Evaluating Grid Resilience: Strategic Backup Using Solar and Battery Storage

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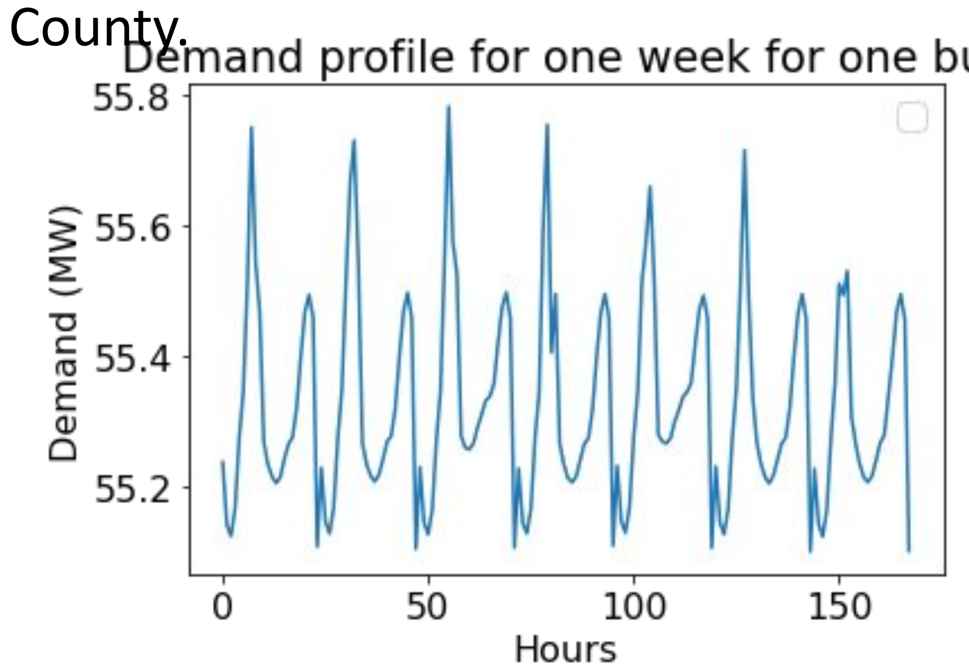
Introduction

According to a study published by Climate Central, 61% of all major outages in California between 2000-2023 were caused by extreme weather events. Our project seeks to investigate the efficacy of integrating solar and storage systems at certain substations within the network to maintain power supply to unserved loads during outages caused by these events. We aim to achieve the following goals:

- Simulate faults and assess impacts on the default IEEE 57-bus power system
- Retrofit the network with temporal load profiles, solar generation, and battery storage
- Simulate branch faults and create a nodal admittance matrix for each fault
- Optimize under different faults and configurations

Model and Dataset

The IEEE 57-bus network has **57 buses, 7 generators, 80 branches and 42 load nodes**. We utilize the Thorve et al. 2023 study on residential use profiles in the United States to gather the load profile data. We find that around 67% outages occurred during the summer months between June and September from 2014-2019. For the initial set of experiments, we take into account the load profiles for only one week of July for the model optimization. For solar data, we use the NREL's PVwatts Calculator filtered to Santa Clara County.



Methodology

We formulate a DCOPF linear optimization problem in CVXPY to solve various grid fault scenarios.

$$\text{Minimize} \quad \sum_{t=1}^{T} \left(\sum_{i=1}^{N} C_i \cdot P_{g_i}(t) \right)$$

Power Balance Constraint

$$P_{g_i}(t) - P_{d_i}(t) - P_{s_i}(t) - P_{b_i}(t) = \sum_{j=1}^{N} B_{ij}(\theta_i(t) - \theta_j(t)), \quad \forall i$$

Generation Constraint

$$P_{\min_i} \le P_{g_i}(t) \le P_{\max_i}, \quad \forall i$$

Line Flow Limit Constraint

$$|B_{ij}|(\theta_i(t) - \theta_j(t)) \le line\_Limit_{ij}, \quad \forall (i,j)$$

Storage State of Charge and battery Constraints

$$Min\_SOC \le E_i(t) \le Max\_SOC, \quad \forall i$$

$$-charge\_rate \le P_{b_i}(t) \le discharge\_rate \quad \forall i$$

$$E_i(t) = E_i(t-1) + P_{b_i}(t)/Capacity_b$$

Reference bus constraint

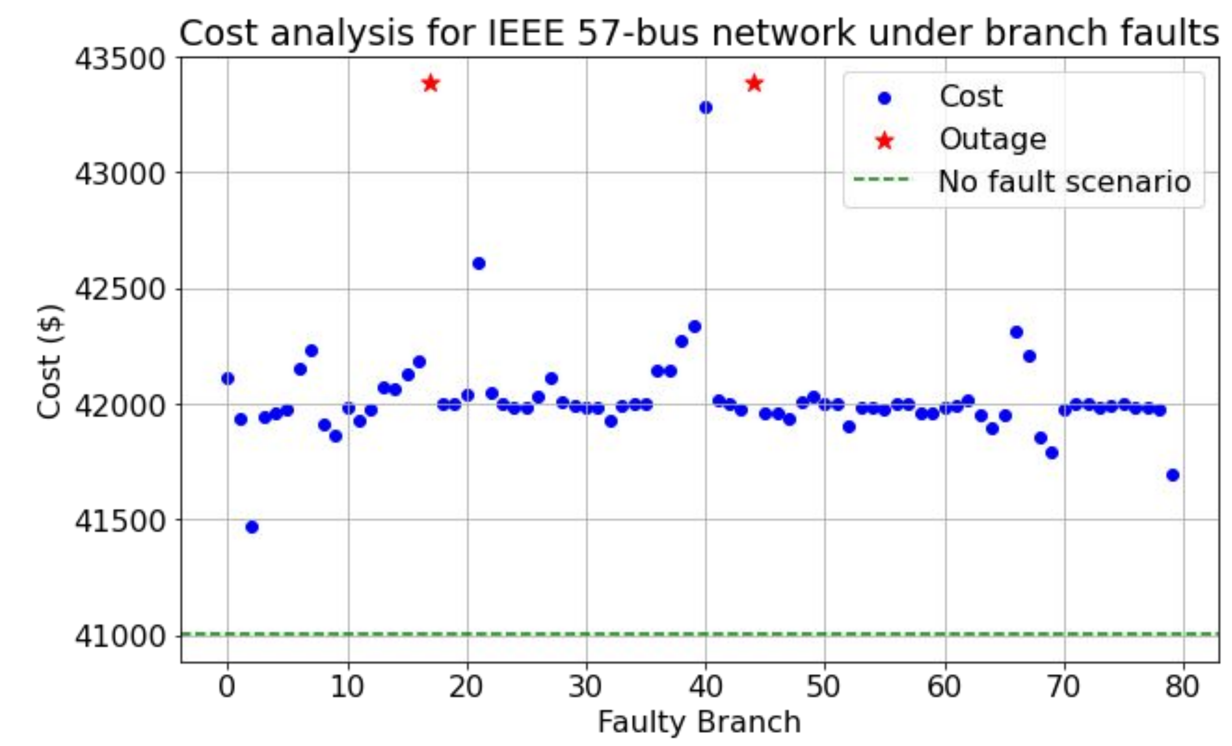
$$\theta_0(t) = 0$$

Additional Assumptions:

1. IEEE 57-Bus network doesn't have line limits. We assume the limits to be 100 MW based on demand-capacity and relevant literature.
2. For generation pricing, we assume peak price = 300 \$/MWh during 3PM-9PM and off-peak price = 150 \$/MWh for the rest.
3. Even though, in case of an extreme weather event, more than one branch can possibly become faulty, we only assume one faulty branch per scenario for simplicity.
4. In our experiments, we only place solar + storage systems at generator nodes.

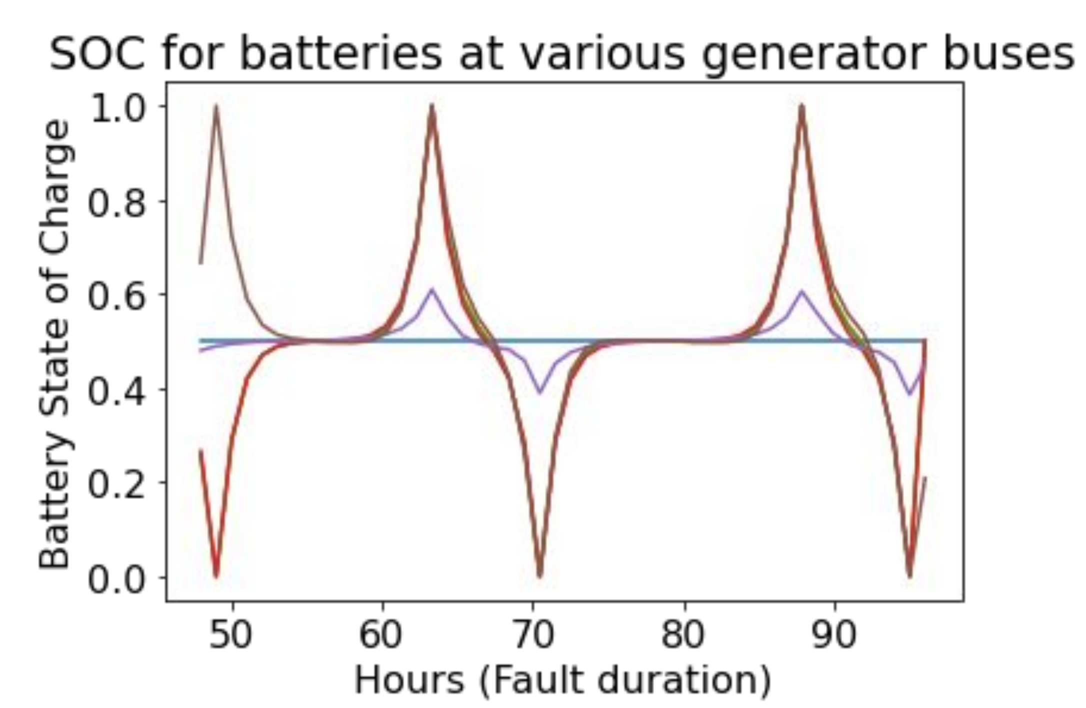
Experiments and Results

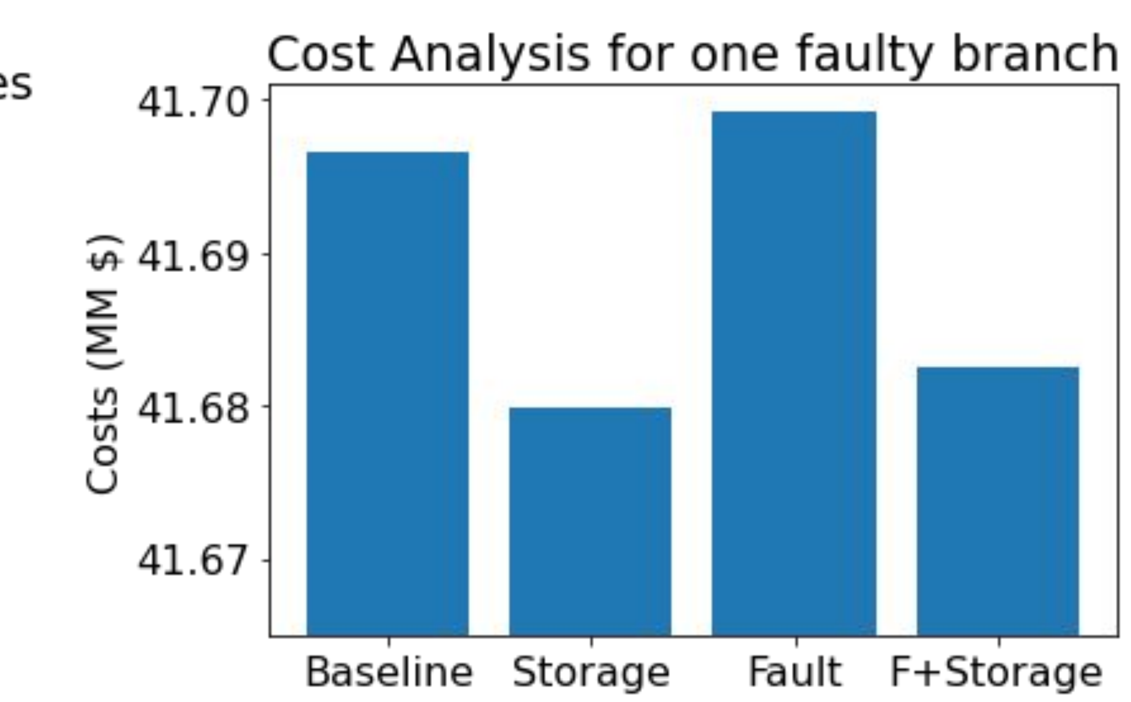
We run first set of experiments on the default IEEE network. The data is only for one snapshot in time. There are 80 branches in the network. We simulate faults on each branch one by one, create a nodal admittance matrix and solve a DCOPF problem.



The plot shows the optimal cost values for each of the fault scenarios. The green dotted line represents no fault scenario. Not only we experience cost increment during various faults, two branches can potential cause an outage.

As the next step, we retrofitted the network with hourly load profiles and solar at the generator nodes for 168 hours i.e. one week. For our analysis, we simulated an outage for 48 hours in the middle of the week and analyzed the cost savings. For our simulated branch fault (Bus 36 and Bus 40), the solar plus storage (3 MWh energy capacity) can reduce the total weekly cost by ***16,720 \$***.





Conclusion & Next Steps

We show that the installation of solar storage systems is contributing to significant cost savings both under normal operating conditions and during faults. With the current storage capacity, the payback period is approximately **1.3 years.** Our next steps include conducting additional sensitivity analyses, examining the impact of faults over various durations during the week, simulating faults over cascading branches, and varying battery sizes.