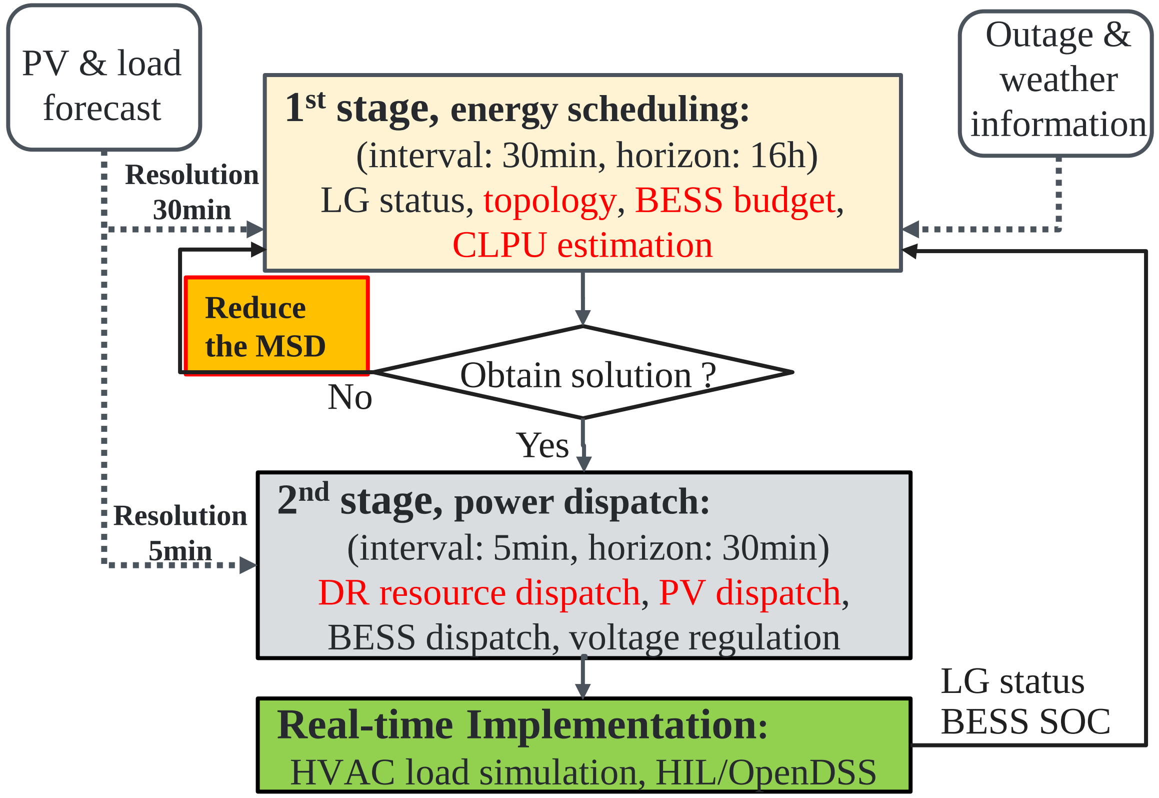
Minimum service duration	Time /hour									
	1	2	3	4	5	6	7	8	9	10
-	✓		✓		✓		✓		✓	
2 hour	✓	✓		✓	✓			✓	✓	✓
3 hours	✓	✓	✓		✓	✓	✓		✓	✓
4 hours	✓	✓	✓	✓					✓	✓



Forecast Error

- Updated forecast
- Demand response (2nd stage)
- System reserve
- Minimum service duration adjustment
  - The current forecasted load is higher than the previous load forecast
  - EMS cannot meet the MSD constraints





Outlines

- **Energy Management System of Renewable-powered Microgrids for Resilience Service in Distribution System (Proj-1)**
  - Research Background and the Project
  - Energy Management System(EMS) Design
    - Overview
    - **Flexible topology control**
      - **A new set of constraints**
      - **Simulation results**
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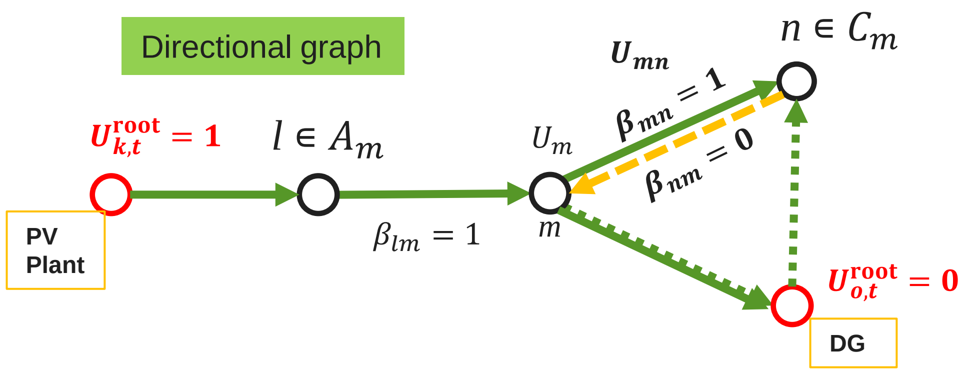
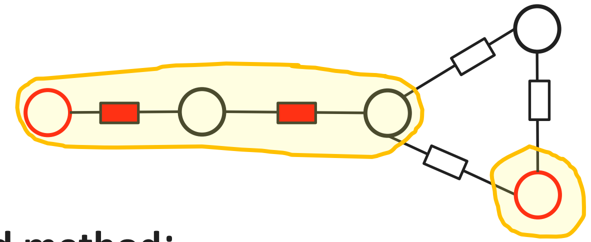
Flexible Topology



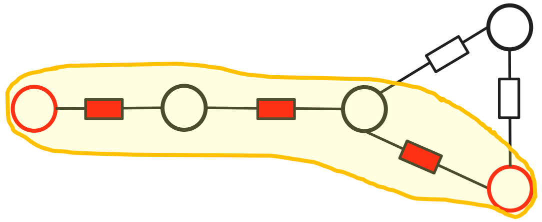
Spanning-tree Method [1]:

- Allow only 1 grid-forming source to supply a microgrid



Developed method:

- Allow multiple grid-forming sources to co-supply a microgrid

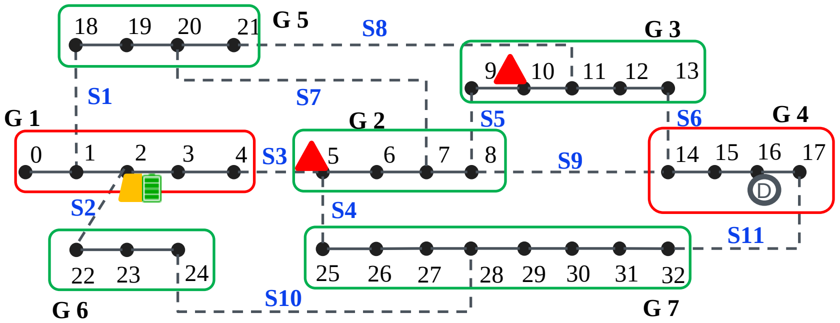


- **Topology control**
  - Typical method: Spanning tree based
  - Proposed method
    - Optimizing the number of microgrids
    - Maximizing the total benefit of different DERs
      - Diesel generator runs at the max power
    - root candidate variable $U^{root}_{m,t}$

$$U_{m,t}(t) - U^{root}_{m,t} \le \sum_{n \in A_m \cup C_m} \beta_{nm,t}(t) \le \frac{U_{m,t} + U^{root}_{m,t} + 1}{2}$$

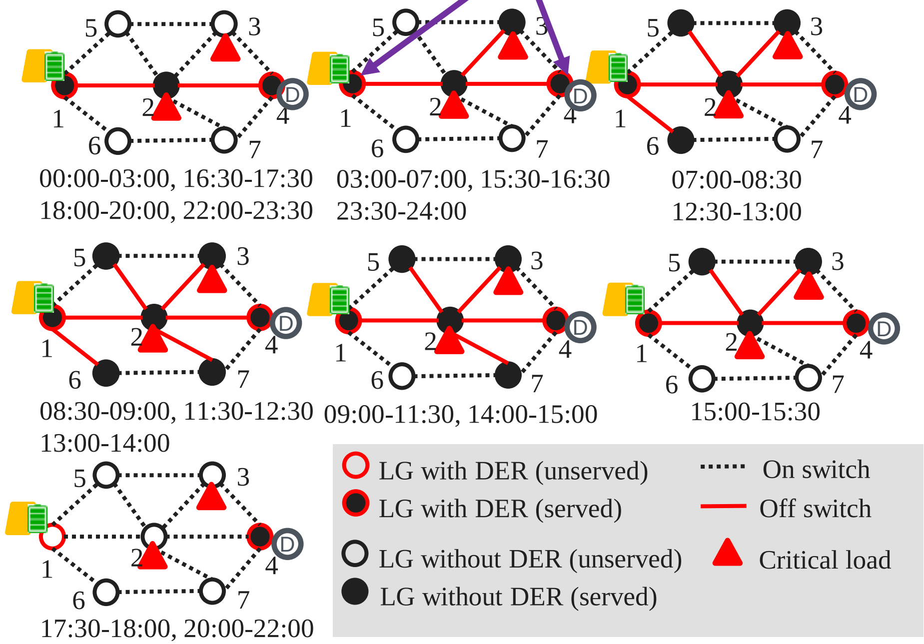
[1] Y. Wang, Y. Xu, J. Li, J. He, and X. Wang. "On the Radiality Constraints for Distribution System Restoration and Reconfiguration Problems," *IEEE Transactions on Power Systems*, vol. 35, no. 4, pp. 3294 - 3296, Apr. 2020

Flexible Topology: Case study

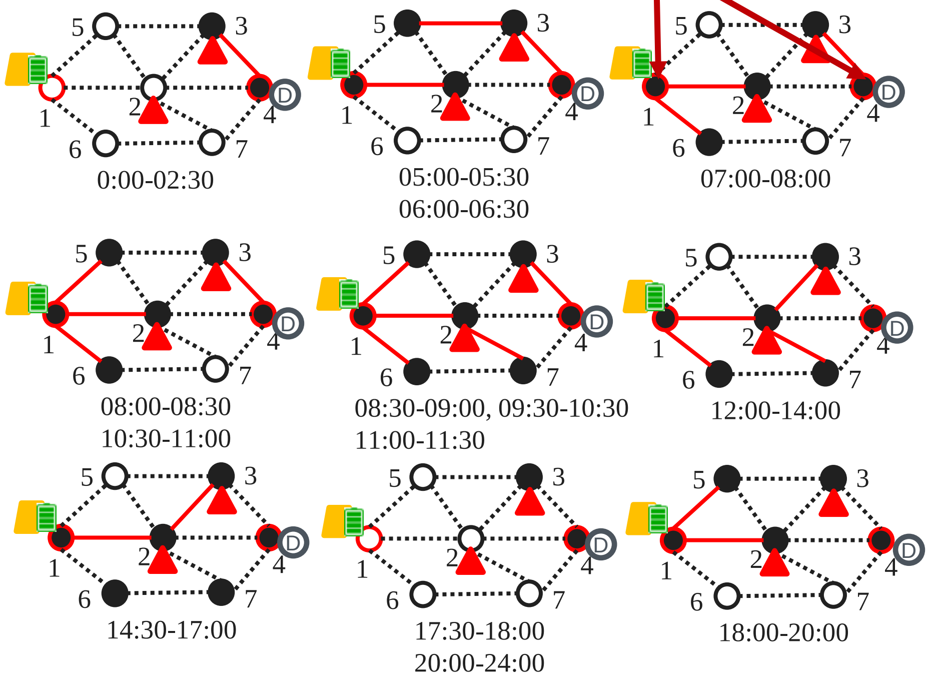


- **Accounting for feeder topology constraints**
  - Flexible topology constraints that allow multiple grid-forming sources to cooperate in one or more microgrids
    - IEEE 33-bus system, day-ahead
    - More served load, less switching operations

2 sources power 1 microgrid



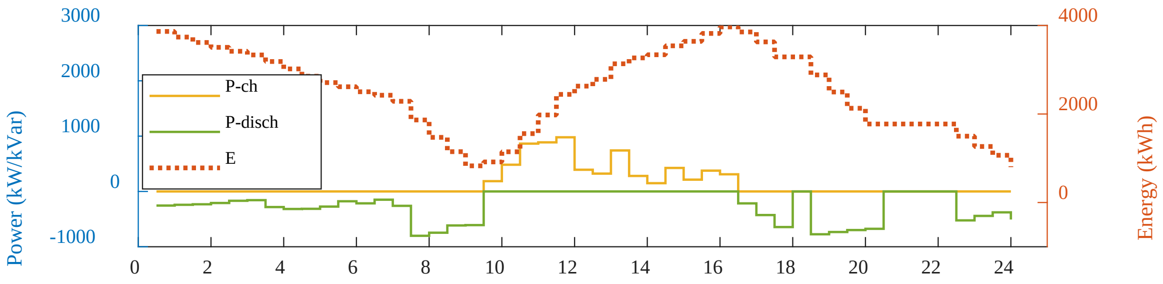
2 separate microgrids



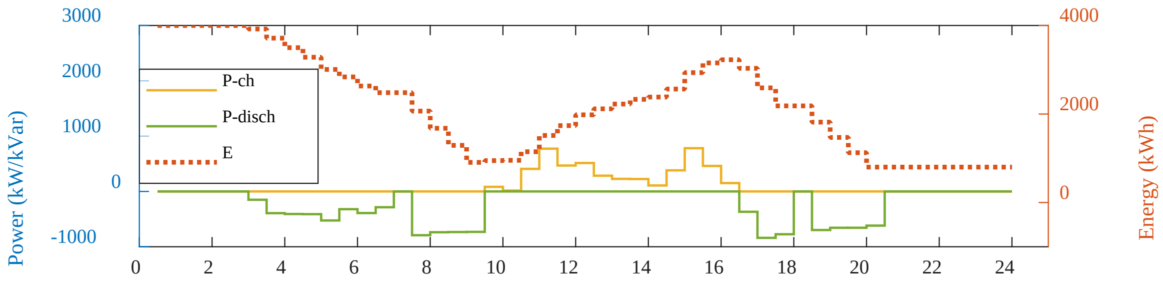
Flexible Topology: Case study

- **Coordinating Multiple DERs in a Microgrid**
  - IEEE 33-bus system, day-ahead
  - More served load, less switching operations

Multi-source cooperation	Total supply (kWh)			Critical load served time (h)		Num of Switching Operation
	Total	From DG	From PV plant	Node 5	Node 10	
✓	22,818	8,054	14,765	21.5	14	23
X	20,492	5,646	14,846	14.5	16.5	36



DG maintains Max. power



DG outputs at low level

Proposed: DG mainly within the microgrid hybrid PV formed

Existing: DG and hybrid PV plant run separate microgrids

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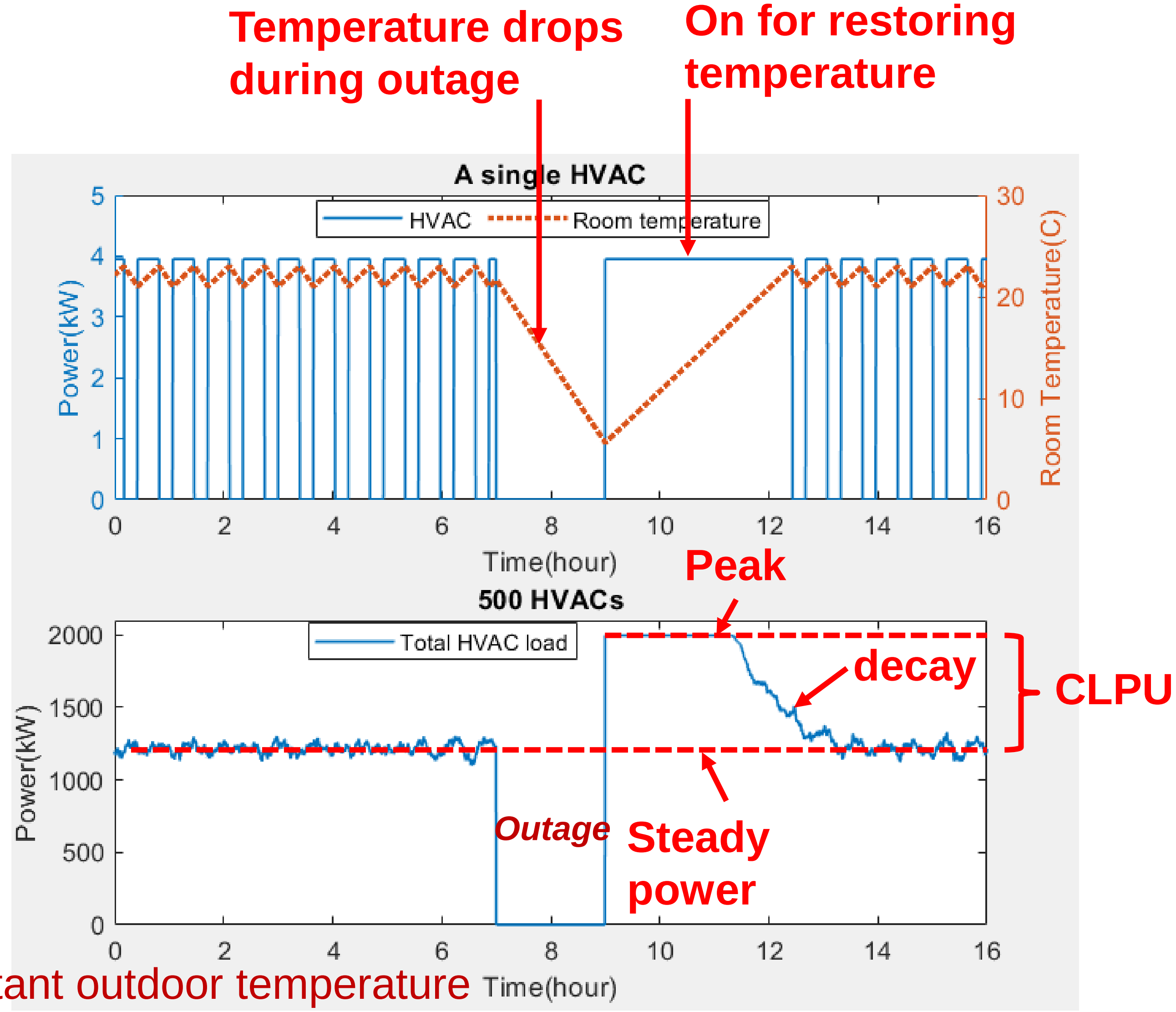
What is a Cold Load Pickup event?

- **CLPU phenomenon**
  - After interruptions, the Heating, Ventilation, and Air Conditioning (HVAC) all are turned on simultaneously
  - Significantly more consumption since HVACs occupies 50% load
  - Steady power, CLPU peak, decay



Assuming constant outdoor temperature

Why modeling CLPU effects?

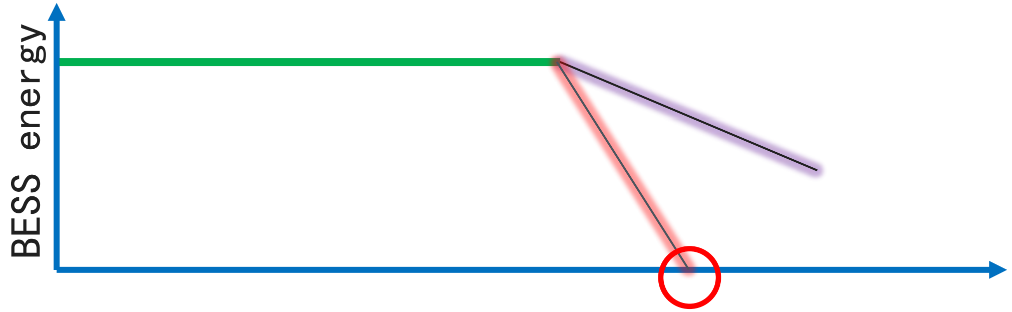
- **If CLPU is not considered**
  - There may **not be enough power reserve** to meet the load.
  - There will be an **energy deficit** in the hour where cold load pickup is required
  - Microgrid is forced to **shut down**

Additional consumption

Microgrid expected load level

power reserve level

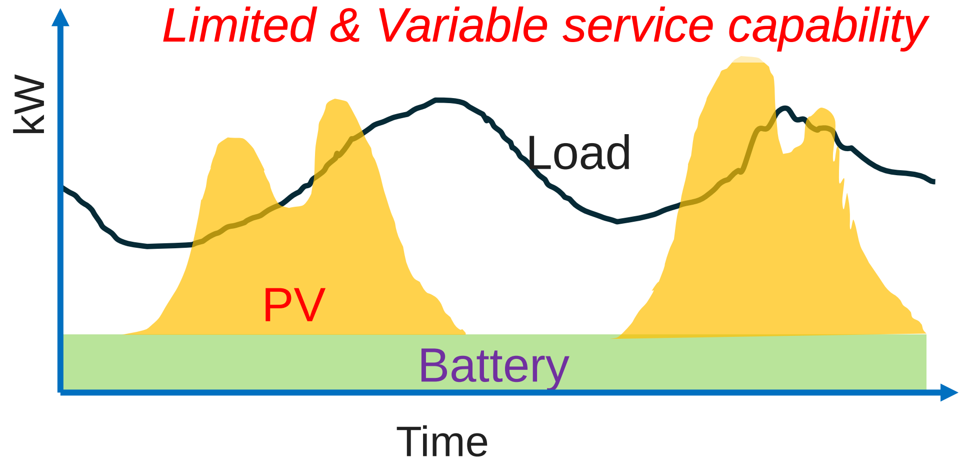
Microgrid expected load level

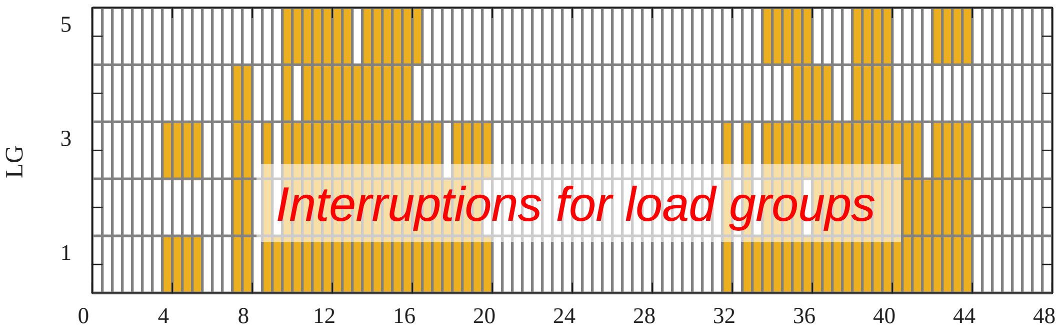


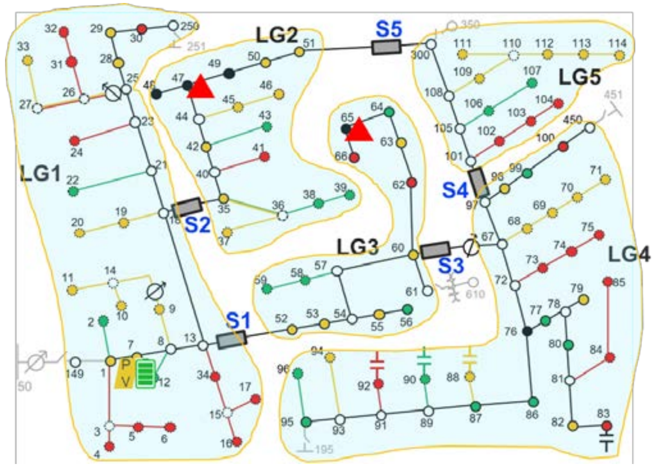
Drains the battery energy

Why modeling CLPU effects?

- **Multiple-interruptions:** Service interruptions are inevitable for microgrid powered by intermittent generation resources
  - Main power sources are intermittent: PV and wind
  - Limited power storage capacity
  - Time-varying load
  - Load shedding is needed for maintaining power and energy balance
  - Thus, multiple CLPU events are expected





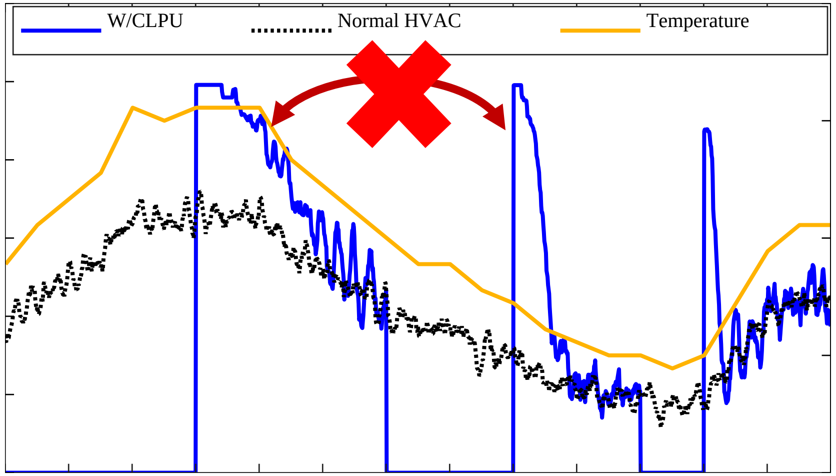


State-of-the-art

Ref.	Microgrid Operation Setup			Microgrid Unit Commitment Algorithm Setup						Verified dynamic responses §
							CLPU			
	3-phase unbalanced system	Outage duration	Main energy source*	Optimization stages	Rolling horizon	Forecast error	Y/N	CLPU events	CLPU model	
[11]		< 1 hour	DG	RT	✓		✓	one	fixed	✓
[12]		up to days	DG	DA		✓	✓	one	fixed	
[13]	✓	up to days	DG + BESS	DA		✓	✓	one	fixed	
[14]	✓	several hours	DG	RT		✓	✓	one	candidate	
[15]		several hours	DG	RT		✓	✓	one	candidate	

CLPU is sensitive to temperatures and interruptions

- **Fixed CLPU**
  - Obtained by CLPU under a specified temperature and interruption scenario
  - Same curve parameter used for all scenarios
  - **Very low accuracy**
    - CLPU is sensitive to temperatures and interruptions



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[12]		up to days	DG	DA		✓	✓	one	fixed	
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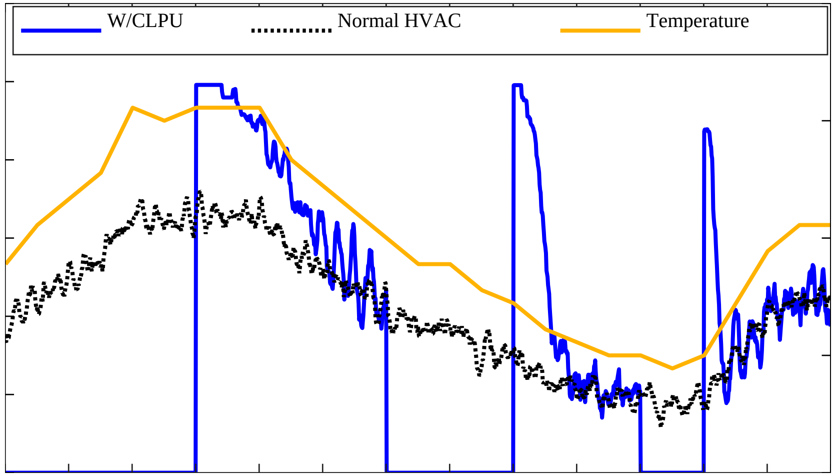
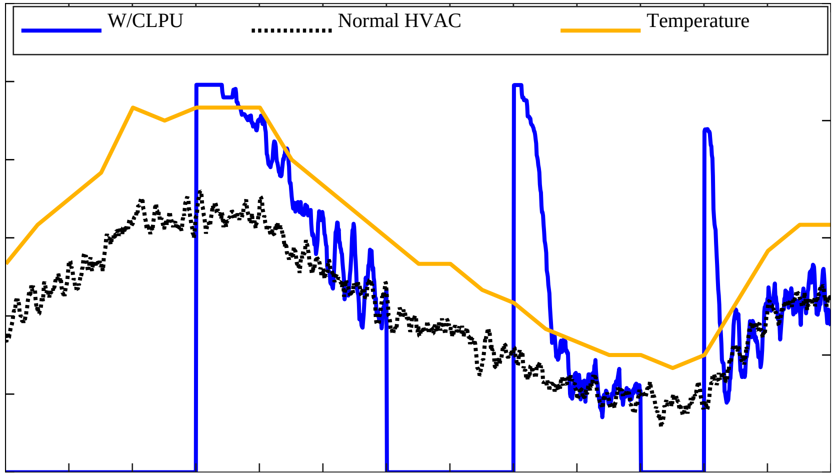
[14]	✓	several hours	DG	RT		✓	✓	one	candidate	
[15]		several hours	DG	RT		✓	✓	one	candidate	

- **Candidate**
  - Generate a set of CLPU profiles considering all CLPU occurrence scenarios then EMS select one
  - Impractical when outage is long
    - The number, timing(temperature), duration of interruptions
    - Too many candidates



CLPU Challenge in EMS

- **Challenges**
  - CLPU model that adapts to time-varying temperature and variable interruption
    - ~~Fixed CLPU~~
  - No exhaustive CLPU simulation for each implementation
    - ~~Candidate set~~
  - In EMS, CLPU is decision dependent, CLPU should be estimated within EMS



The number, timing, duration of interruptions are decided by the EMS !

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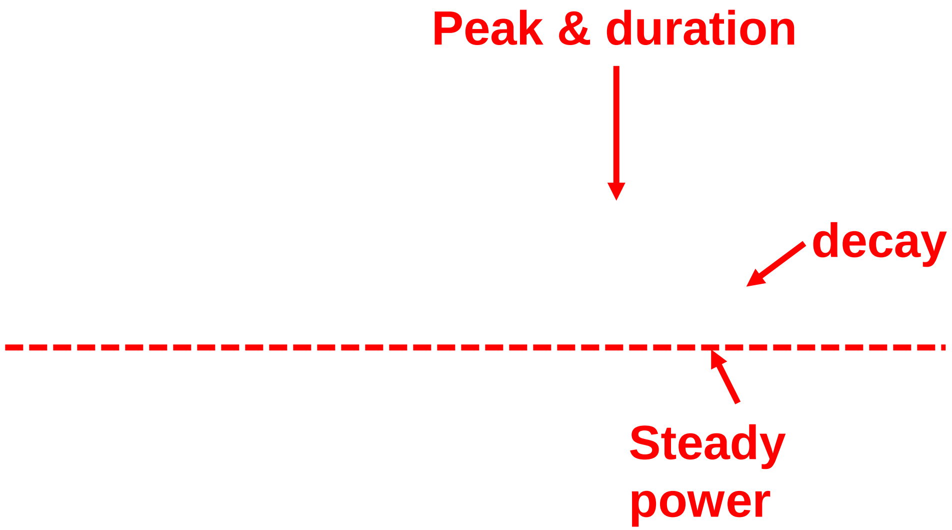
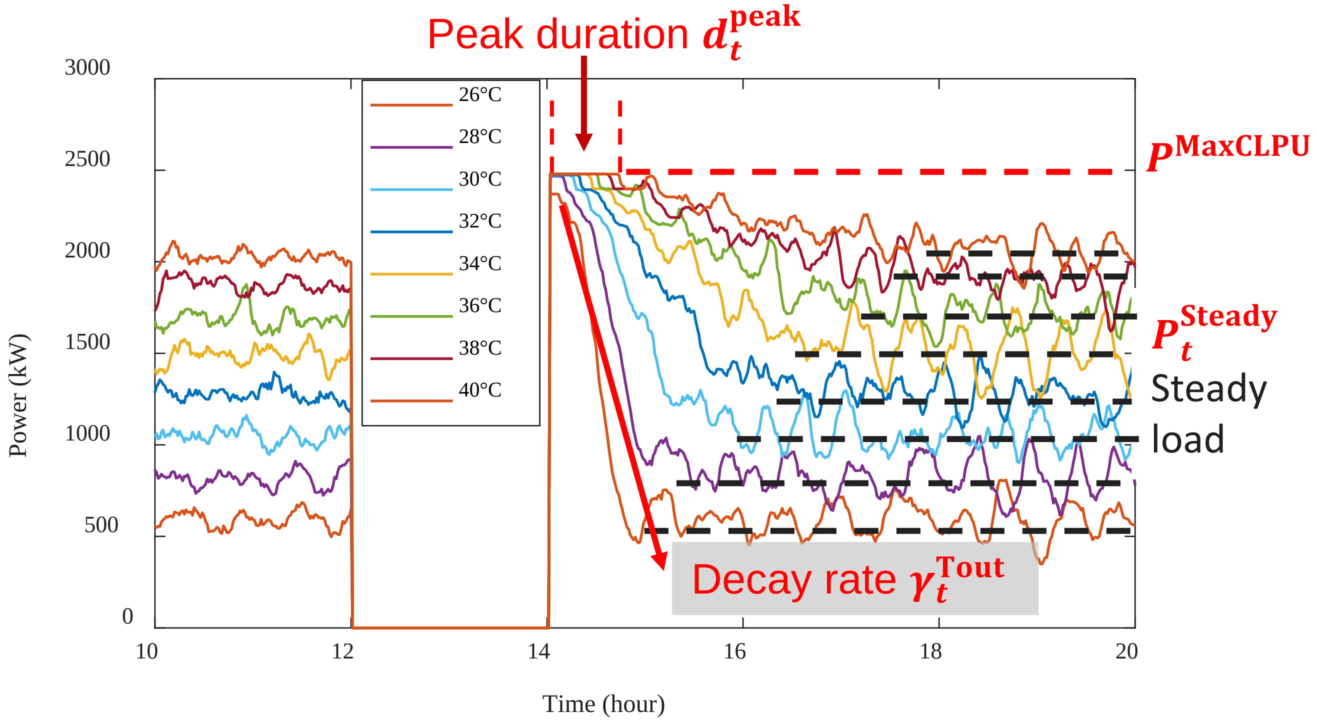
Adaptive CLPU

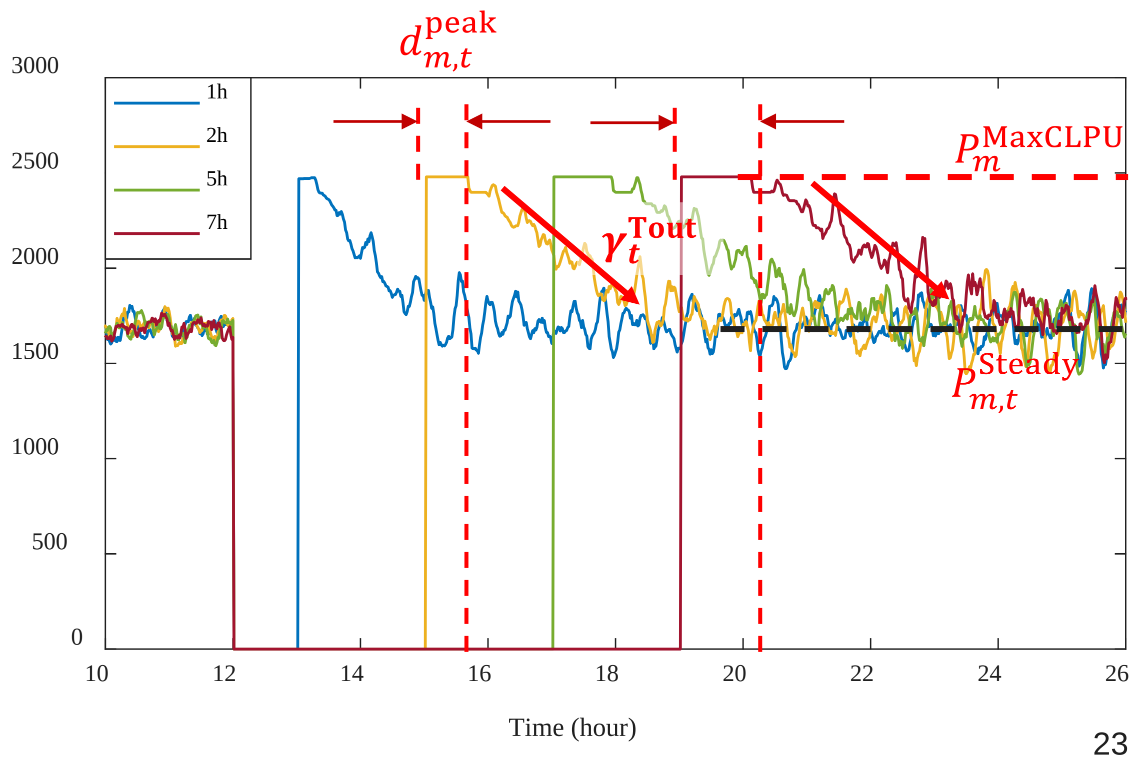
- **Goal: Adaptive CLPU**
  - Adapt to temperature and interruption
  - No need CLPU simulation for each implementation
    - Use offline obtained parameters
- **CLPU feature identification**
  - Using 1100 heterogeneous HVACs
  - Simulate CLPU under different scenarios
    - Constant temperature: 22 - 40ºC
    - Interruption duration: 1-12 hour
  - Identify characteristic parameters



CLPU Feature Identification

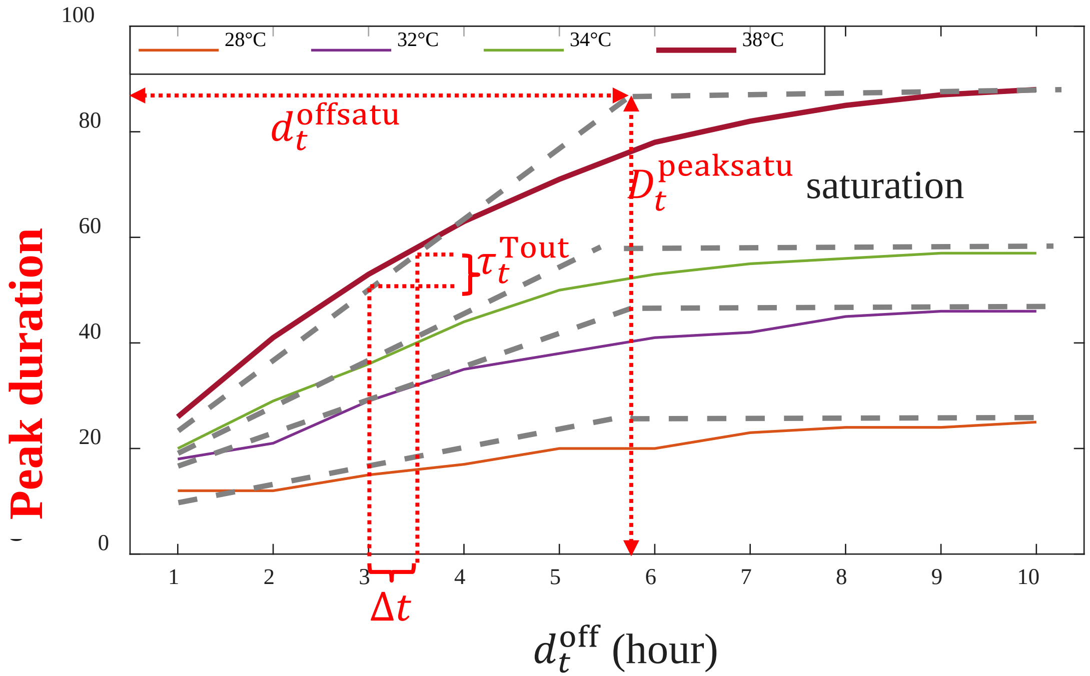
- **Ambient temperature**
  - Very slightly impact on **CLPU peak** P^{MaxCLPU}
  - Decides **steady load** P_t^{Steady}
  - Higher temp → longer **peak duration** d_t^{peak}
  - Higher temp → slower **decay rate** γ_t^{Tout}
- **Interruption duration**
  - Very slightly impact on **CLPU peak** P^{MaxCLPU}
  - Very slightly impact on **decay rate** γ_t^{Tout}
  - Longer outage → longer **peak duration** d_t^{peak}



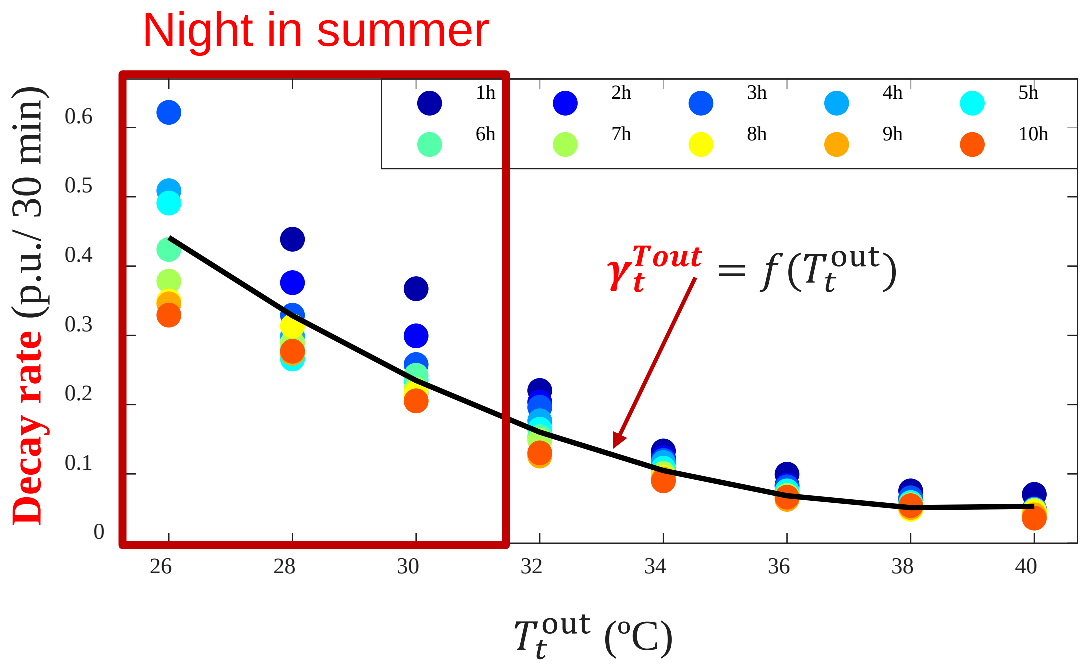


Model CLPU

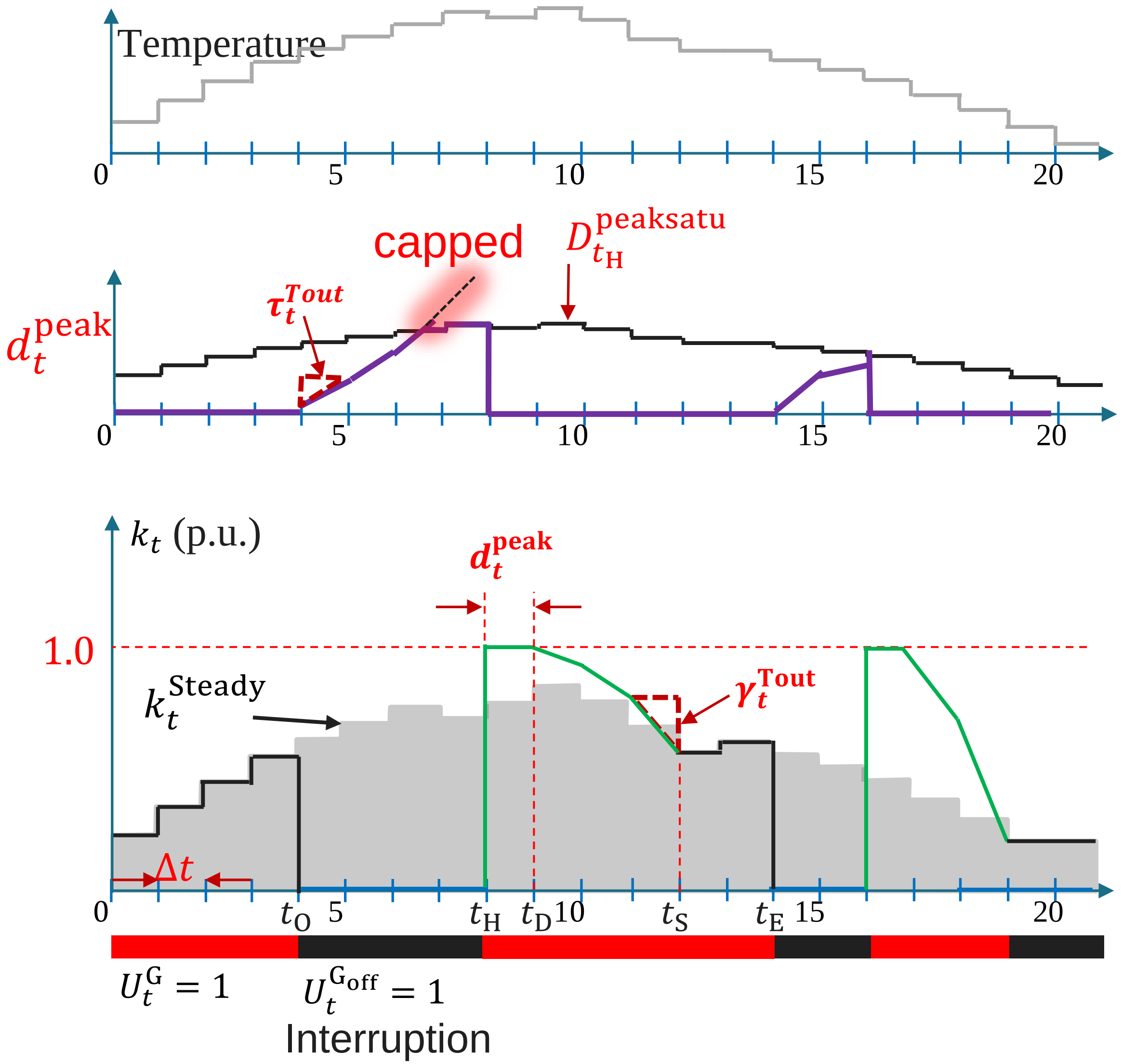
- **Simplification:**
  - Peak duration d_t^{peak}
    - Capture impacts by temperature and interruption using peak duration rate τ_t^{Tout}
    - Saturation D_t^{peaksatu}
    - **2-piece linearized curves of temperatures**



- **Simplification**
  - CLPU decay rate γ_t^{Tout}
    - when > 30ºC, nearly no impact of interruption
    - when < 30ºC, nighttime usually has long (>5h) interruptions due to **no PV**
    - Using **equivalent curve** to capture the impact of temperature



Adaptive CLPU model



- ## Adaptive CLPU model

Count peak duration

$$d^{\mathrm{peak}}_{t_H} = \begin{cases} \sum_{t=t_O}^{t_H} \tau_t^{\mathrm{Tout}}, & \sum_{t=t_O}^{t_H} \tau_t^{\mathrm{Tout}} < D^{\mathrm{peaksatu}}_{m,t_H} \\ D^{\mathrm{peaksatu}}_{m,t}, & \sum_{t=t_O}^{t_H} \tau_t^{\mathrm{Tout}} \geq D^{\mathrm{peaksatu}}_{m,t_H} \end{cases}$$

HVAC load factor

$$k_t = \begin{cases} 0, & t \in (t_O, t_H) \\ 1, & t \in [t_H, t_D] \\ 1 - \sum_{t=t_D}^{t} \gamma_t, & t \in (t_D, t_S) \\ k_t^{\mathrm{Steady}}, & t \in [t_S, t_E] \end{cases}$$

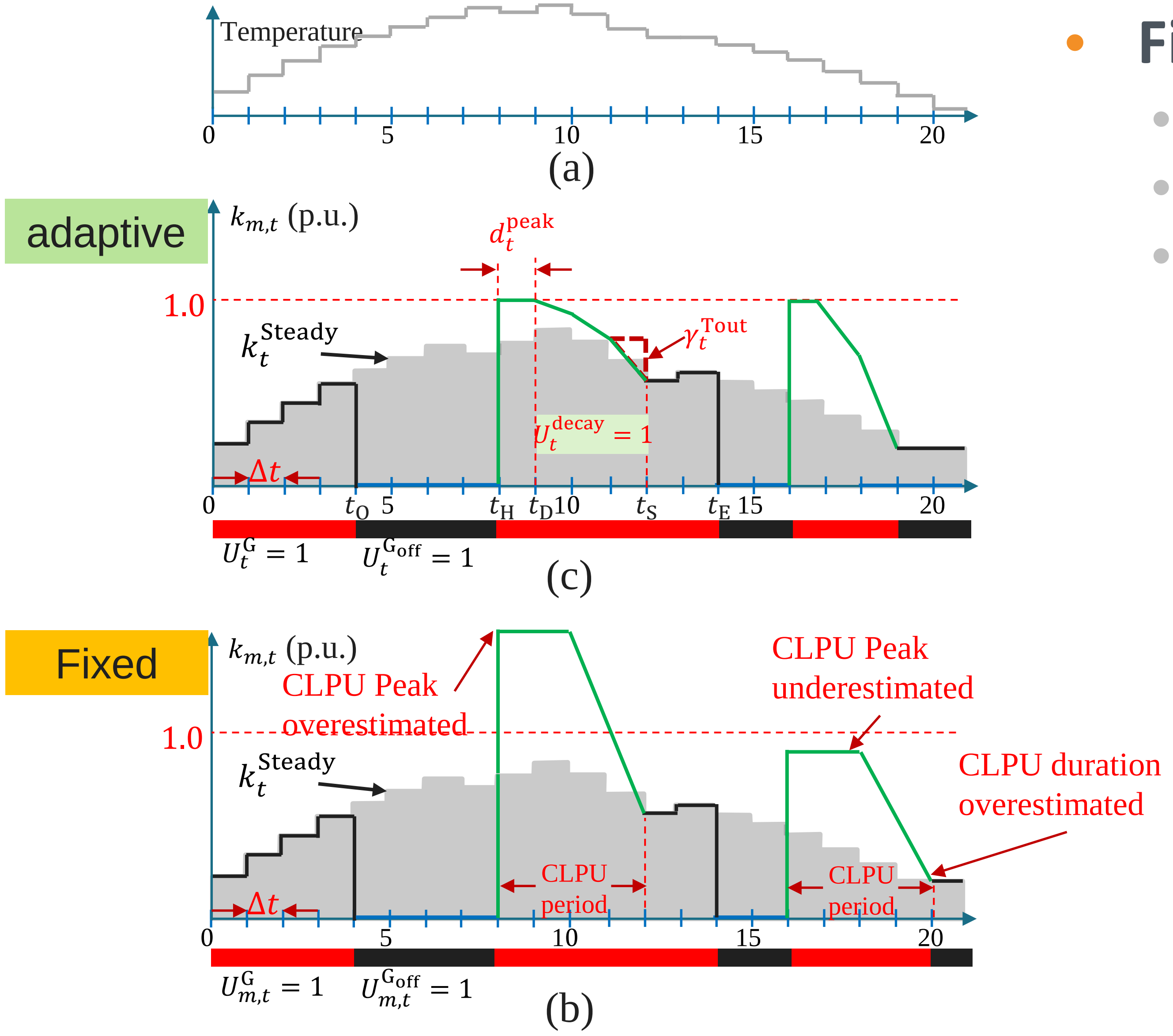
CLPU load factor

$$k_t^{\mathrm{CLPU}} = \begin{cases} 0, & t \in [t_O, t_H) \\ k_t - k_t^{\mathrm{Steady}}, & t \in [t_H, t_E] \end{cases}$$

CLPU load consumption

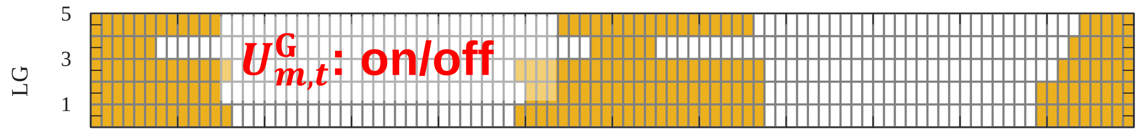
$$\boldsymbol{P}_t^{\mathrm{CLPU}} = k_t^{\mathrm{CLPU}} P^{\mathrm{MaxCLPU}}$$

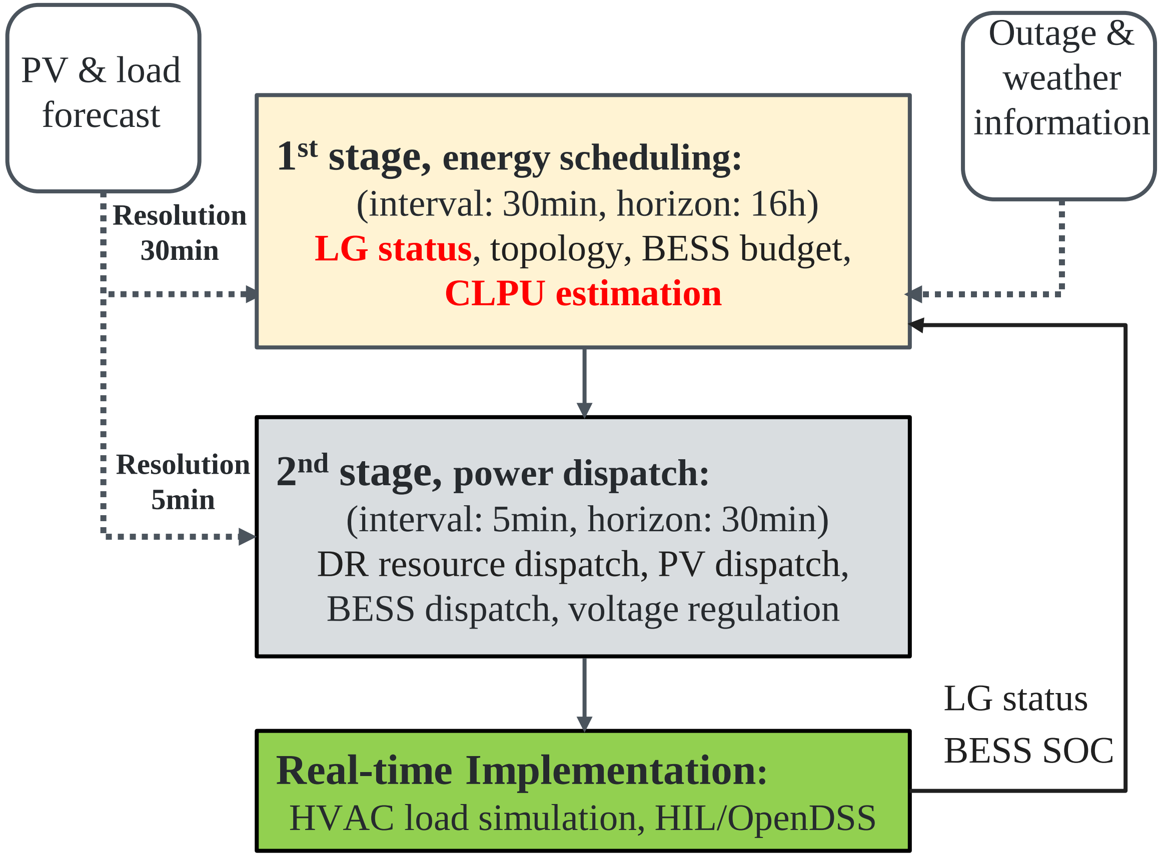
Comparison CLPU models



- **Fixed v.s. Adaptive CLPU model**
  - Peak estimation error
  - Peak duration estimation error
  - Decay estimation error

EMS: Adaptive CLPU Integration





- **1st stage: energy scheduling**
  - CLPU estimation using adaptive CLPU
  - Penalty CLPU to serve more baseload (non-HVAC)

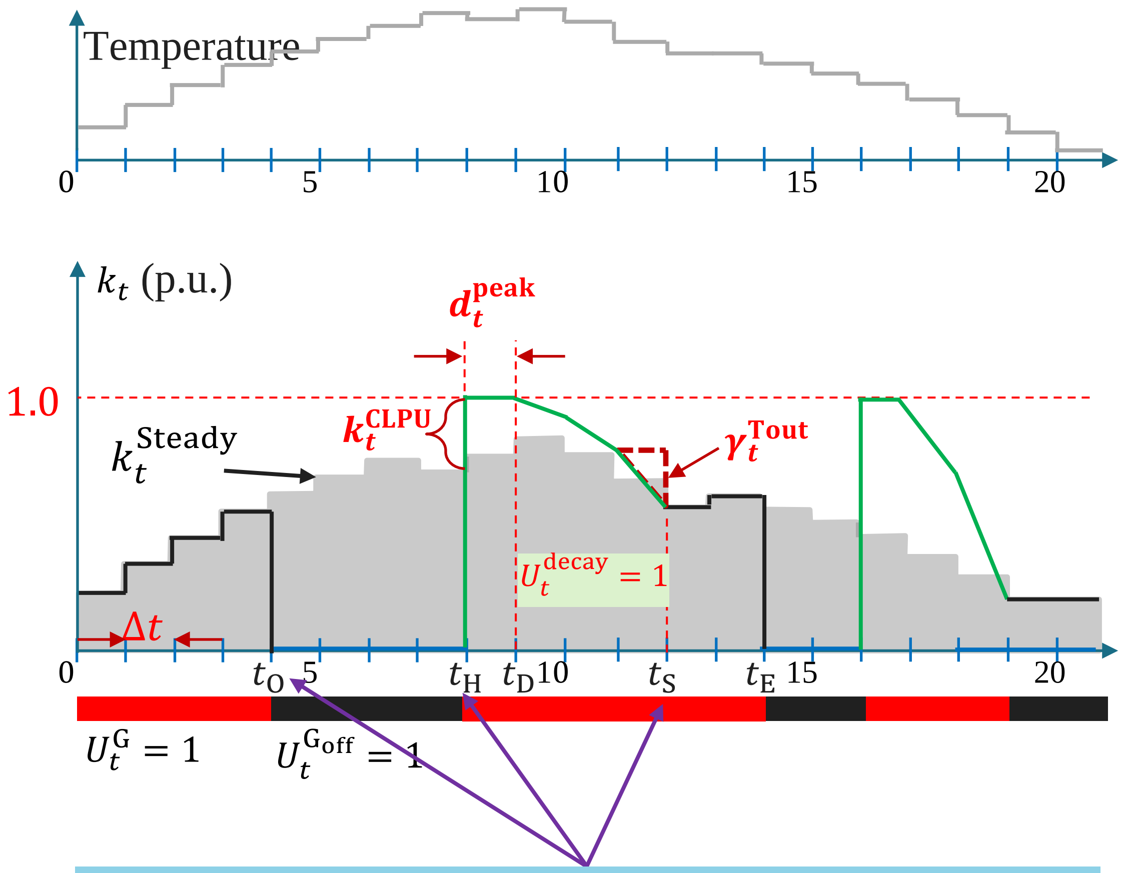
$$\textbf{max.}\ f_1^{\text{load}} - c^{\text{PV}} f_1^{\text{PVcurt}} - \underbrace{\boldsymbol{f_1^{\text{CLPU}}}}_{\text{CLPU penalty}}$$

$$P^{\text{serve}}_{m,p,t} = \boldsymbol{U^{G}_{m,t}} P^{\text{norm}}_{m,p,t} + \boldsymbol{P^{\text{CLPU}}_{m,p,t}}$$

decision-dependent

- **2nd stage: power dispatch**
  - Interpolate the 1st stage CLPU estimation

EMS: Adaptive CLPU Integration

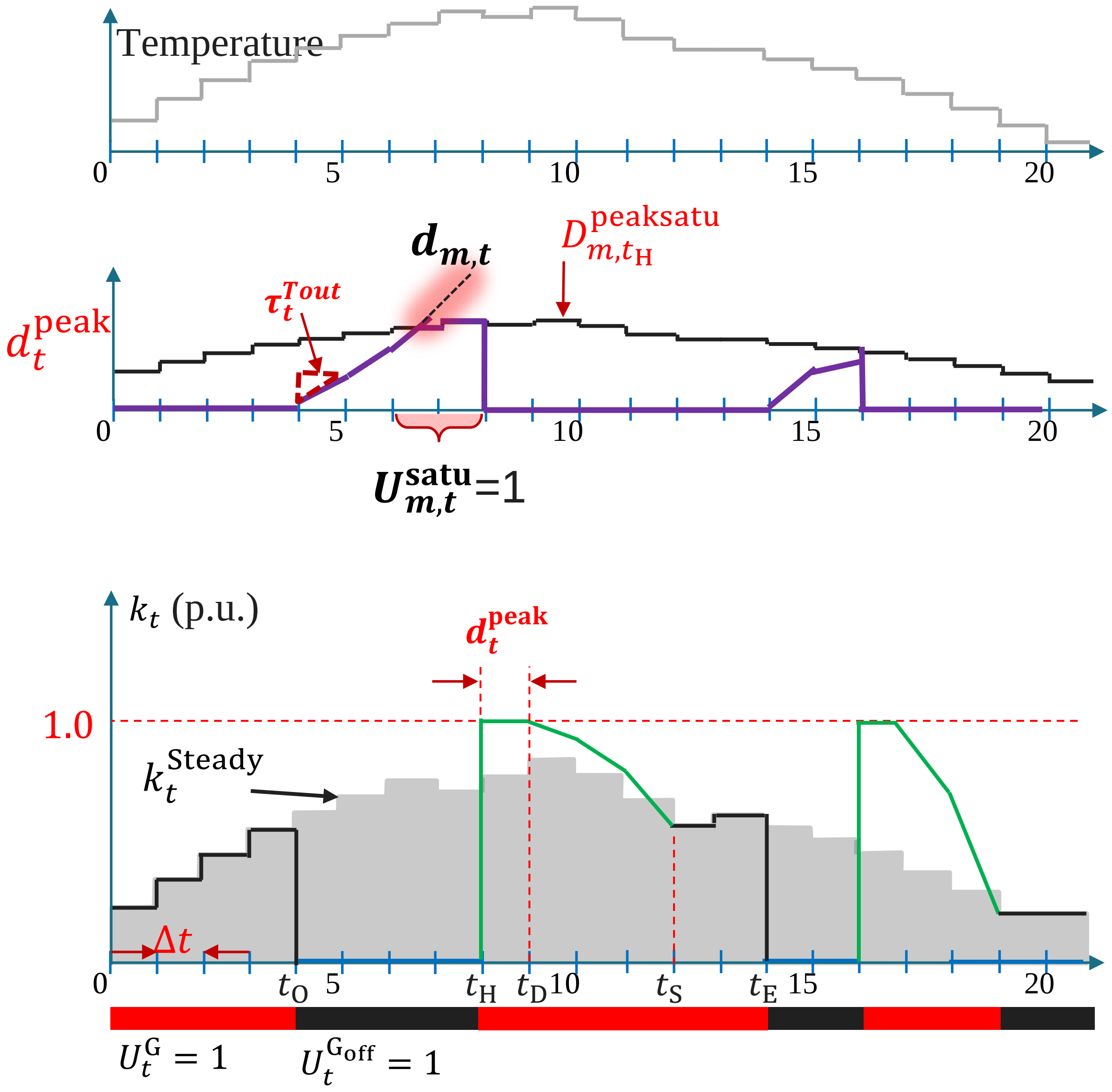


The number, timing, duration of interruptions are optimized by the EMS !

- **Adaptive CLPU enhanced EMS (1st)**
  - Group status/interruption is decision variable
  - EMS cannot use the adaptive CLPU model directly
  - Reformulation for integration in MILP EMS algorithm [1]

[1] Rongxing Hu, Ashwin Shirsat, Valliappan Muthukaruppan, Yiyan Li, Wenyuan Tang, Mesut Baran, Ning Lu, et al., "Adaptive Cold-Load Pickup Considerations in 2-Stage Microgrid Unit Commitment for Enhancing Microgrid Resilience." Applied Energy, 2024

EMS: Adaptive CLPU Integration



Step 1: CLPU Peak duration

$$d^{\text{peak}}_{t_\text{H}} = \begin{cases} \sum_{t=t_\text{O}}^{t_\text{H}} \tau^{\text{Tout}}_t, & \sum_{t=t_\text{O}}^{t_\text{H}} \tau^{\text{Tout}}_t < D^{\text{peaksatu}}_{m,t_\text{H}} \\ D^{\text{peaksatu}}_{m,t}, & \sum_{t=t_\text{O}}^{t_\text{H}} \tau^{\text{Tout}}_t \geq D^{\text{peaksatu}}_{m,t_\text{H}} \end{cases}$$

$$U^{\text{Goff}}_{m,t} = 1 - U^{\text{G}}_{m,t}$$

$$0 \leq \boldsymbol{d_{m,t}} \leq M U^{\text{Goff}}_{m,t}$$

ignores saturation and cumulate peak duration when outage with $\boldsymbol{d_{m,t}}$

$$\boldsymbol{d_{m,t}} + M U^{\text{G}}_{m,t} \geq d_{m,t-1} + \tau^{\text{Tout}}_{m,t} U^{\text{Goff}}_{m,t} \Delta t$$

$$\boldsymbol{U^{\text{satu}}_{m}} \leq U^{\text{off}}_{m,t}$$

count saturation with $\boldsymbol{U^{\text{satu}}_{m,t}}$

$$d^{\text{peak}}_{m,t} \geq D^{\text{peaksatu}}_{m,t} \boldsymbol{U^{\text{satu}}_{m,t}}$$

$$d^{\text{peak}}_{m,t} \geq \boldsymbol{d_{m,t}} - M \boldsymbol{U^{\text{satu}}_{m,t}}$$

! Minimize CLPU

Outlines

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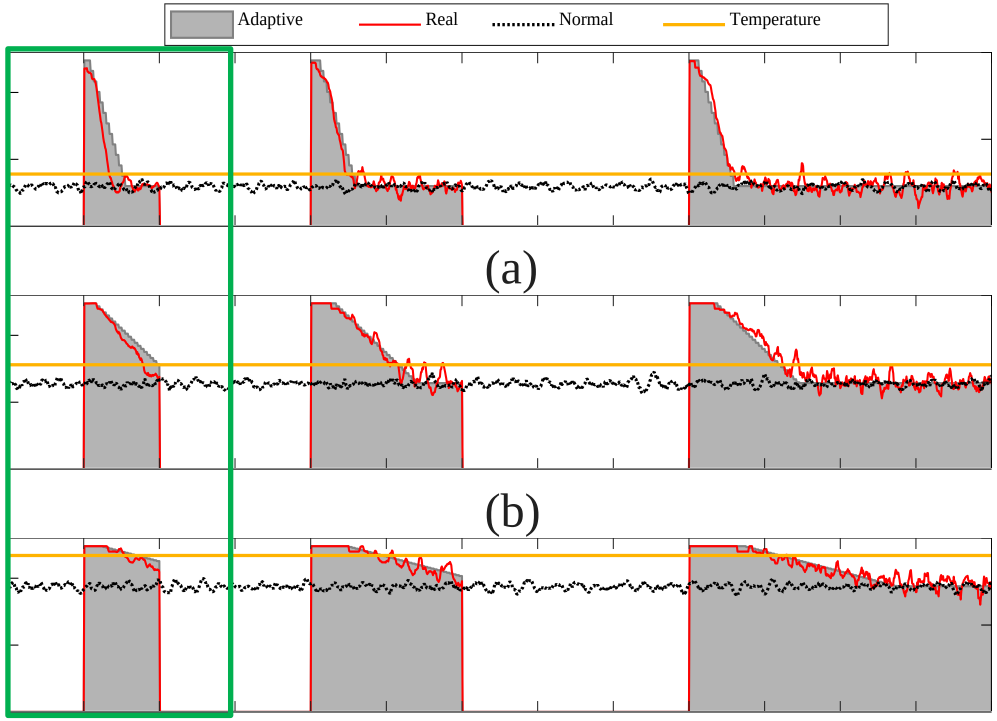
    - Overview
    - Flexible topology control
    - **Adaptive cold load pickup model**
      - Motivation and literature review
      - Proposed model and its integration in EMS
      - **Simulation results**
- Other Projects
- Ongoing Work and Future Work

Adaptive CLPU Verification

- **Static verification of the adaptive CLPU model**
  - Predefined temperature and interruption duration
  - Constant or time-varying temperature

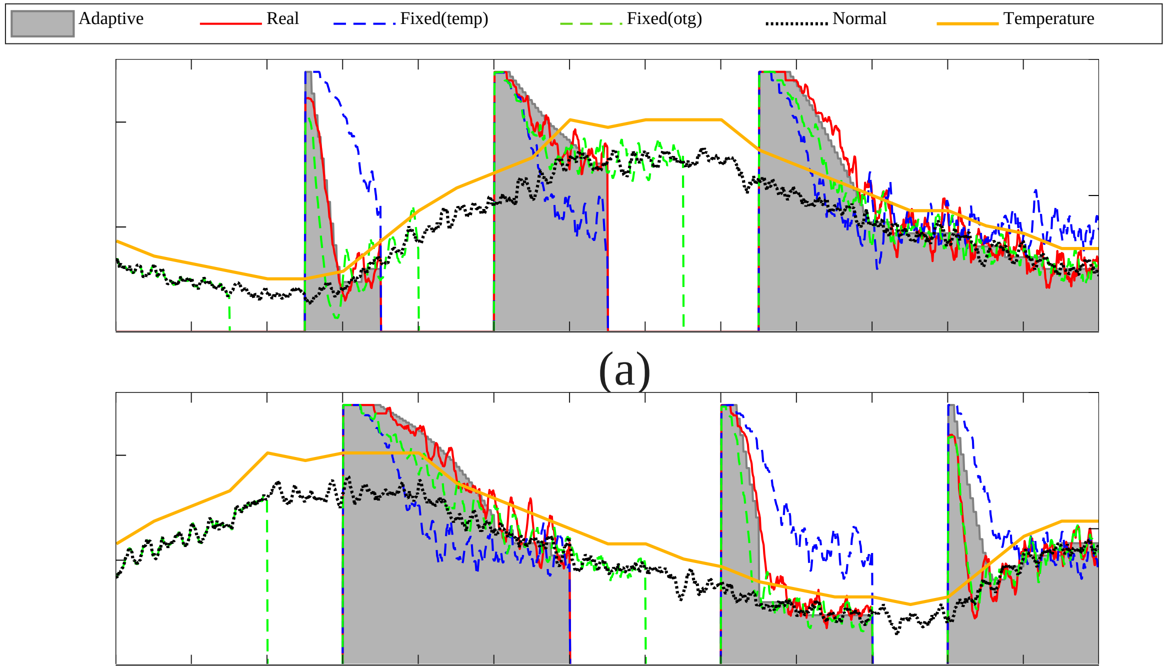
1) Using average temperature (**Fixed-temp**)
2) Predefined interruption duration (**Fixed-temp**)



(a)

(b)

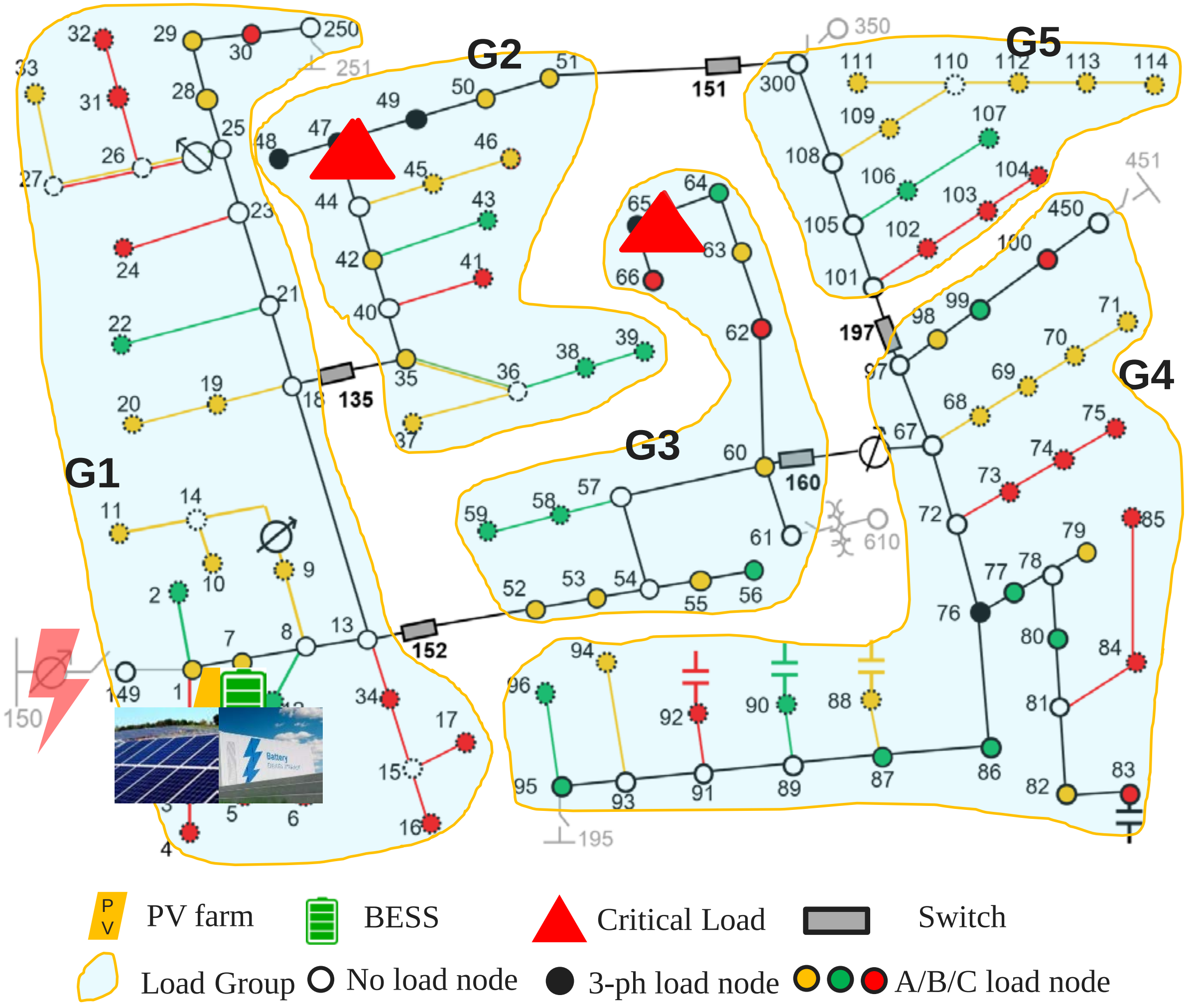
(c)



(a)

(b)

CLPU Enhanced EMS: Case Setup



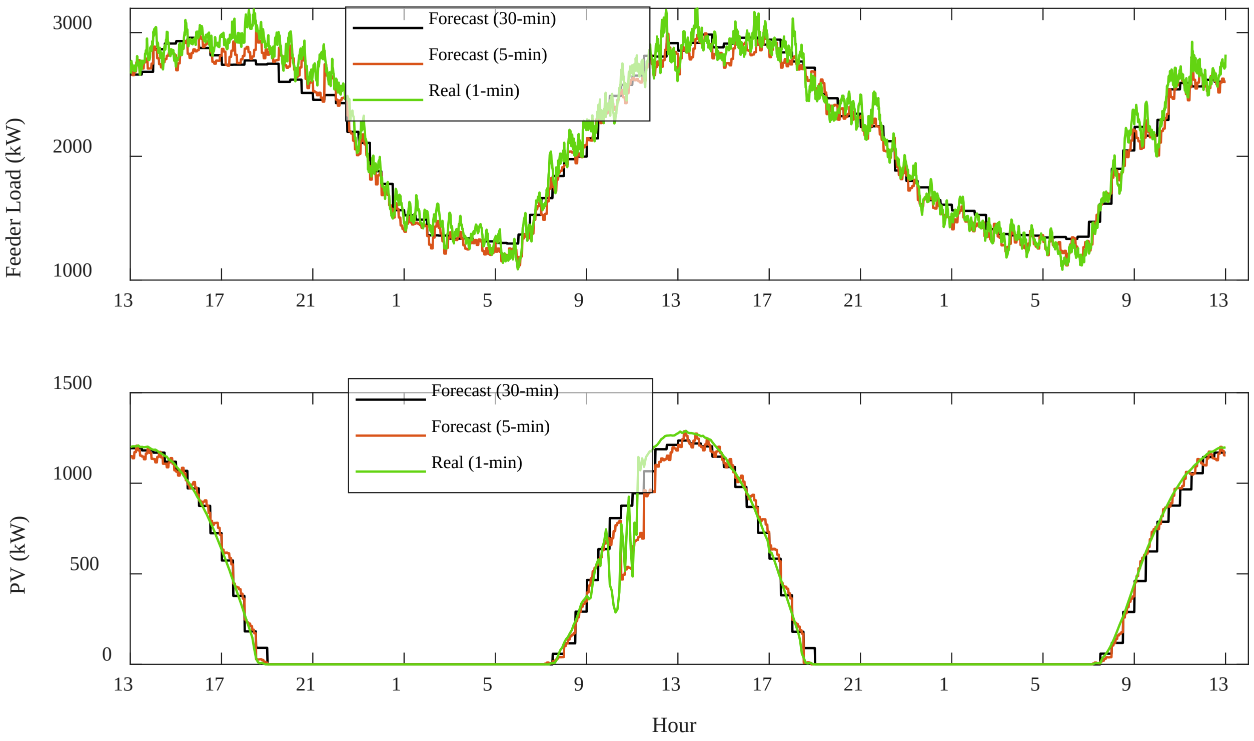
- **Test system**
  - 123-bus system, unbalanced
  - 5 switches, 5 node groups, 1 loop
  - Interval: 30 minutes (1st); 5 minutes (2nd)
  - Horizon: 16 hours (1st); 30 minutes (2nd)
- **Generation**
  - Hybrid PV plant: PV, 4,500 kW; battery, 6,000 kWh (3000 kW)
  - Reserve: **15 %**
- **Load**
  - Critical load: **node 47** (40 kW per phase), **node 65** (50 kW per phase)
  - **Preferred service period**: 7:00-9:00, 18:00-20:00
  - **Minimum service duration** : 2 hours

Outage

Substation is down for 2 days

CLPU Enhanced EMS

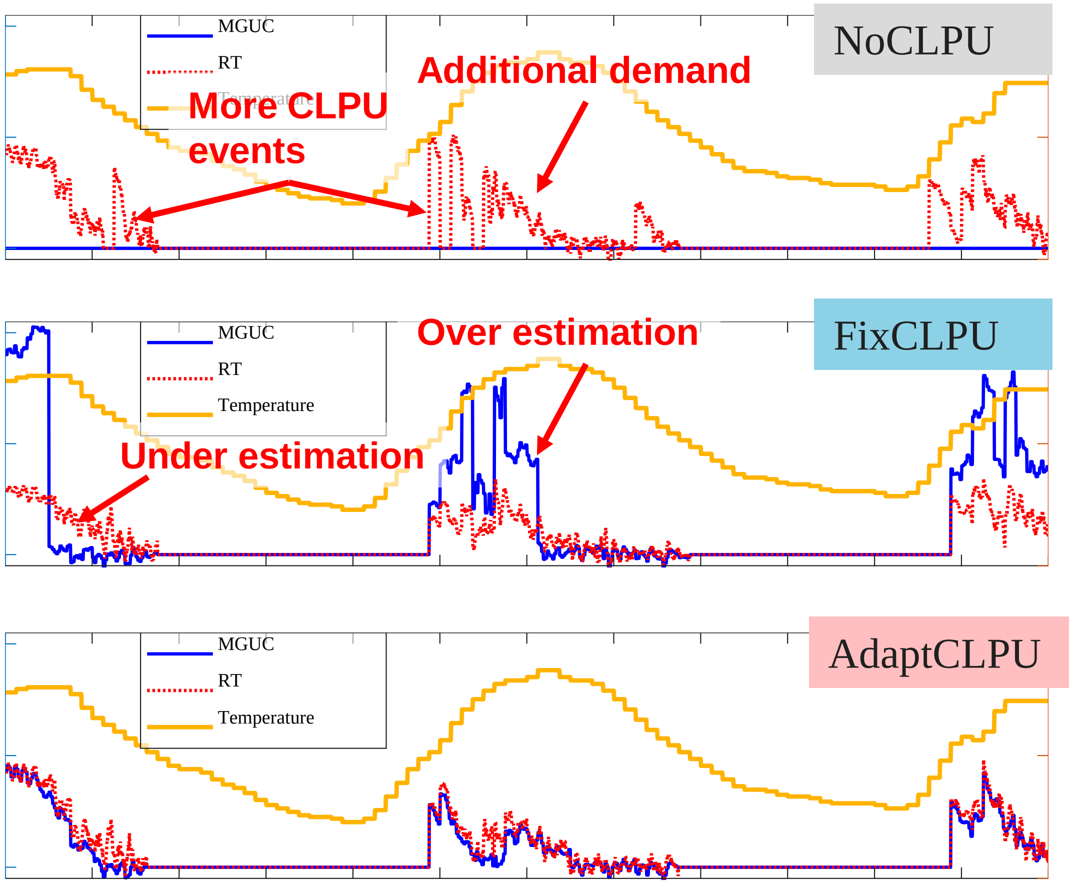
Case	CLPU Model	
1	NoCLPU	do not consider the CLPU effect.
2	FixCLPU	CLPU increment equal to normal load, 2h CLPU duration (ave_temp 29ºC)
3	AdaptCLPU	Adaptive CLPU model



Normal load and PV during the 2-day outage

CLPU Enhanced EMS

- CLPU

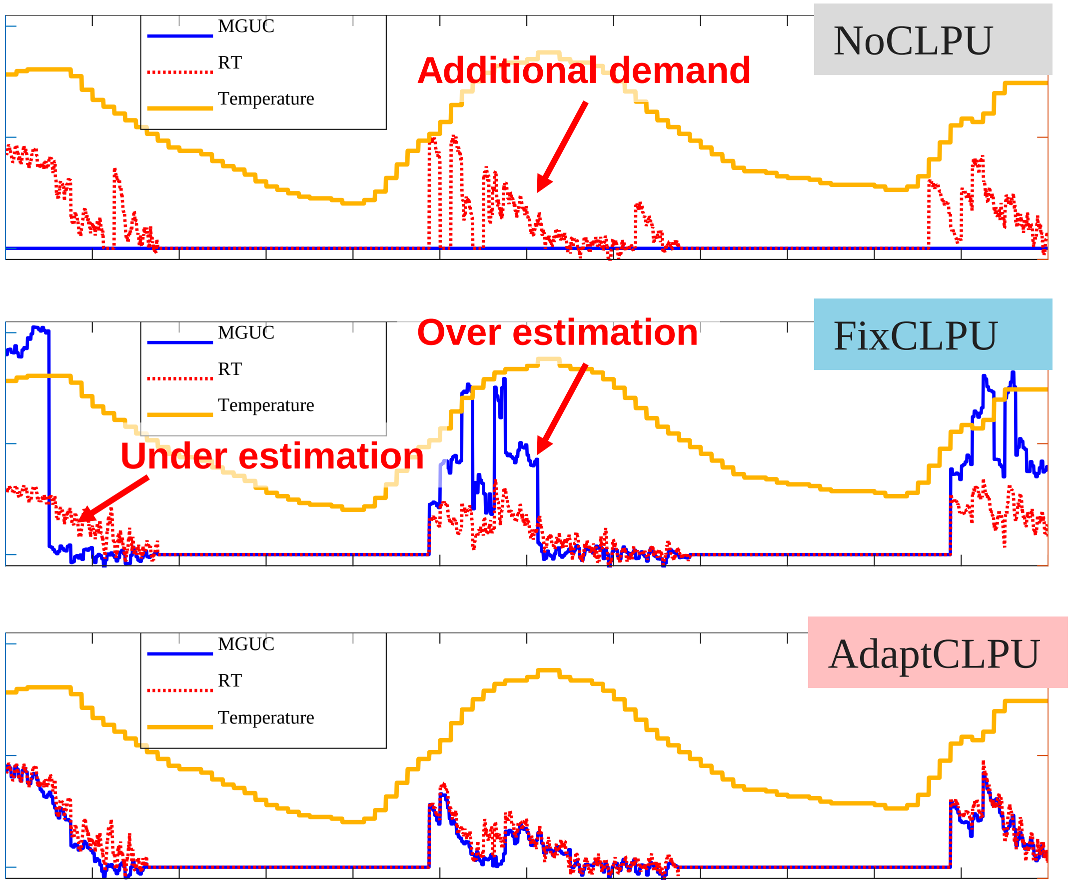


MGUC: EMS scheduling

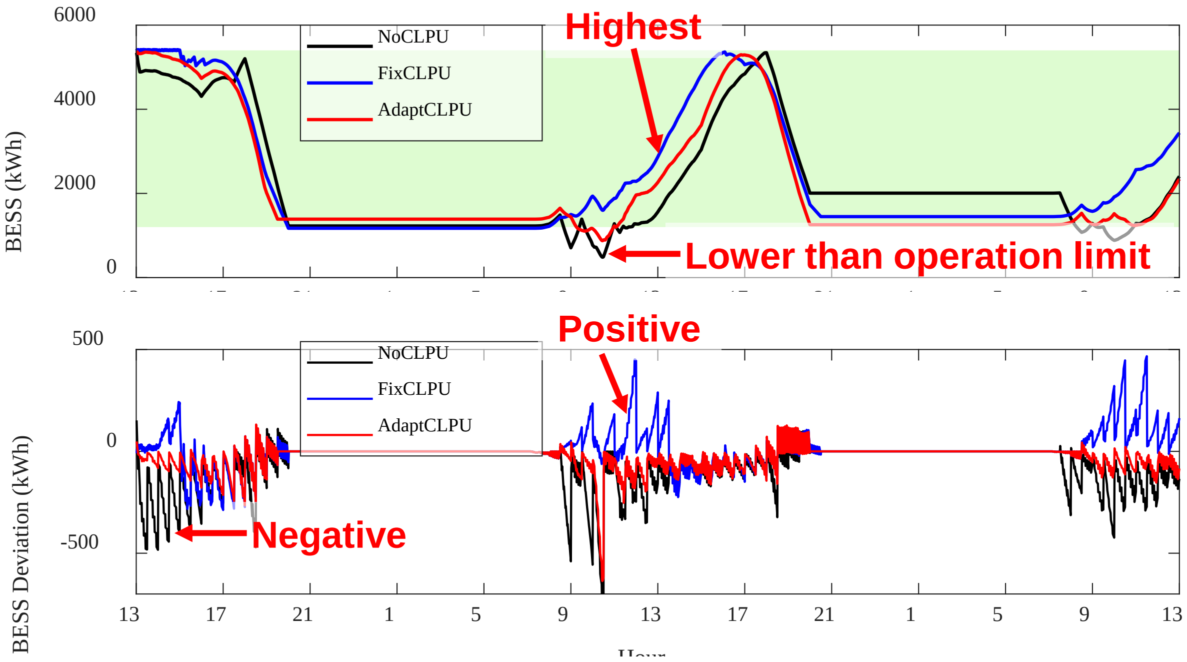
RT: real-time simulation (1-min)

CLPU Enhanced EMS

- CLPU & BESS



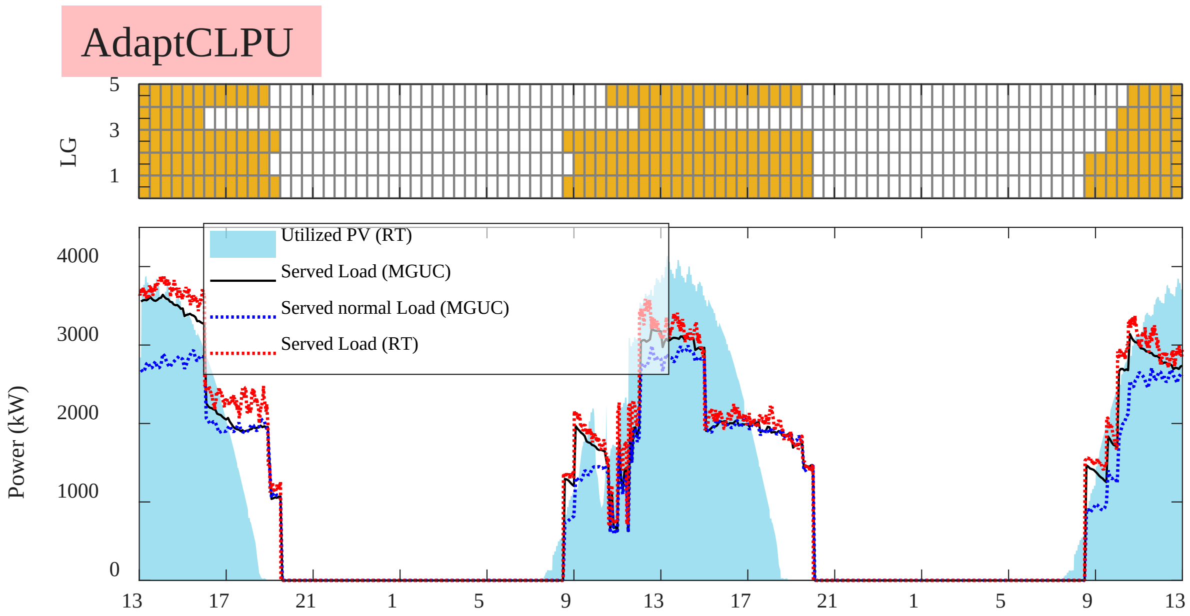
MGUC: EMS scheduling
RT: real-time simulation (1-min)

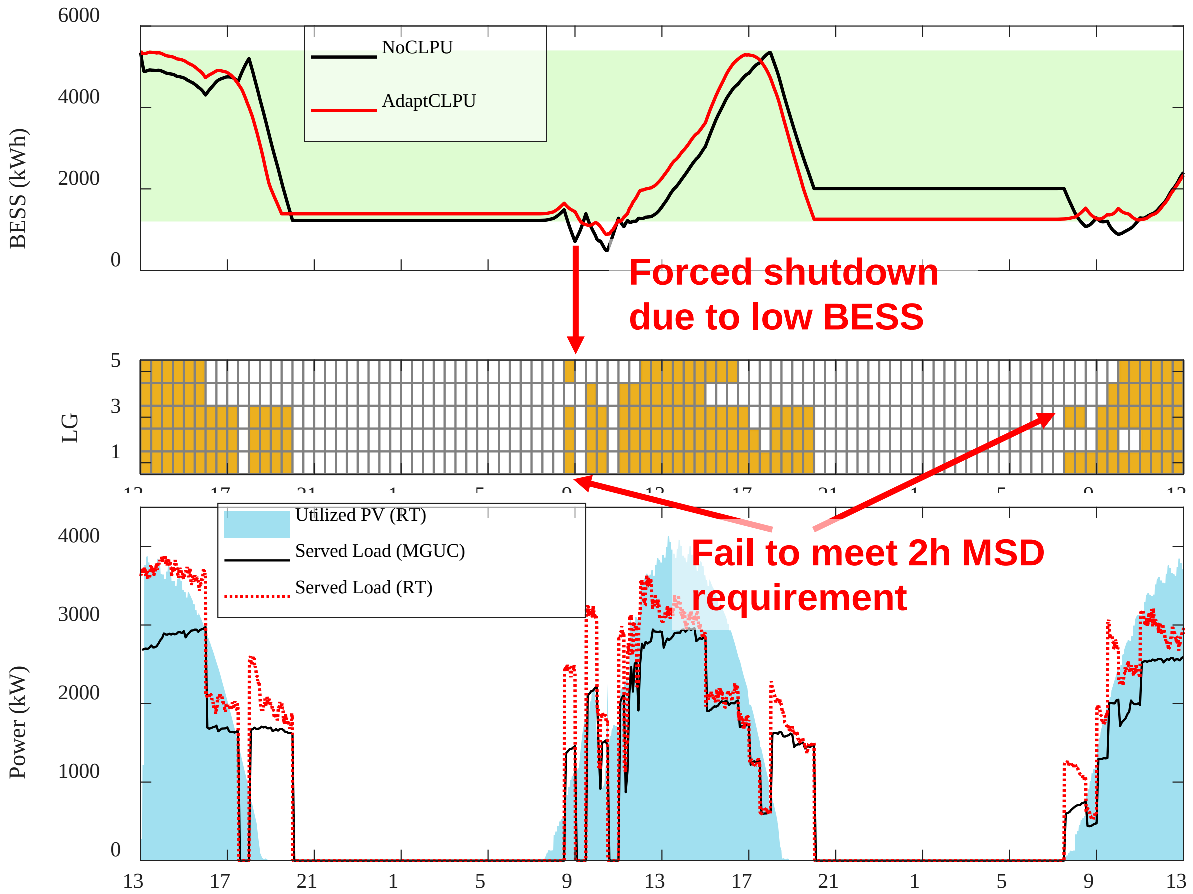


- **NoCLPU**: large unscheduled demand → negative BESS deviation
- **FixCLPU**: CLPU overestimation→ high SOC level and positive BESS deviation

CLPU Enhanced EMS

- **AdaptCLPU v.s. NoCLPU**

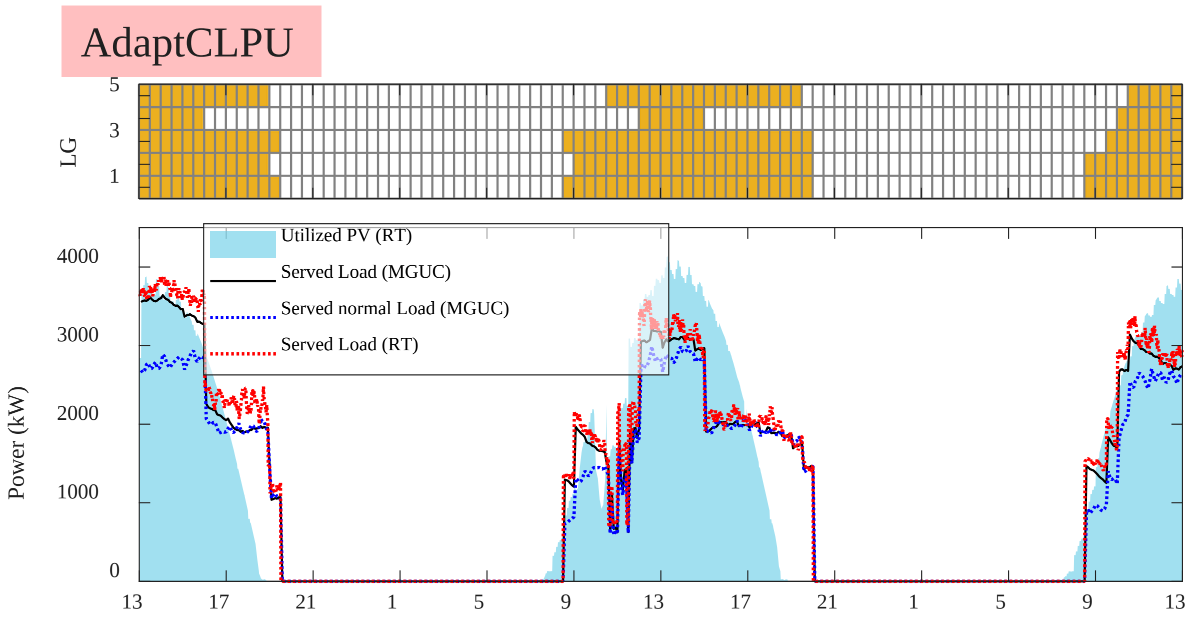


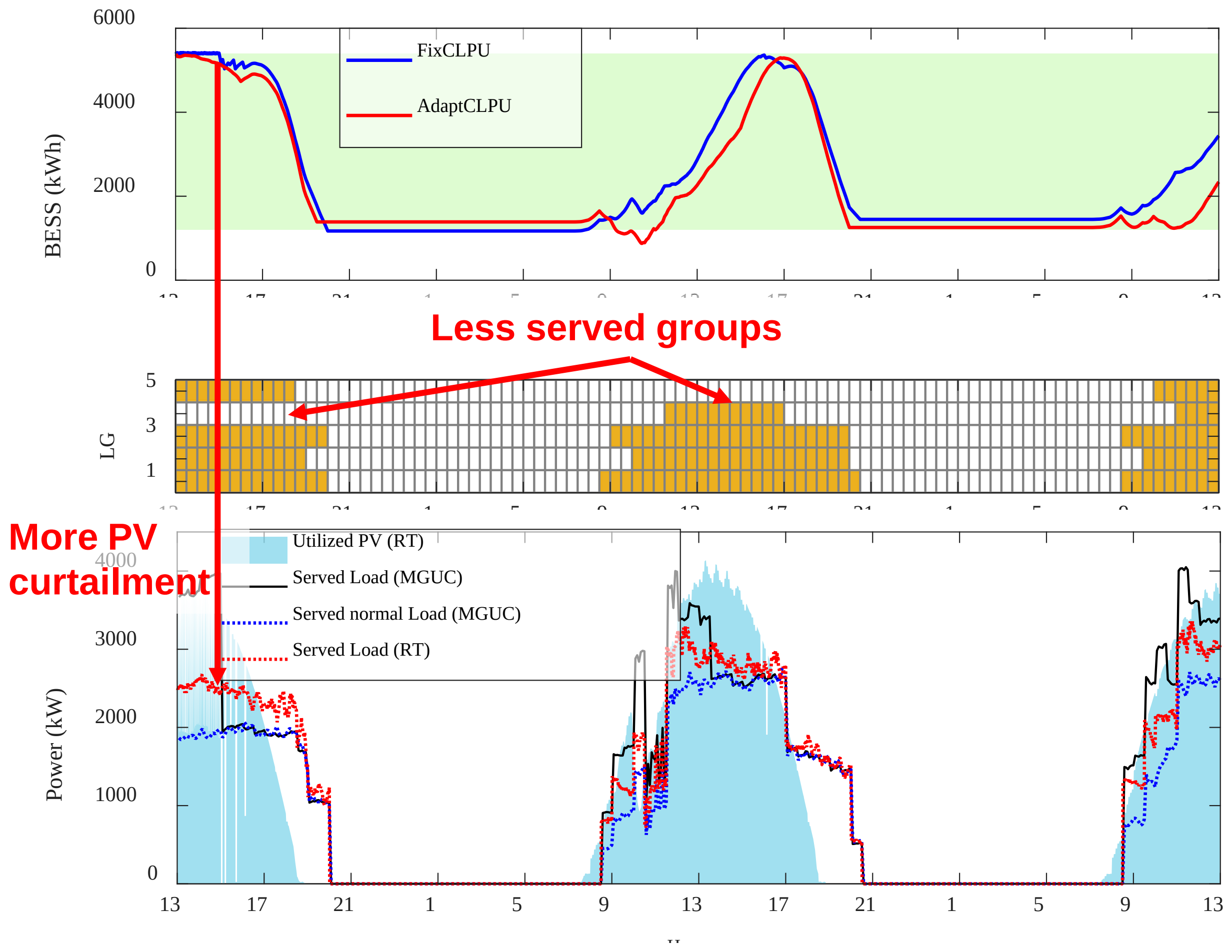


- **NoCLPU**
  - Lower customer comfort (minimum service duration)
  - Unstable microgrid operation

CLPU Enhanced EMS

- AdaptCLPU v.s. FixCLPU





- FixCLPU
  - Lower customer comfort (unfair)
  - Less PV utilization

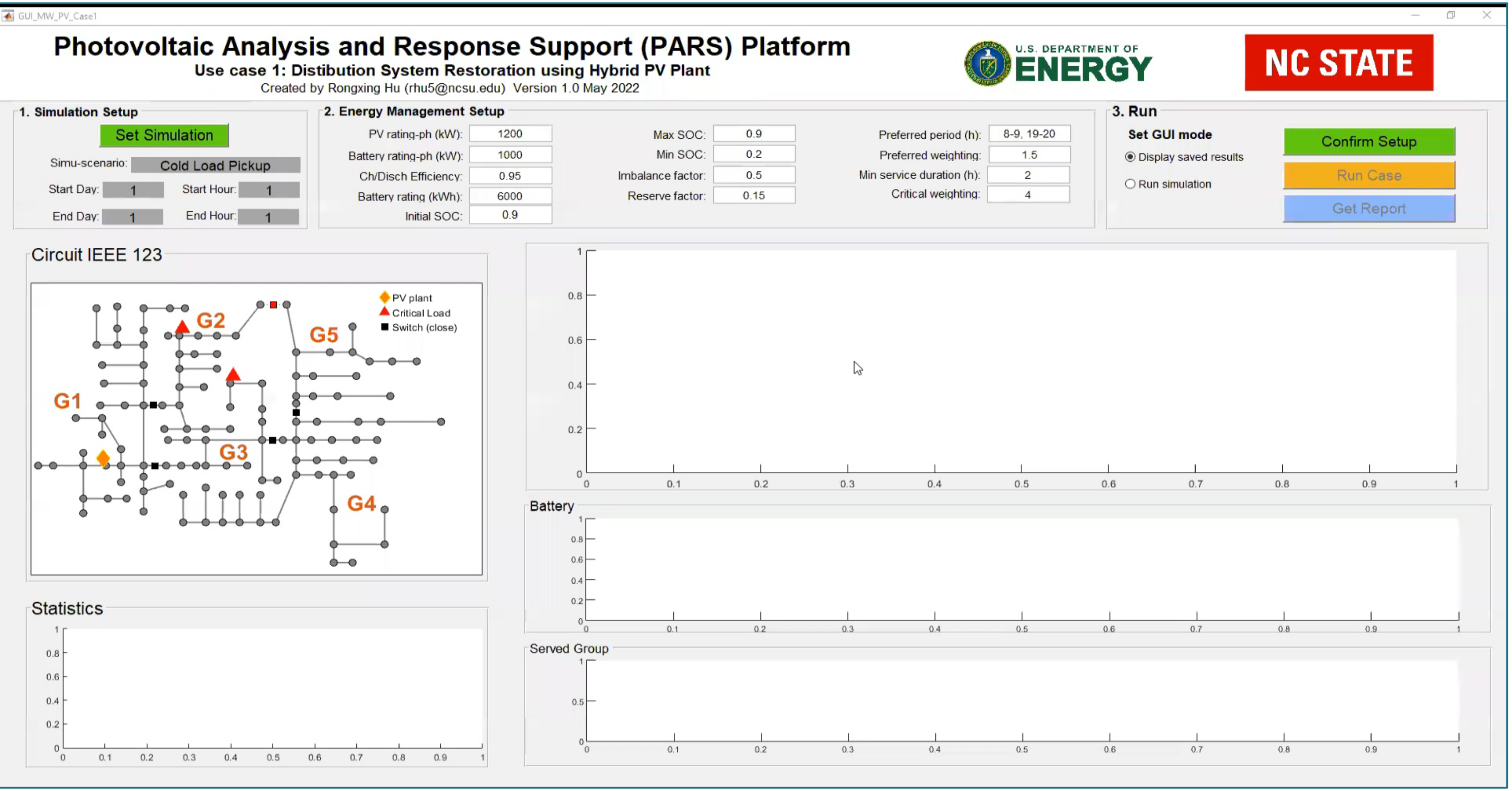
Overall Performance

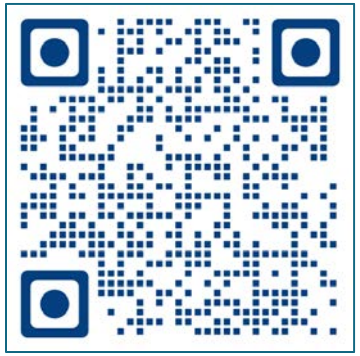
- ## Overall performance

Case	Served load (kWh)	Served load in preferred periods (kWh)		Served critical load (kWh)	Served baseload (kWh)	Curtailed PV (kWh)	CLPU (kWh)		
		total	CLPU part				Actual	Estimated	Estimation deviation
NoCLPU	54493	**10196**	1757	4734	21438	2999	7697	-	-7697
FixCLPU	50737	7445	540	4814	20464	5877	**5893**	12885	+6992
AdaptCLPU	**55173**	7771	667	**4857**	**22210**	**2591**	6835	5565	**-1270**

- **AdaptCLPU**
  - **More** served total load, critical load, baseload
  - **Less** PV curtailment and CLPU estimation error

GUI Demonstration





https://youtu.be/b5sv8SozFSk

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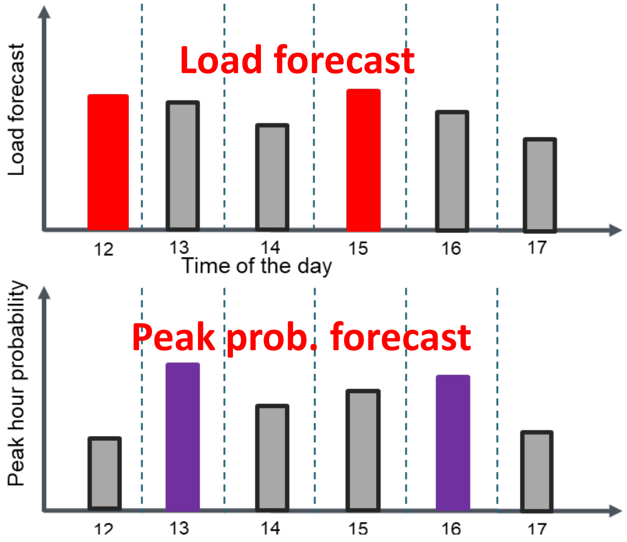
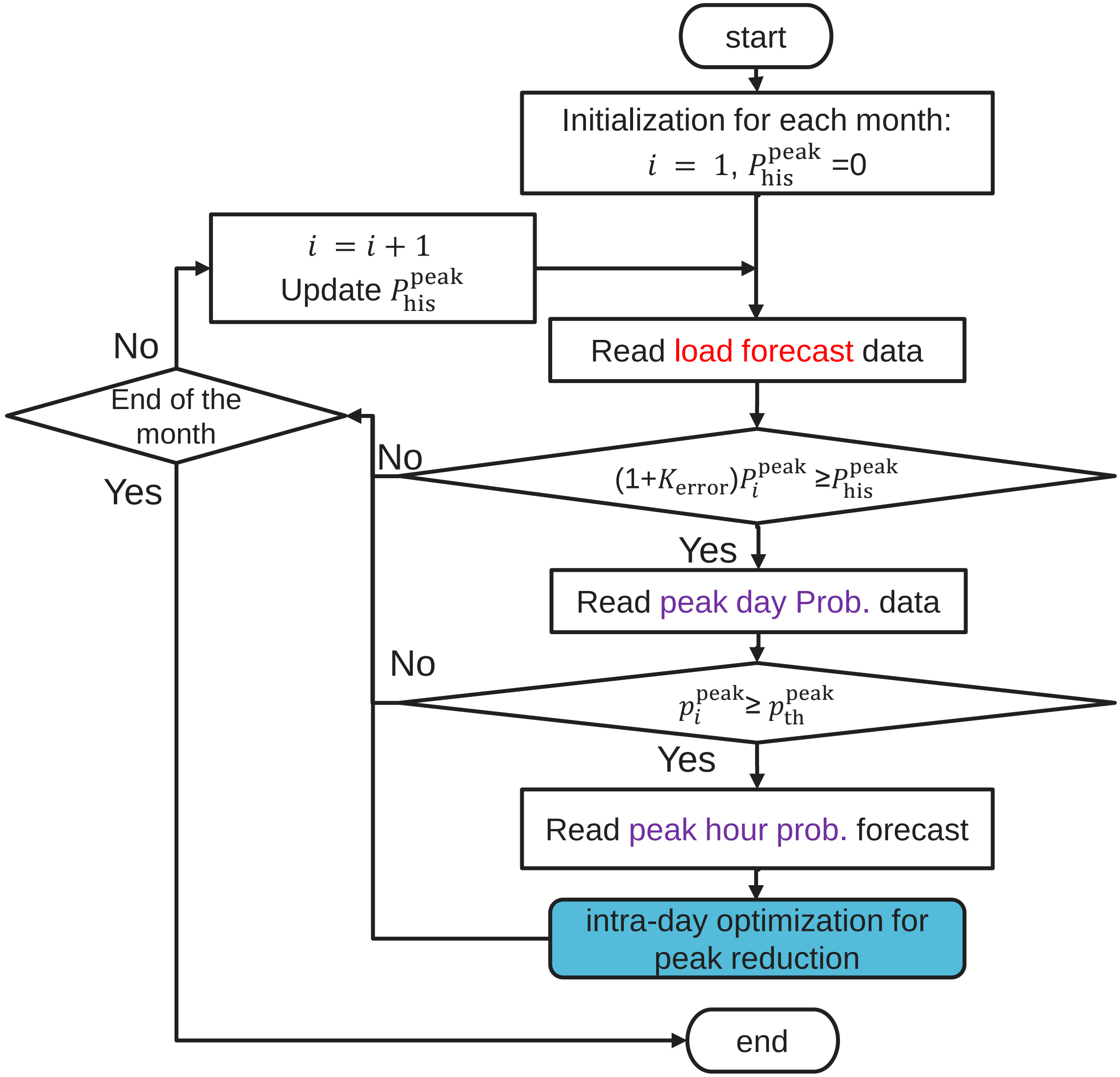
    - Flexible topology control
    - Adaptive cold load pickup model
    - Phase Imbalance
- **Other Projects**
  - Energy Storage Application Analytics (Proj-2)
  - Avista's Shared Energy Economy Model Pilot (Proj-3)
  - Coordinated Real-time Sub-Transmission Volt-Var Control Tool (Proj-4)
- Ongoing Work and Future Work

Project – 2

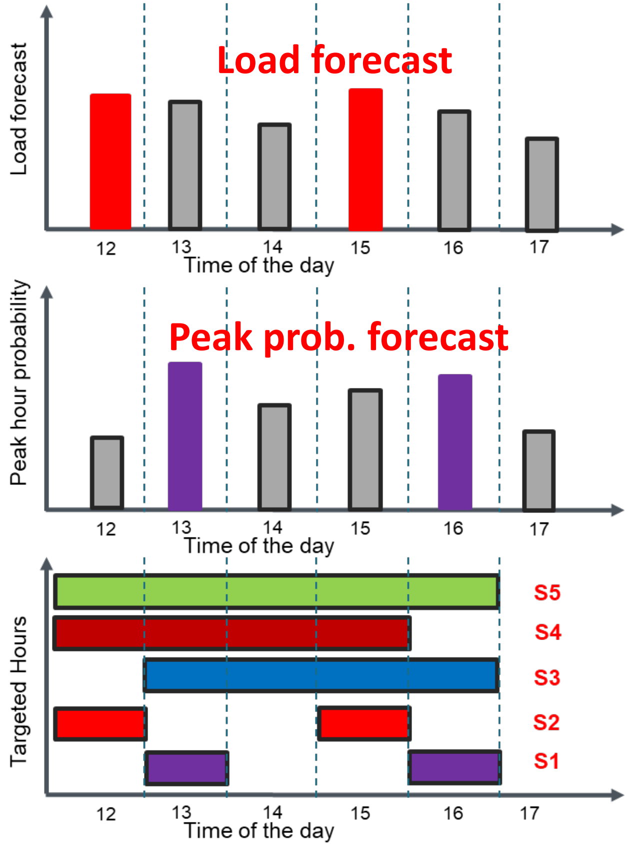
- **Energy Storage Application Analytics**
  - PNNL, NCSU, and local small utility @ ElectriCities
  - Coordinating BESS, Diesel generators, CVR, demand response of HVAC to reduce peak load
    - Monthly peak (hourly), **20$/kW**,(energy rate: 0.03 $/kWh)

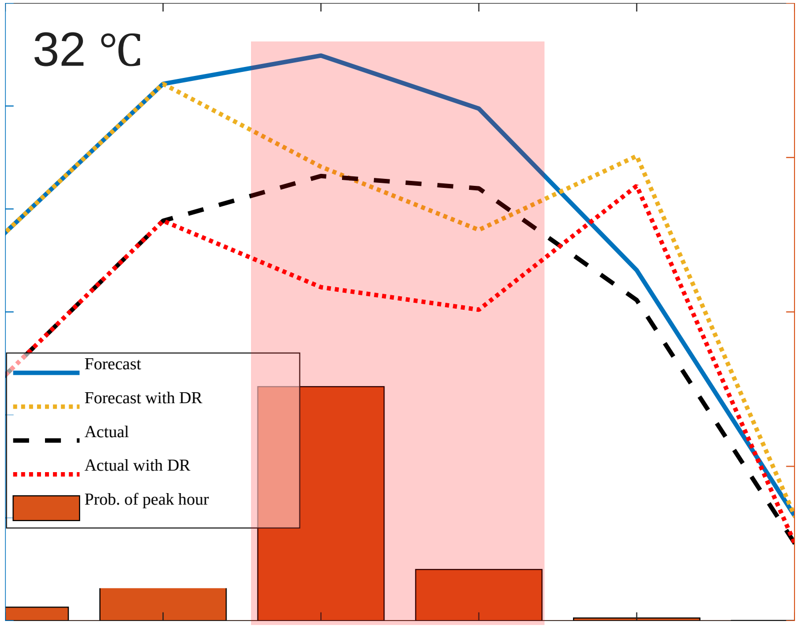


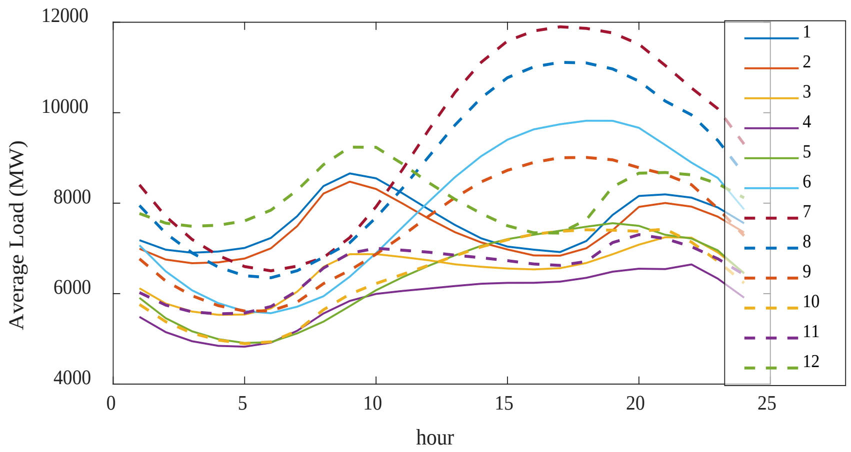


Project - 2

- **Energy Storage Application Analytics**
  - Benefit analysis, Reduction strategy
  - Payback load of DR





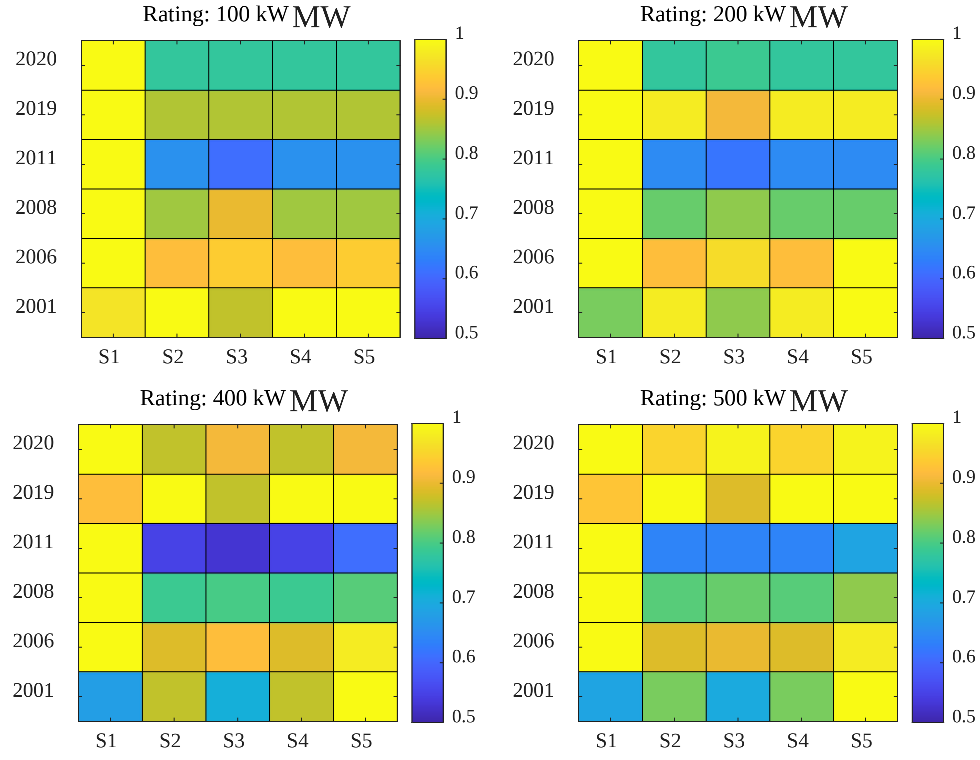


	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
S1	T	T	T	T		T		T		T	T	T
S2												
S3												
S4					T		T					
S5					T	T	T	T	T	T	T	

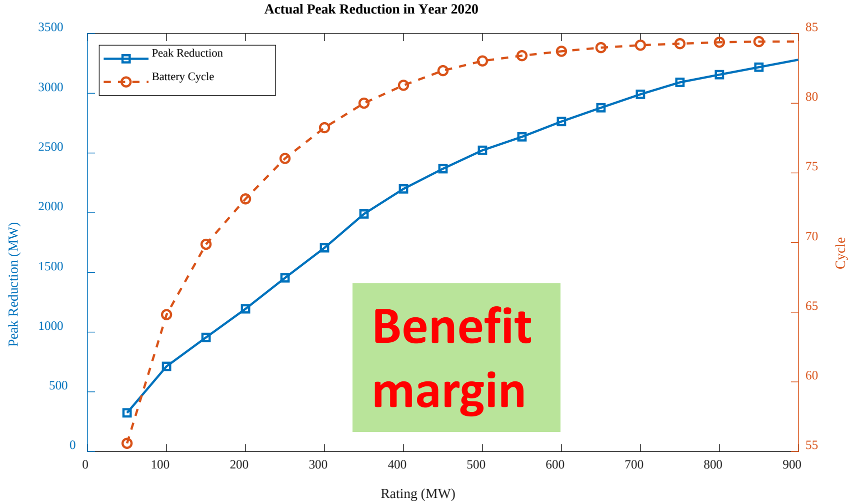
Strategy selection

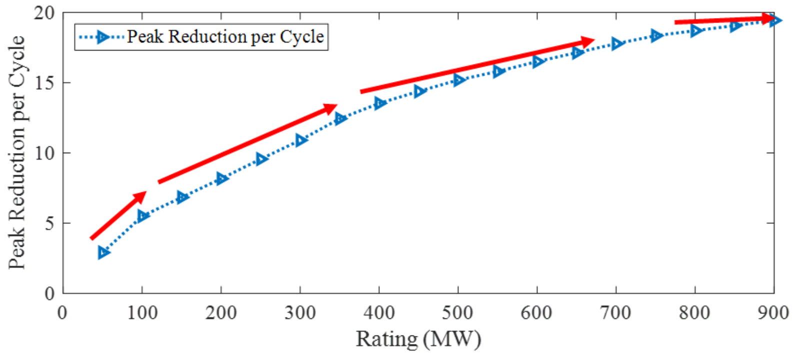
Project - 2

- **Energy Storage Application Analytics**
  - Benefit analysis, Reduction strategy
  - Payback load of DR



	Rating (MW)				
	100	200	300	400	500
S1	5	5	4	4	4
S2	1		1	1	1
S3					1
S4	1		1	1	1
S5	1	1	2	3	4





- **Avista's Shared Energy Economy Model Pilot (Proj-3)**
  - Internship project at PNNL
  - Techno-economic Assessment of the WSU campus microgrid
    - Microgrid EMS: BESS, PV, Flexible building load (virtual BESS)
    - Cost of investment, energy, and demand charge, resilience improvement
    - Estimated optimal battery reserve requirement for DR program (contract)

Table 4.2. Present Value Costs vs. Benefits in The Base Scenario

	Costs	Benefits
Capacity value		$137,033
Energy arbitrage		$196,175
Ancillary services		$29,743
Energy charge reduction		$163,906
Demand charge reduction		$283,462
Demand response		$93,082
BESS capital cost	$1,670,000	
PV capital cost (excluding residual)	$875,467	
PV O&M cost	$28,181	
BMS upgrade cost	$342,000	
Total	$2,915,648	$903,402

Cost and benefits

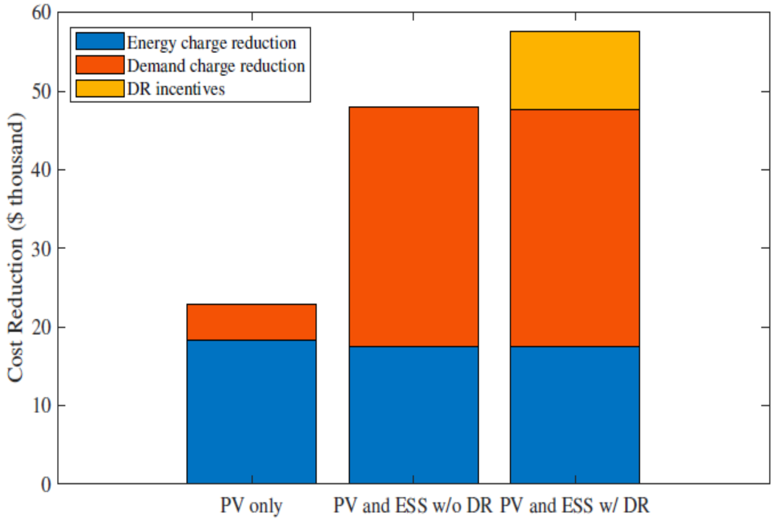
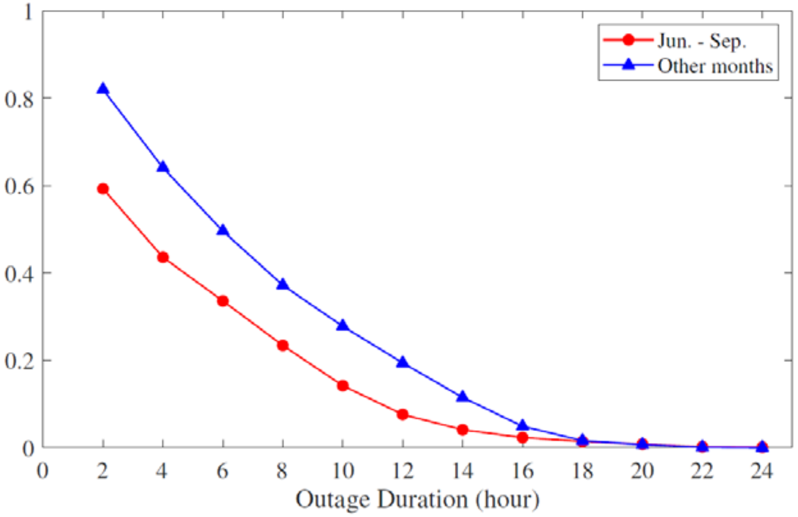


Figure 4.7. Annual cost saving.

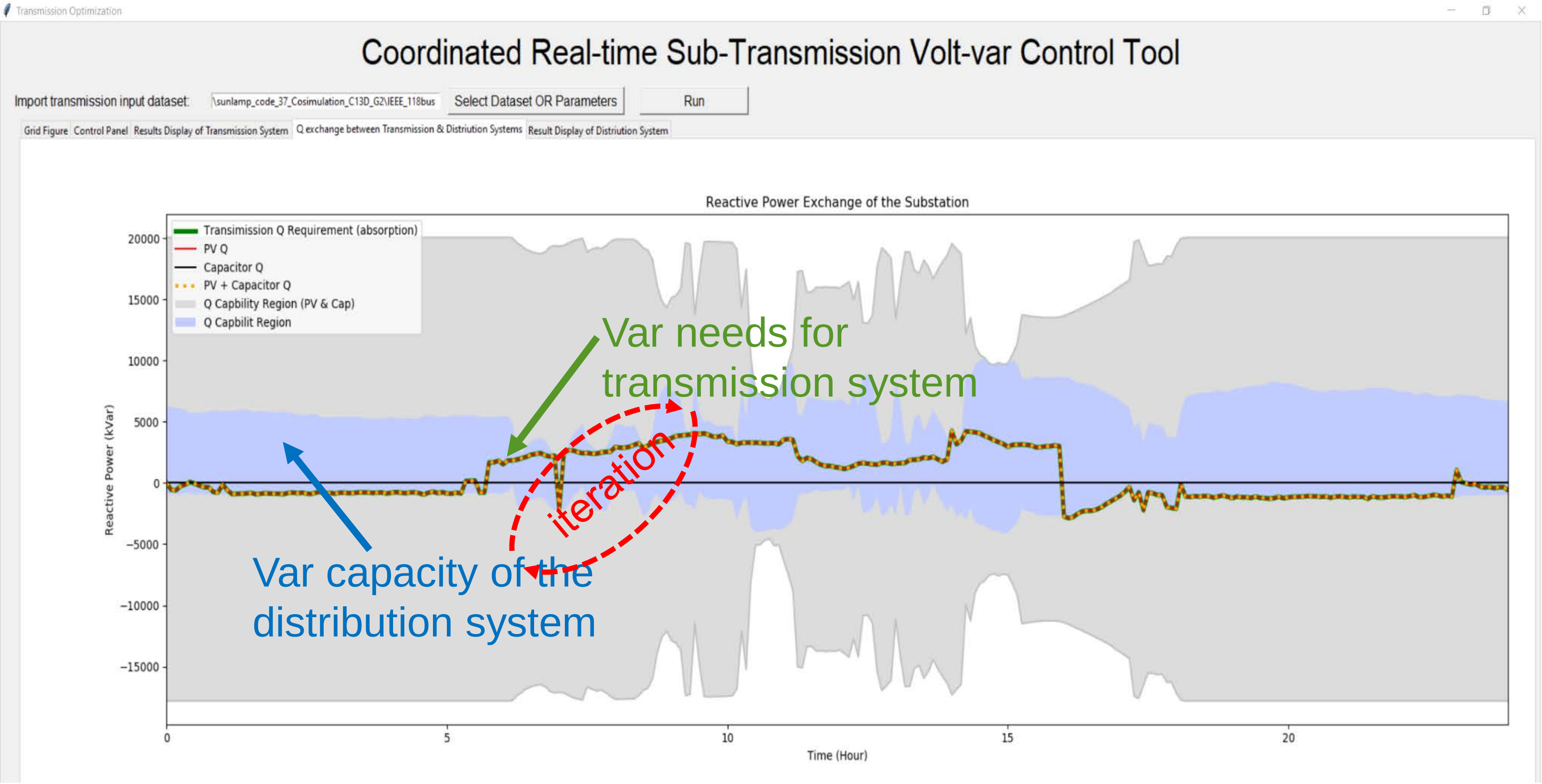
Annual cost saving

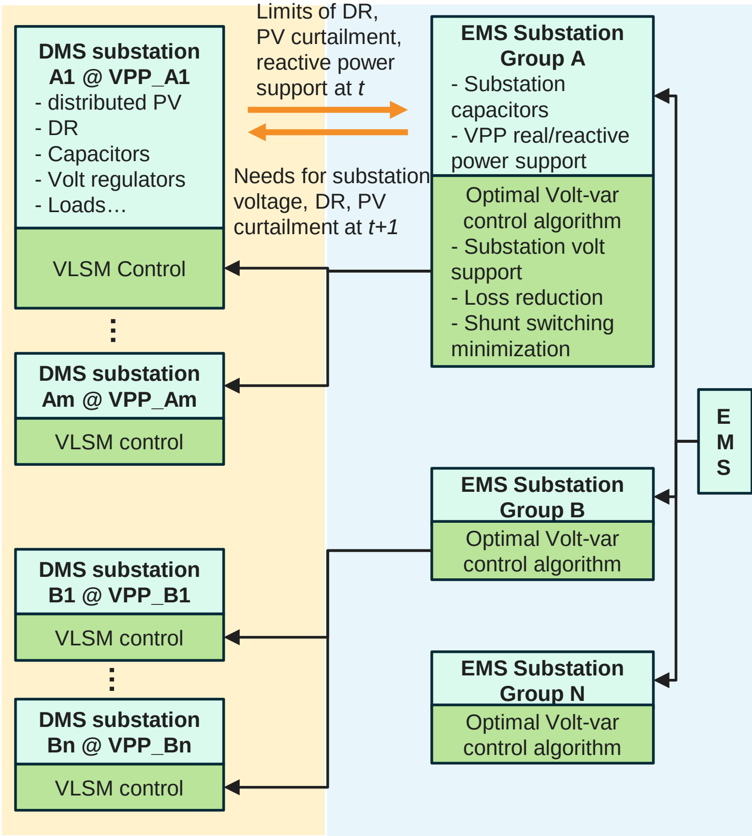


gure 4.10. Survivability with a random BESS SOC when an outage occurs.

Resilience improvement (survivability)

- **Integration of the Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT) into Energy Management Systems (EMS)**
  - Developed a python-based GUI for the real-time (5-min) co-simulation platform
  - Validated control strategies for the coordinative transmission-distribution Volt-Var control





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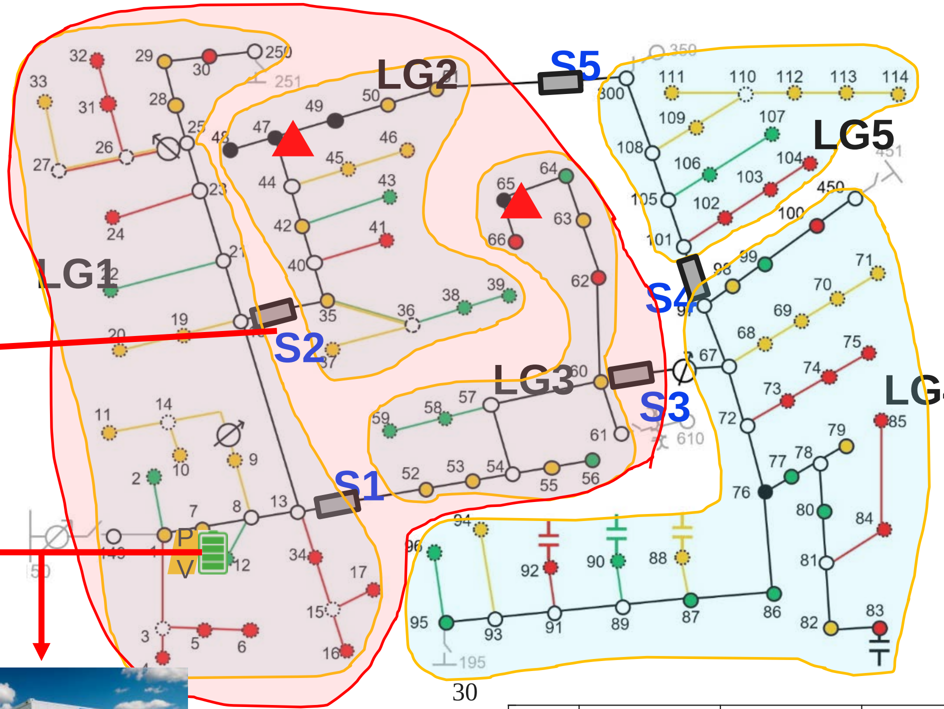
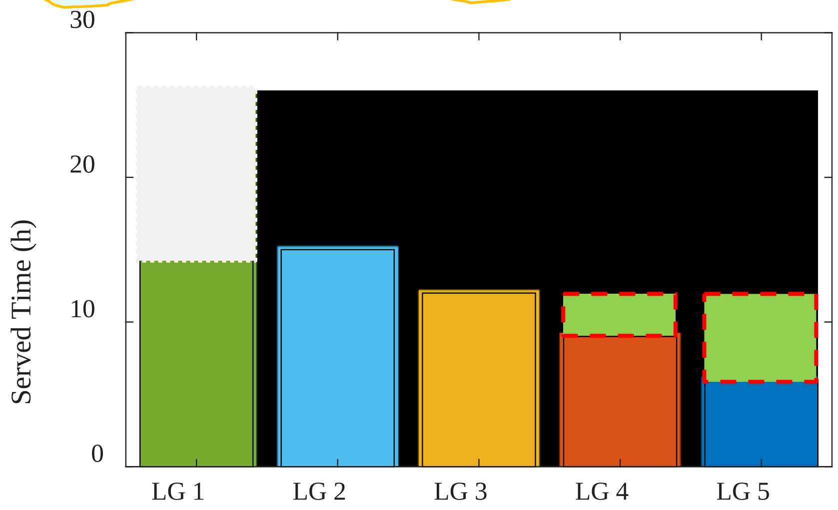
  - Coordinated Real-time Sub-Transmission Volt-Var Control Tool (Proj-4)
- **Ongoing Work and Future Work**

Ongoing Work: Equity-oriented



Smart switch

Hybrid PV plant



- **Service restoration via MW-PV & battery system powered microgrid**
  - More served loads
  - More served customers
- **Main Considerations**
  - Switch on/off Load group
  - No sub-meter control capability
  - Radial topology
  - Customer comfort
  - Cold load pickup (HVAC)
- **Fairness**
  - Location-dependent
  - Ignore value of different loads

Future Work

- **Model-Free approach for operation and control of microgrids and DERs**
  - RL approach for microgrid resiliency service
  - Volt-Var Control for high renewable-penetrated distribution systems
- **Transmission-distribution systems' co-simulation considering high-penetration distributed PV systems**
  - Local DERs → distribution system could be power source (e.g. at noon) → co-simulation
  - So many feeders and detailed circuit → not possible to conduct co-simulation directly
  - How to simplify the distribution systems (eg.500-bus→10-bus)
- **Virtual Power Plant (VVP) and demand response (DR)**
  - Demand-side resources (DSRs) @ PV systems, electric vehicles (EV), and HVACs
  - Users' benefit @ Peak load reduction, energy cost reduction…
  - DSRs are aggregated for transactions, how to consider the operation/control constraints of distributed DSRs?

List of Related Publication

1. **Rongxing Hu**, Ashwin Shirsat, Valliappan Muthukaruppan, et all., "Adaptive Cold-Load Pickup Considerations in 2-Stage Microgrid Unit Commitment for Enhancing Microgrid Resilience," *Applied Energy*, *2024*. (Proj-1, EMS-CLPU)
2. **Rongxing Hu**, Ye Kai, Hyeonjin Kim, et al., "Design Considerations of a Coordinative Demand Charge Mitigation Strategy." *In 2023 PESGM*. (Proj-2)
3. **Rongxing Hu**, Yiyan Li, Si Zhang, et al., "A Load Switching Group based Feeder-level Microgrid Energy Management Algorithm for Service Restoration in Power Distribution System." *In 2021 PESGM*. (Proj-1, EMS-topology)
4. **Rongxing Hu**, Ning Lu, et al., "Equity-oriented Resiliency Service via Microgrid in Distribution System." *Manuscript in preparation*. (Proj-1, EMS-equity)

5. Ashwin Shirsat, Valliappan Muthukaruppan, **Rongxing Hu**, et al., "A secure and adaptive hierarchical multi-timescale framework for resilient load restoration using a community microgrid," *IEEE Transactions on Sustainable Energy*, 2023. (Proj-1, EMS)
6. Yiyan Li, Si Zhang, **Rongxing Hu**, et al., "A meta-learning based distribution system load forecasting model selection framework," *Applied Energy*, 2021. (Proj-1, forecast)
7. Si Zhang, Mingzhi Zhang, **Rongxing Hu**, et al., "Reinforcement Learning for Volt-Var Control: A Novel Two-stage Progressive Training Strategy." *In 2022 PESGM*. (Proj-1, volt control)
8. Ashwin Shirsat, Valliappan Muthukaruppan, **Rongxing Hu**, et al., "Hierarchical Multi-timescale Framework for Operation of Dynamic Community Microgrid", *In 2021 PESGM*. (Proj-1, EMS)
9. Valliappan Muthukaruppan, **Rongxing Hu**, Ashwin Shirsat, et al., "Multi-Feeder Restoration using Multi-Microgrid Formation and Management", submitted to *2024 PESGM*. (Proj-1, EMS)

FREEDM SYSTEMS CENTER

Review Activities and Presentations

NC STATE UNIVERSITY

- **Reviewer**
  - IEEE Transactions on Sustainable Energy (60+, outstanding reviewer)
  - Applied Energy (20+)
  - IEEE Power Engineering Letters (5+)
  - IEEE Open Access Journal of Power and Energy (15+, outstanding reviewer)
  - 2021-2024 IEEE PES General Meeting (10+)
- **Presentation**
  - "Design Considerations of a Coordinative Demand Charge Mitigation Strategy", PESGM conference, 2023
  - "Distribution Resiliency Frameworks with High PV Penetration", FREEDM Tech Webinar, 2022
  - "A Load Switching Group based Feeder-level Microgrid Energy Management Algorithm for Service Restoration in Power Distribution System", PESGM conference, 2021

Thank You

(Q&A)