Reliability-Driven Optimum Standby Electric Storage Allocation for Power Distribution Systems

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Outline

- Introduction
- Study Approach
- Case Study
- Results
  - Base Case
  - Impact of Standby Electric Storage
    - Reliability
    - System Cost
  - Optimum Standby Electric Storage Capacities
- Conclusion

Introduction

- Significance of Power System Reliability:
  - Aging power system infrastructure
  - Fast load growth
  - High customer expectations
  - Sensitive electronic devices
  - Integration of intermittent power generation
- Power System Reliability:
  - Generation
  - Transmission and substation
  - Distribution (85% of outage hours)
- Distribution System Reliability Evaluation
  - System indices
  - Load-point indices

Introduction

- Integration of Distributed Energy Resources (DER) in Distribution Systems
  - Distributed generation (wind, solar, etc.)
  - Energy storage (battery, etc.)

- Standby Electricity Storage System
  - Decrease in load interruption
  - Improvement of power restoration

Study Approach

Data Acquisition

Load Flow Study:
- Network topology and capacities.
- Impedances of lines and transformers.
- System load curves.
- Location and primary capacities of DER.

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Reliability Study:
- Failure rates of system components.
- Repair durations of system components
- Location of the protection devices.
- Interruption cost function.

Initial Processing

Define load states based on the load curves

Define the outage contingencies based on the failure data

Standby Storage Capacity Optimization

Reliability Evaluation (State Enumeration)

For each contingency, perform the following steps:
- Clear the fault and isolate the faulted component.
- Try to restore the loads by doing system reconfiguration.
- Run the load flow study on the distribution system.
- Identify possible overloads and voltage violation and do load shedding.
- Take the system back to its normal configuration after the contingency.

Calculate the reliability indices for:
- The DER connected load points.
- The distribution system.

Calculate the Total Cost = standby storage cost + interruption cost

Sensitivity Analysis:
- Sensitivity of the Total Cost to standby storage capacity at individual DER connected load points.

Particle Swarm Optimization:
- Determine the optimum the set of standby storage capacities which minimize the Total Cost.

Study Approach

- Objective Function:

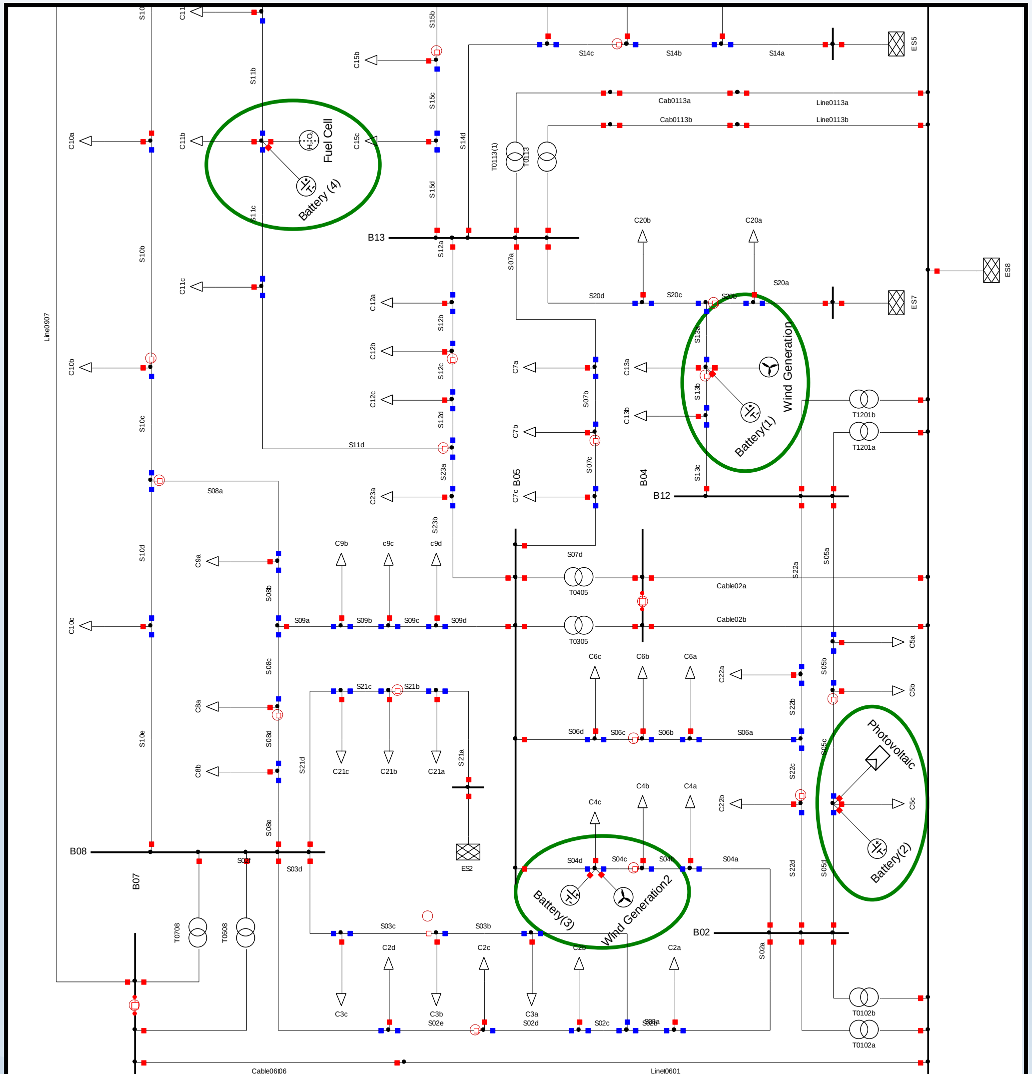
$$Total\ Cost = EIC + \sum_{k=1}^{N} C_{store}(Cap_{L_k})$$

- Subject to (for each contingency):

$$\mathrm{V}_{\mathrm{n,min}} < V_{\mathrm{n}} < \mathrm{V}_{\mathrm{n,max}} \quad : \mathrm{n} = \{1,2,3, \dots \mathrm{N_B})$$

$$\mathrm{P}_{m} < \mathrm{P}_{m,\mathrm{max}} \quad : \mathrm{m} = \{1,2,3, \dots \mathrm{N_{Lines/Transformers}})$$

Case Study



Distribution System with Four Integrated DER

Case Study

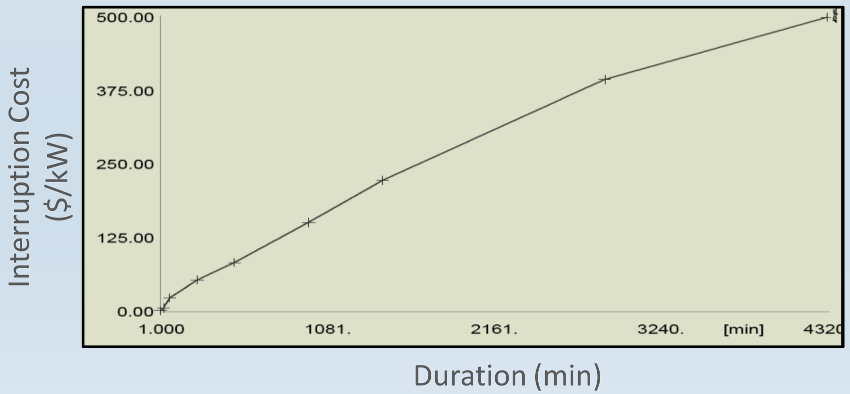
- Input Data:

Distribution System Statistics

No. of busbars	86
No. of lines	92
No. of transformers	13
No. of loads	56
No. of customers at LP1	440
No. of customers at LP2	460
No. of customers at LP3	320
No. of customers at LP4	60

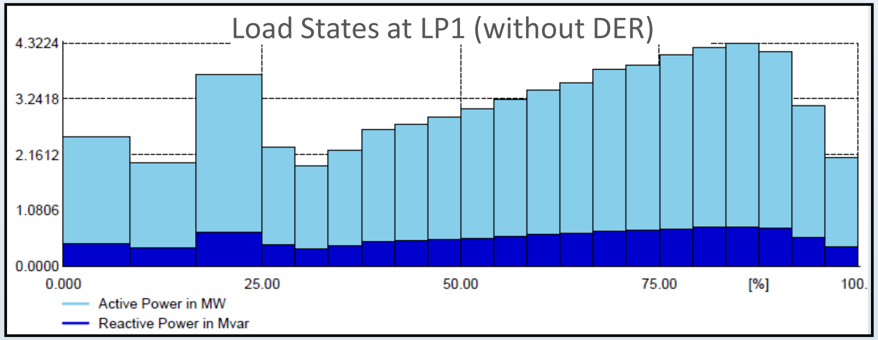
Failure and Repair Data

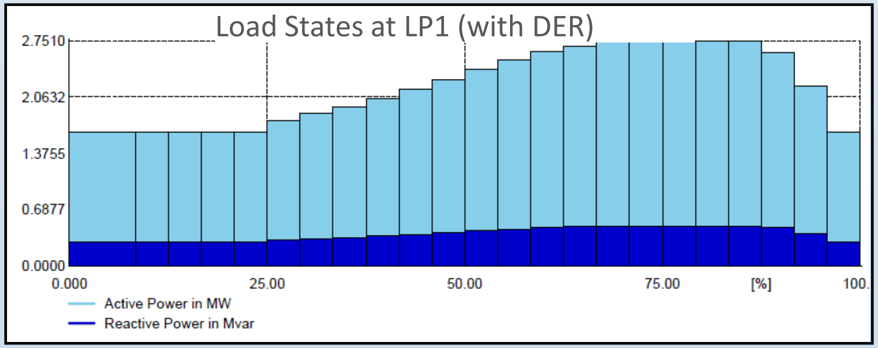
Component	Failure rate	Repair duration
Underground Cables	0.01/(km, year)	128 hrs
Overhead Lines	0.015/(km, year)	54 hrs
Power Transformers	0.006/year	116 hrs
11kV Busbar	0.009/year for terminal; 0.015/year per connection	7 hrs
33kV Busbar	0.006/year for terminal; 0.015/year per connection	12 hrs



Case Study

- Load Flow Data:





Load Flow Results

Parameters	Without DER	With DER (Base Case)
Peak Load at LP1	4.32 MW	2.75 MW
Peak Load at LP2	3.98 MW	2.53 MW
Peak Load at LP3	2.77 MW	1.76 MW
Peak Load at LP4	0.52 MW	0.33 MW
Total System Peak Load	53.4 MW	48.4 MW
Total System Power Loss	1.4 MW	1.15 MW

Results

- Base Case:
  - System Reliability Indices

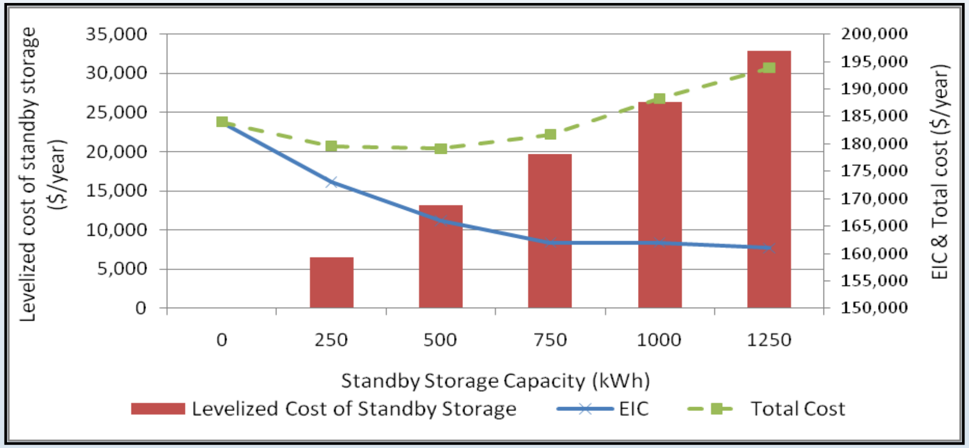
System Reliability Indices (Base Case)				
SAIFI 1/(customer, year)	SAIDI hrs/(customer, year)	ASAI	EENS (MWh/year)	EIC (k$/year)
0.46	4.02	0.99954	145.5	184

  - Load Point Reliability Indices

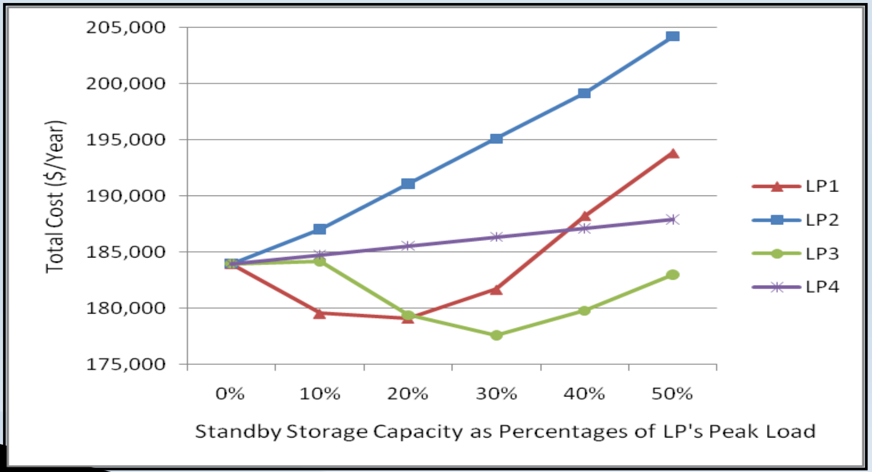
Location	Load Point Reliability Indices (Base Case)			
	LPIF (1/year)	LPIT (hrs/year)	LPIC (k$/year)	LPENS (MWh/year)
LP1	0.47	3.39	30	8.9
LP2	0.34	3.11	16.2	7.5
LP3	0.36	2.63	7.78	4.3
LP4	0.58	5.24	0.5	1.8

Results

- Impact of Standby Electric Storage at LP1

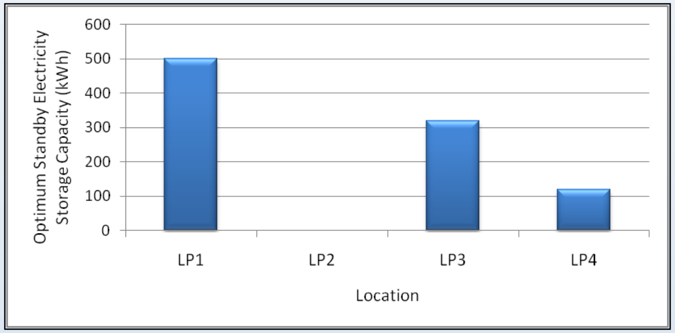


- Impact of Standby Electric Storage at LP1-LP4



Results

- Optimum Standby Storage Capacities



- Load Point Reliability Indices with Optimum Capacities

Location	Load Point Reliability Indices (With Optimum Standby Storage Capacities)			
	LPIF (1/year)	LPIT (hrs/year)	LPIC (k$/year)	LPENS (MWh /year)
LP1	0.47	3.1	20	5.8
LP2	0.34	3.05	16.1	7.35
LP3	0.36	2.62	5.4	3.1
LP4	0.53	4	0.2	0.6

Conclusions

- Optimum Capacities of Standby Electricity Storage system
  - Reliability analysis
    - State enumeration
    - Power flow
  - Particle swarm optimization method

- To Minimize:
  - system cost of interruption + Cost of standby storage capacity

- The Total Cost Dropped by 10% with the Optimum Capacities
- Standby Electricity Storage Could be Cost Effective

Thank You

- Question ?