CIGRE US National Committee
2021 Grid of the Future Symposium

Presentation Title:
Impacts of Weather-Related Outages on DER participation in the Wholesale Market Energy and Ancillary Services

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October 2021

Problem Statement

- ➢ Development of consumer-owned DERs is accelerated driven by carbon-free future, grid resilience, favourable electricity time-of-day pricing, and possibility to trade power.
- ➢ DERs can offer ancillary service products (ASPs) to the wholesale market (WEM).
- ➢ DERs are connected to the distribution grid where the number of outages is high.
- ➢ They are usually energy limited resources whose stored energy might be drained during outages to supply their local loads when the grid is unable to do so.
- ➢ Therefore, they may be vulnerable to large distribution grid outages where many of them might be disconnected.
- ✓ The impact of weather-related distribution feeder outages on the performance of DER aggregators participating in the WEM is investigated.

N-Grid Features

- Controllable loads.
- PV generation and inverter
- Battery energy storage and bidirectional charger
- EV and bi-directional chargers

❖ All the components are connected to a common AC bus rated at 230-240V.

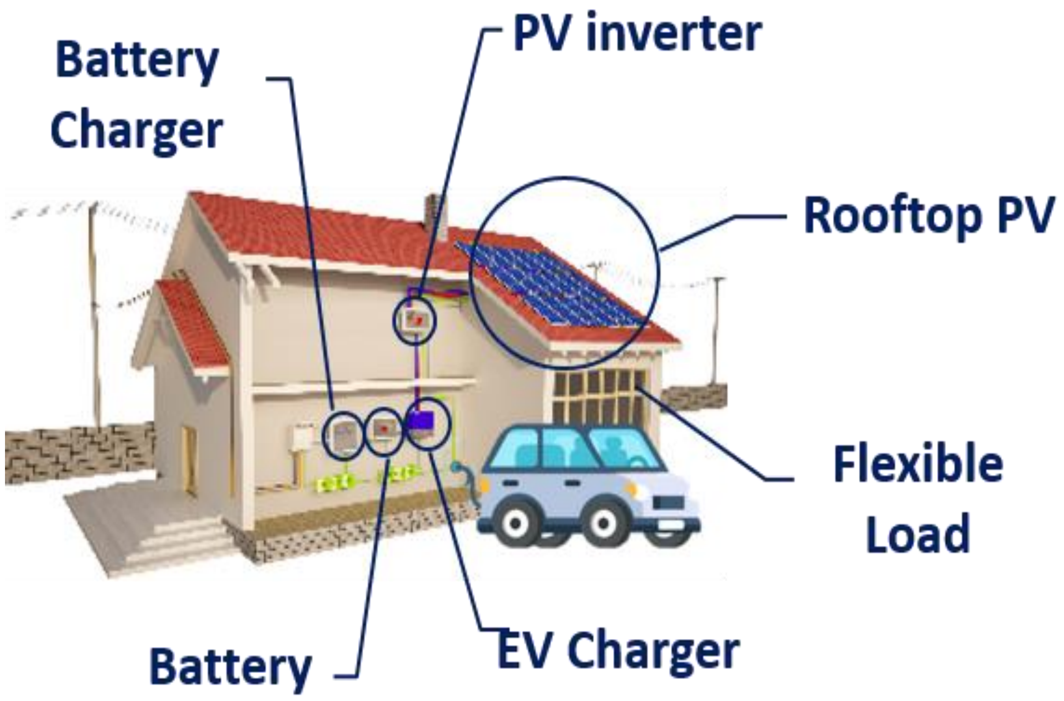


Fig. 1. n-Grid Architecture

Harvesting n-Grid Flexibility

Mode 1	n-Grids to market operator via aggregator
Mode 2	n-Grids to distribution system operator (DSO) with or without aggregator
Mode 3	n-Grids in peer-to-peer exchange with DSO coordination, and with or without aggregator

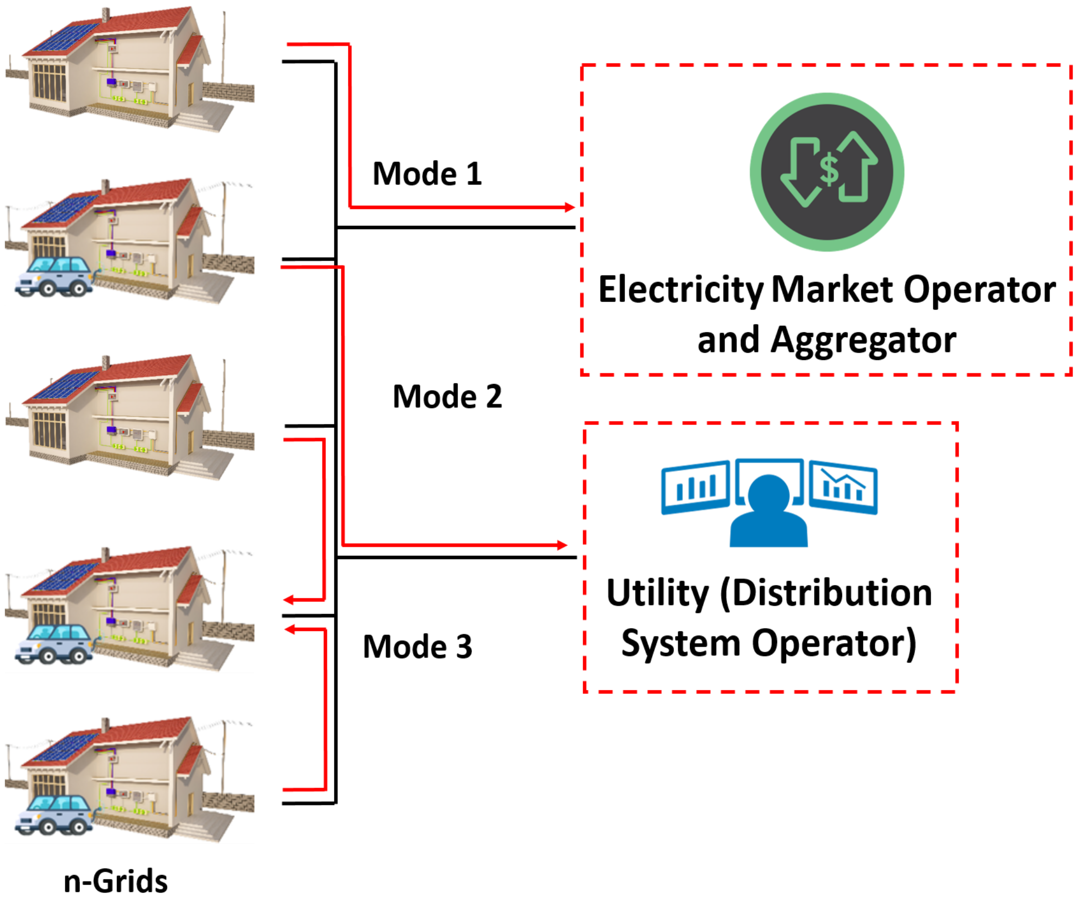


Fig. 2. n-Grid operating modes

Benefits of n-Grid Resource Flexibility for WSM

- Modern WSMs suffer of low flexibility caused by high penetration of intermittent renewable resources, e.g., wind farms and solar plants.
  - The high ramp rate and storage capacity of n-Grids can be utilized to cover renewable generation intermittencies.
  - Their ramp rate can be also employed in procurement of spinning reserve and frequency regulation.
  - Under attractive incentives, they can participate in demand response and load shedding programs.

N-Grid in Wholesale Market (WSM)

Table 1. Different ASPs offered in the market

Type of ASP	Main purpose	Requirements	Time-frame
Frequency regulation	Maintain Freq. to 60Hz	Equipped with AGC	~ 4 Sec
Spinning reserve	Contingency Response	Sync. to Grid	< 10 min
Non-spinning reserve	Contingency Response	Be able to Sync. to Grid	< 10 min

- The minimum capacity required for participation in the WSMs in the US is 100 kW to 1 MW.
- Participation of n-Grids in the WSM calls for an aggregator to aggregate n-Grids' resources and participate in the WSM on their behalf.

N-Grid Resource Management for WSM

- The aggregator is envisioned as a mediator between the n-Grids and the WSM.
- It can manage the n-Grids resources directly through internet of things (IoT).
- The aggregator must capture different uncertainties to ensure its profitability:
  - market prices,
  - EVs arrival, departure and initial energy,
  - ambient temperature,
  - PV generation and
  - n-Grids' electric load.

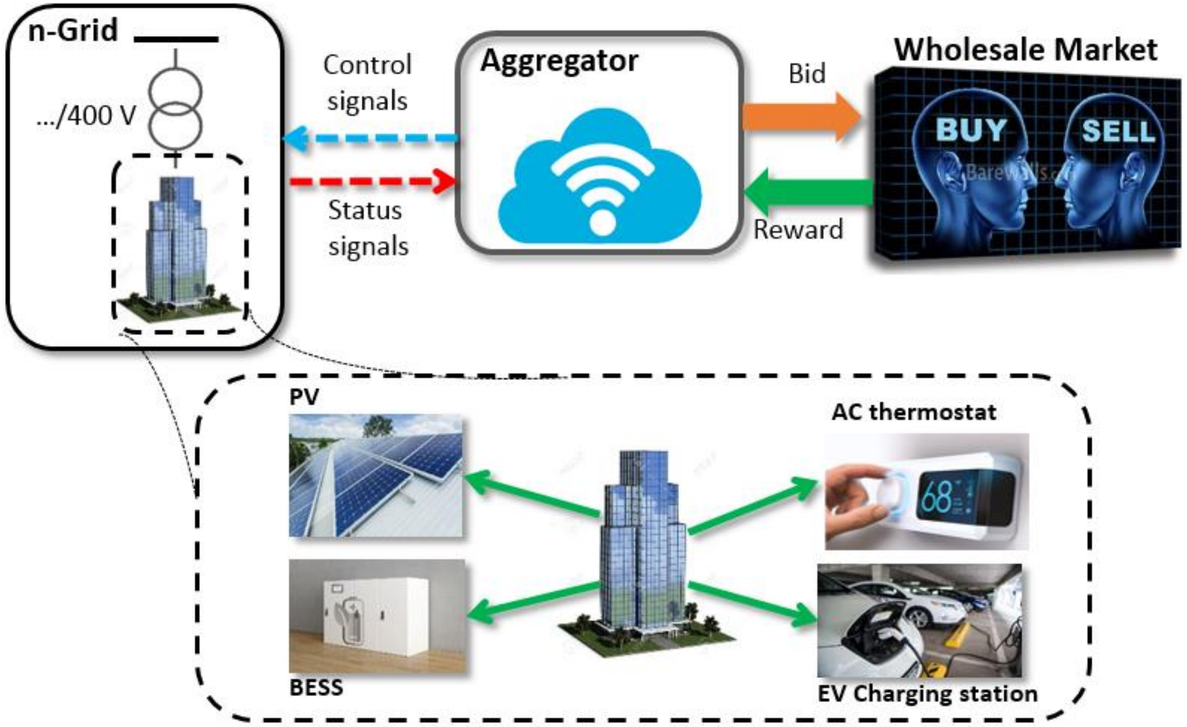


Fig. 3. The n-Grid aggregator framework for participation in WSM.

Weather-related Outages

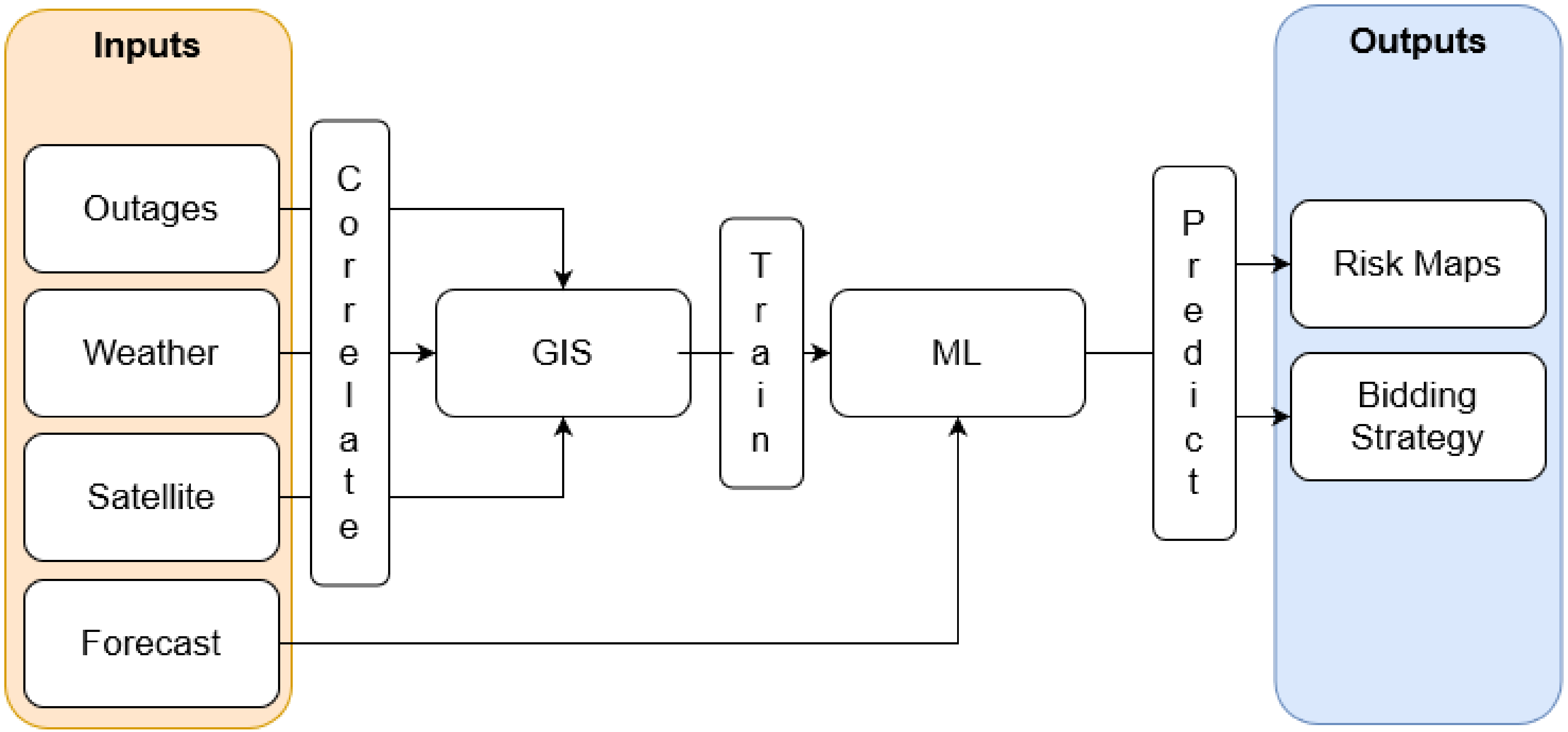
Problem

- Short Circuits are major cause of outages in the system
- Weather related outages are on the rise

Solution

- Correlate historical outages, weather forecast, satellite imagery etc.
- Train ML algorithm (gradient boosting)
- Predict risk levels in the network
- Optimize bidding strategy

Spatiotemporal Correlation



The process is outlined on the diagram

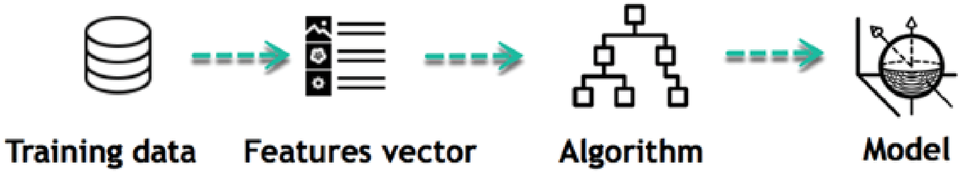
Basics of ML

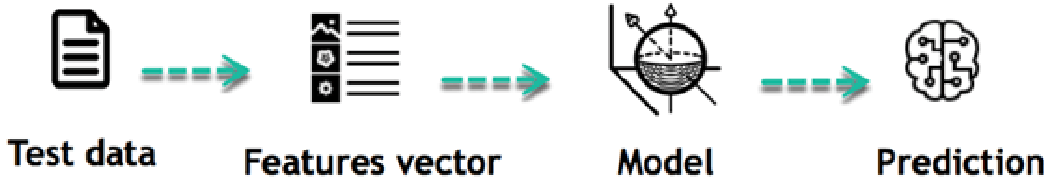
- Get Data
- Clean, Preprocess, Wrangle Data
- Train model, calculate performance metrics
- Test model
- Improve and Update

Objective:

Find parameters Θ of some function f that approximates target variable y by minimizing the loss function J

$$\arg\min_{\theta} J(y, f(X; \theta))$$

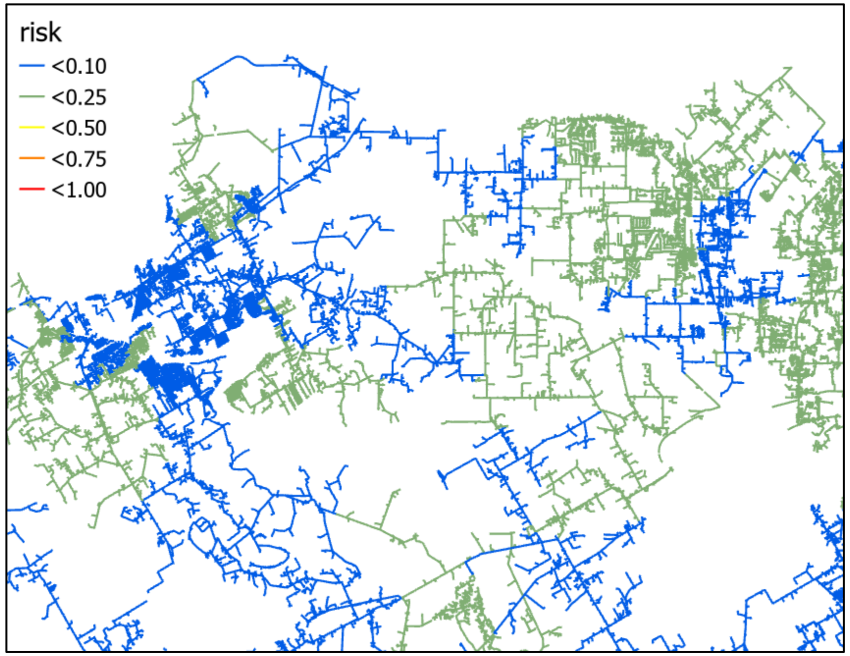




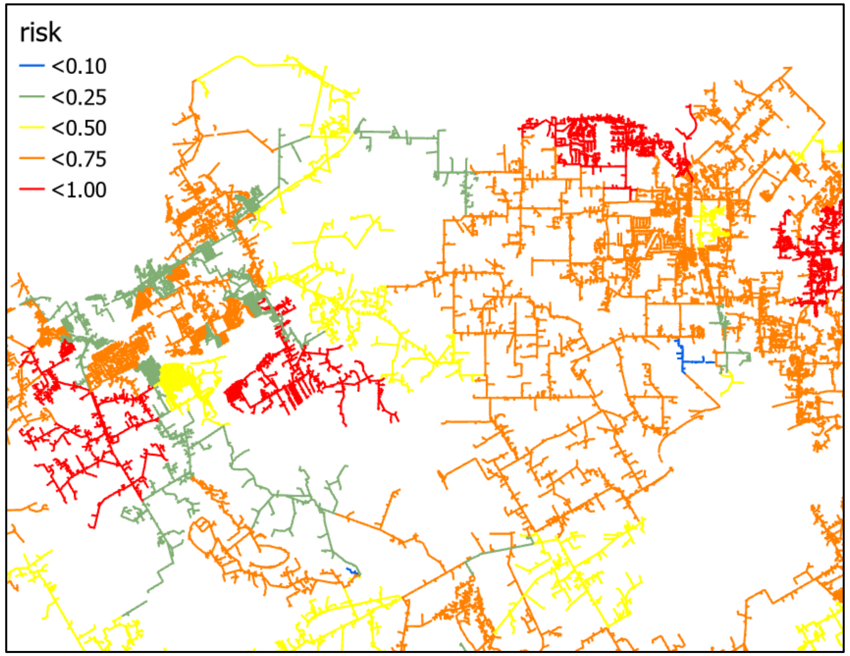
Source: https://www.guru99.com/machine-learning-tutorial.html

Risk Maps

- Algorithm outputs risk maps
- Allows operators to assess the situation immediately



Low Risk



High Risk

Node Availability Computation

1- Pick up l^p number of the feeders with highest probability of failure at each hour.

2- Generate feeder states with the combination of failures up to n^{out} simultaneous outages. Total number of feeder states will be: $\binom{l^p}{0} + \binom{l^p}{1} + \cdots + \binom{l^p}{n^{out}}$.

3- For each feeder state, determine the grid state. A grid state is an array of length N (number of nodes) showing the availability of each grid node.

4- By doing so for all the feeder states, we will derive $S \times N$ grid state matrix denoted by GS and a $S \times 1$ grid state probability matrix denoted by GSP, where S is the total number of unique grid states and N is the total number of nodes.

5- Normalize the elements of GSP matrix so the summation of probabilities becomes 1.0.

6- The matrix of availability of nodes can be calculated by $[PR^n] = [GS]^T [GSP]$.

Bidding Adjustment

$$F = \max \sum_t \left(prof_t^{p,da} + prof_t^{sr,da} + prof_t^{p,rt} + prof_t^{sra} \right)$$

$$prof_t^{p,da} + prof_t^{p,rt} = p_t^{da}\lambda_t^{p,da} + \Delta p_t^{rt}\lambda_t^{p,rt} = p_t^{da}\lambda_t^{p,da} + \left(p_t^{rt} - p_t^{da}\right)\lambda_t^{p,rt}$$

$$= p_t^{da}\left(\lambda_t^{p,da} - \lambda_t^{p,rt}\right) + \lambda_t^{p,rt}\int_{-\infty}^{+\infty} pr^p . \tilde{p}_t^{rt} . dp = p_t^{da}\left(\lambda_t^{p,da} - \lambda_t^{p,rt}\right) + \lambda_t^{p,rt}\sum_s pr_{s,t} . p_t^s$$

$$= p_t^{da}\left(\lambda_t^{p,da} - \lambda_t^{p,rt}\right) + \lambda_t^{p,rt}\sum_n pr_{n,t} . p_t^n$$

Subject to technical constraints of EVs, BESSs and Loads

Case Study and Simulation Results

- ➢ Each node contains 100 n-Grids with PV, BESS and EV charging stations.
- ➢ We assume the outage probability of each line at hours 9 and 15 is 0.2 and for the rest of time-steps is 0.
- ➢ The priority of n-Grids when disconnected from the grid is to supply their own load.

We compare two test cases:

- ❑ TCI: The proposed model in which the probability of weather-related feeder outages is considered,
- ❑ TCII: A deterministic model in which the probability of feeder outages is ignored.

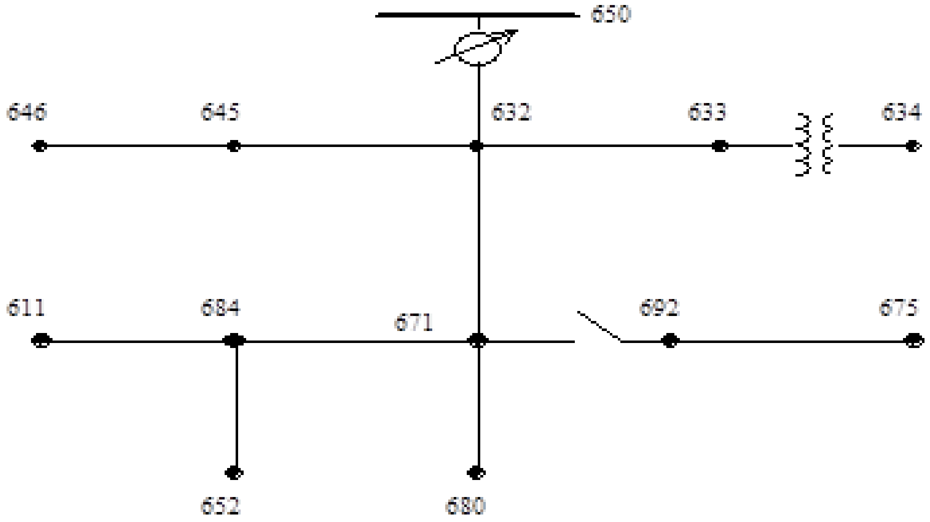


Figure 4 The IEEE 13-bus radial distribution test system topology.

Case Study and Simulation Results

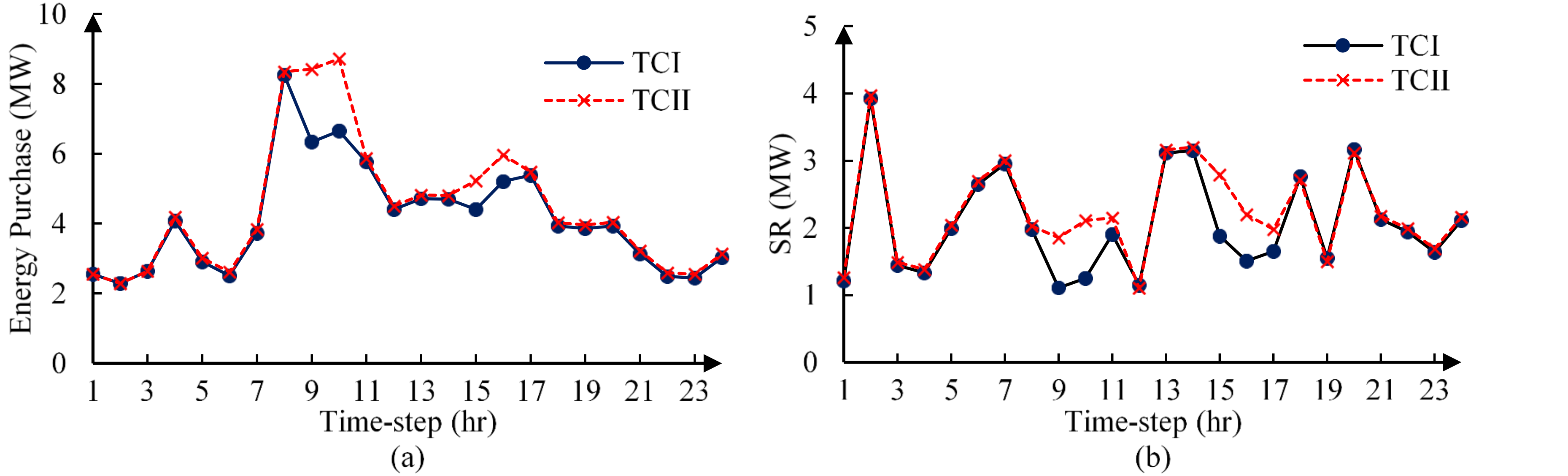


Figure 5 Energy purchase and SR procurement in TCI and TCII.

- The faults are forecasted to occur at hours 9 and 15.

✓ In TCI, the aggregator purchased less energy during and after these hours.

✓ Ignoring the probability of outages in TCII, has led to over-procurement of SR at hours 9-11 and 15-17.

Case Study and Simulation Results

Table 2. Profit and Penalties in TCI and TCII (k$)

Test Case	Energy cost DAM	Energy cost RTM	Profit SR	Penalty SR	Profit SRA	Penalty SRA	Total Cost
TCI	20.51	2.55	3.09	0	0.7	0	19.27
TCII	21.84	1.62	3.13	0.94	0.72	0	20.55

- Ignoring feeder outages has led to the excessive purchase of energy in DAM, in TCII.
- Lower penalty of spinning reserve and much higher profitability by considering feeder outage probabilities in TCI.

Conclusion and Acknowledgement

Conclusion:

- DERs are eligible resources for trading energy and procuring ASPs to the WEM.
- We assessed the impacts of weather-related outages on DER participation in the WEM.
- The simulation results demonstrated the vital necessity of considering the probability of distribution feeder outages in DER scheduling.
- In our case study, it is observed that such a framework has raised the total SR profit by ~29.3% and reduced the total costs by ~6.3%.

Acknowledgement:

➢ This material is based upon work supported by the Department of Energy, Office of International Affairs and Office of Electricity under Award Number DE-IA0000025. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.