Outage Modeling of Expansion Planning Problems of Power Systems

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Introduction

- **Expansion planning problems** refer to the monetary and unit investment ragarding energy production or storage.
- Stochasticity is inherent: generation output of renewables, load demand, climate change, **frequency and duration of outages**, etc.
- Outage modeling has remarkable impacts on designing systems, for example, **microgrids**.
- In most of current studies, a single statistical distribution is used for outage modeling, like a **Poisson process**.
- We attempted to relax this assumption by proposing an **alternative outage model**.
- The scheme is based on the premise that outages are classified into **two categories**: regular and severe.
- A **reinforcement learning** approach is applied to solve the expansion planning problem.
- The objective is to derive the **optimal storage expansion plans** for a specific microgrid in a predetermined time horizon.

Nomenclature

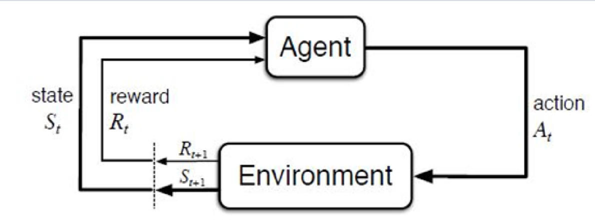
S	State set
A	Action set
f	Transition function
R	Reward function
S^{tf}	Timing feature of the state set
S^{ef}	External feature of the state set
S^{if}	Internal feature of the state set
K	Number of decision periods
SU	Set for available storage units
SC	Set for characteristics of storage units
SL	Set of available storage capacity levels
G	Set of facilities in the microgrid
δ	Indicator function for lost demand
C_p	Critical load factor
$P_{annuity}$	Annual investment payment for storage units, $
y	Number of years in the decision period, yrs
D	Load demand, kWh
T	Grid outage duration, hrs
$CAIDI$	Average interruption duration, hrs/interruption
$VOLL$	Value of lost load, $/kWh

Methodology

MDPs and Reinforcement Learning

The problem is solved using a variant of Q-learning algorithm.

The MDP formulation is provided [1]:



$$S = S^{tf} \times S^{ef} \times S^{if}$$

where:

$$s^{tf} \in S^{tf} = \{1,2,...,K\}$$

$$\vec{s}^{\,ef} = \left(s^{ef}_{i,j}, \forall i \in SU, j \in SC\right) \in S^{ef}$$

$$\vec{s}^{\,if} = \left(s^{if}_{i}, \forall i \in SU\right) \in S^{if}, \;\; \forall i \in SU, s^{tf} \in S^{tf}$$

$$\vec{a} = \left(a_{i,l}, \forall i \in SU, l \in SL\right) \in A$$

s.t.

$$a_{i,l} \in \{0,1\}, \forall i \in SU, j \in SL$$

$$\sum_{i \in SU, l \in SL} a_{i,l} \in \{0,1\}$$

$$r_k(\vec{s},\vec{a}) = -\sum_{i \in SU}\sum_{l \in SL}(K-k+1)\,y\,a_{i,l}\,P^{i}_{annuity} - \sum_{g \in G} VOLL^{g} \sum_{j \in N_k}\sum_{i \in O_{jk}} \delta(t_{ijk},g)\,C_p^{\,g}\,D(t_{ijk},g)$$

Two outage modeling approaches: Single Poisson Process vs. Superposed Poisson Process

Year	2012	2013	2014	2015	2016	2017
CAIDI (hrs/int)	22.55	1.65	1.42	1.95	1.46	1.70

Table 1 CAIDI data provided by NY State for PSEG-L, years 2012-2017 [2]

- *Single Poisson Process*: $\{N(t), t \in [0,+\infty)\}$ with rate λ. The number of outages at any time τ follows Poisson distribution with a rate $\lambda\tau$.
- *Superposed Poisson Process*: $\{N'(t) = N_1(t) + N_2(t)\}$ with rate $\lambda = \lambda_1 + \lambda_2$ where $\{N_1(t), t \in [0,+\infty)\}$ with rate λ_1 is a Poisson process for the regular outage events,. $\{N_2(t), t \in [0,+\infty)\}$ with rate λ_2 is a Poisson process for the severe outage events. Let $\Pr\{Z_n = i\} = \frac{\lambda_i}{\lambda}$ where Z_n is the type of the n^{th} event, $i \in \{1,2\}$.

Case Study

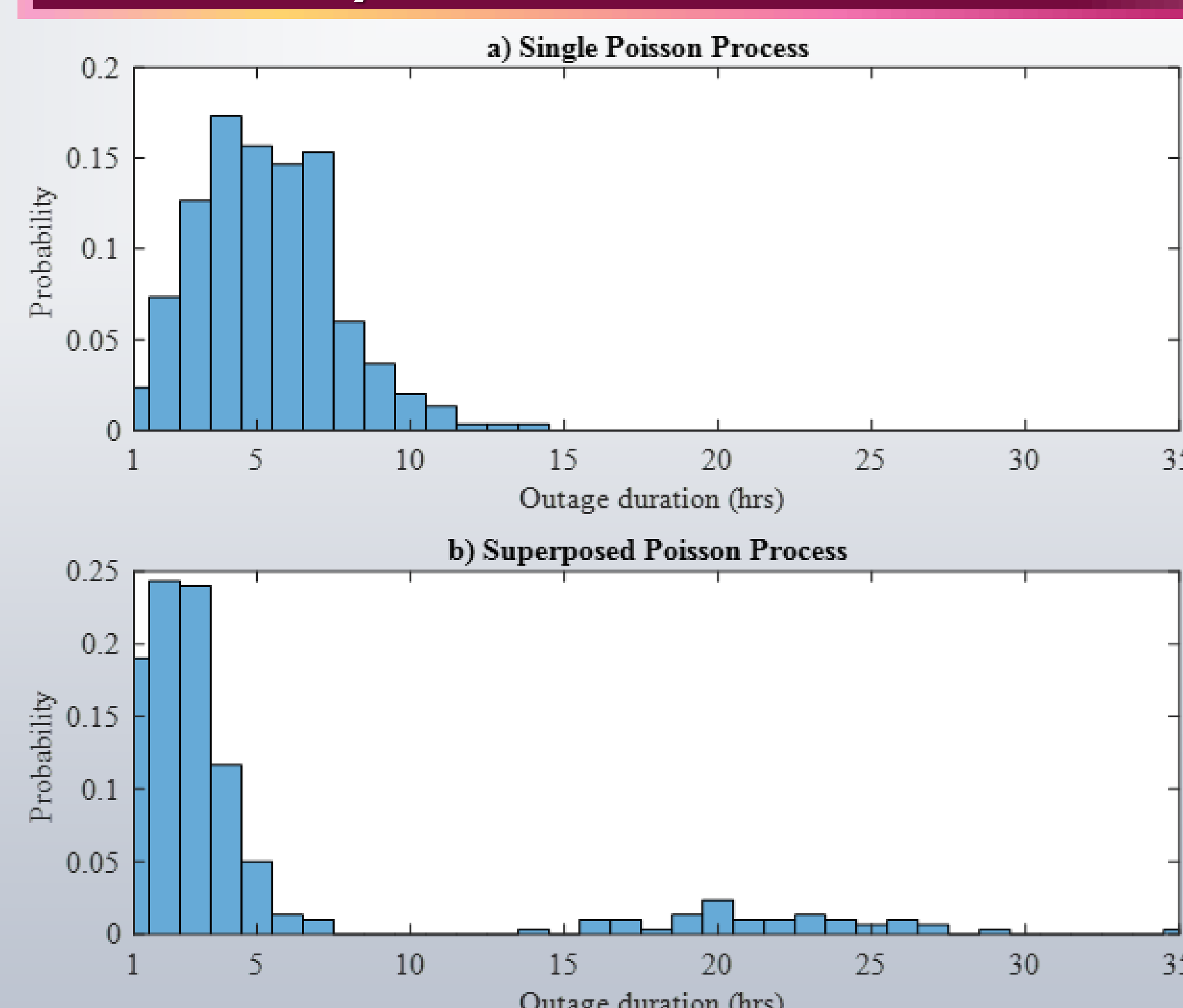


Fig. 1 Distribution of outage duration using two different probabilistic modelling approaches

Major difference!

- Mean duration is the same
- Distribution is not!

A case study for a microgrid in Westhamption, NY is conducted [3].

Numerical assumptions

- The microgrid consists of 2 hospitals, 5 schools and 300 residential facilities
- 4 storage options existing in *SU*: lithium-ion, lead-acid battery, vanadium redox battery and flywheel storage
- Options to install at one of three predetermined levels (300, 1000, 3000 kWh)
- The considered stochastic component is the price of the storage unit, modeled by a DTMC

Results

Discrepancies in both timing and level of investments

- The experiment is implemented twice with identical parameters, except the outage model
- Storage unit prices are declining for both scenarios
- Optimal policies differ significantly
- 7000 kWh total storage capacity in Single PP, 4000 kWh in Superposed PP
- First investment happens one period earlier in Single PP scenario

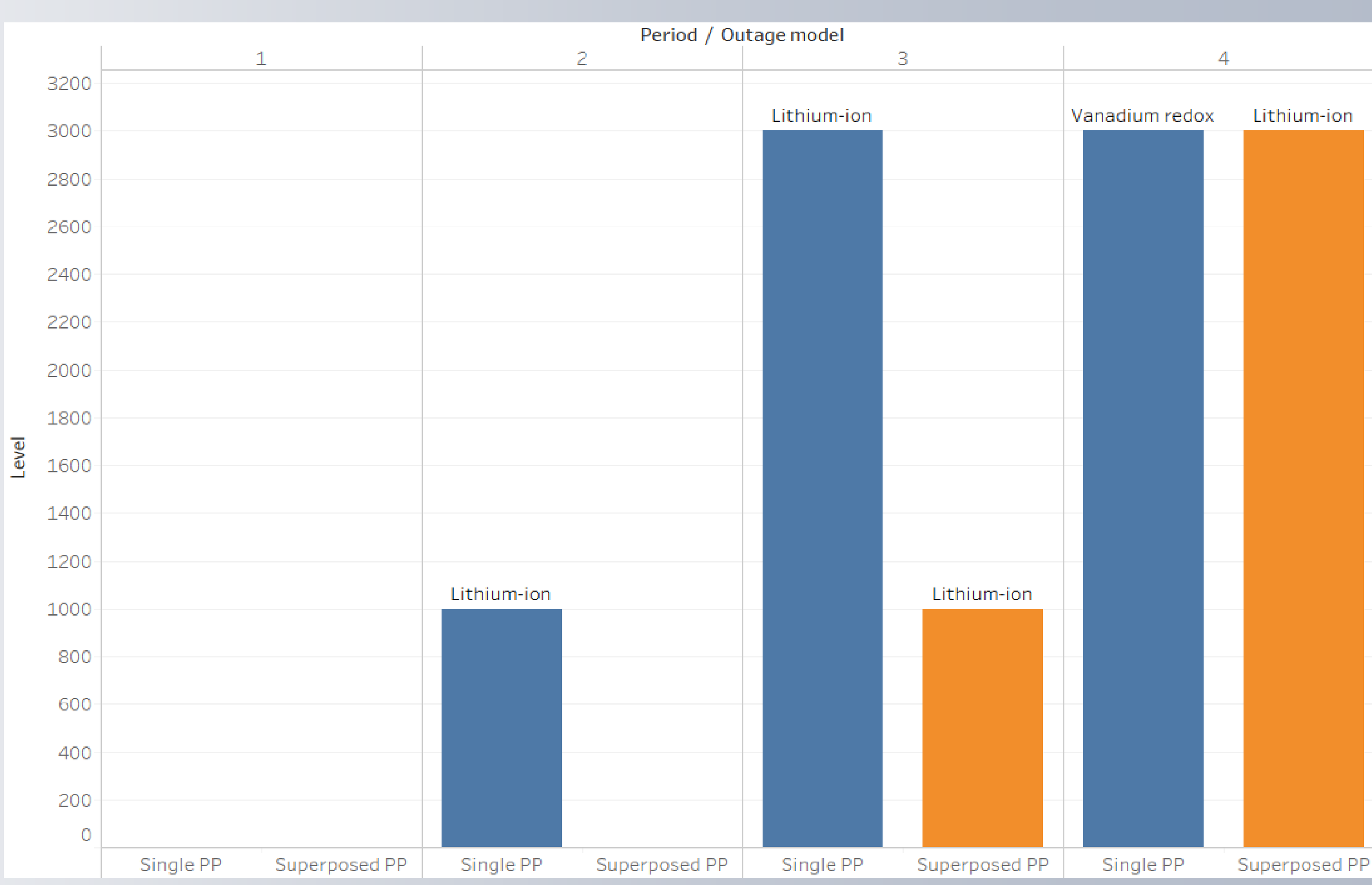


Fig. 2 Optimal policies for both outage models

Conclusions

- In the superposed PP scenario, the vast majority of outages are not long-lasting and can be handled with a moderate amount of storage capacity.
- This could be the underlying reason behind the research findings presented here (timing and level differences).
- The focus of this study is to highlight the importance of analytical and accurate outage modeling, specifically tailored for microgrid applications.
- An open research question is how to derive ways to optimally mitigate the impacts of catastrophic events.

References

1. S. Tsianikas, N. Yousefi, J. Zhou, M. Rodgers, and D. Coit. (2020), A sequential resource investment planning framework using reinforcement learning and simulation-based optimization: A case study on microgrid storage expansion. Available: https://arxiv.org/abs/2001.03507
2. D. o. P. Service, "Electric Reliability Performance Report," 2018
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