Data-Driven Techno-Economic and Resilience Analysis of Community Energy Storage

Rodrigo D. Trevizan*, Alexander J. Headley†, Tu A. Nguyen*, Alvaro F. Bastos*, Henry Guan*, and Stanley Atcitty*

*Sandia National Laboratories, Albuquerque, NM, †University of Memphis, Memphis, TN

Abstract: Several Native American reservations in the United States are located in sparsely populated areas, where the cost of electricity is relatively high and system reliability is substandard. In line with the tribal traditional values of self-determination, many of these communities are seeking energy independence. This paper presents an analysis of the benefits that energy storage systems (ESSs) can provide to a small community that plans to develop a microgrid with local solar photovoltaic (PV) generation. More specifically, this work presents a method for estimating resilience improvements that a given ESS and PV system can provide, and how to size the system using load and solar generation data. Furthermore, the ESS is sized to maximize the economic benefit provided by trading energy with a neighboring electric power utility.

Introduction

- Community energy storage systems (CESS) are owned and controlled by a community, typically in the power distribution grid or to consumers' premises
- Provide grid services and economic benefits to stakeholders
- Serve a wide variety of groups, including urban neighborhoods, tribal communities, and energy cooperatives
- Very often tribal communities operate in isolated power systems or in remote areas with low levels of reliability
- Sizing and estimating the value provided by CESS can be done through mathematical optimization
- We present data-driven methods for valuation and resilience benefits from CESSs for grid-connected microgrids.
- These methods are demonstrated in a case study for a tribal community that seeks economic benefits, improved reliability, and energy independence.
- The techno-economic analysis of a CESS integrated is evaluated using a Mixed Integer Linear Program formulation where the revenue stream from the CESS are energy cost savings.

Project Goal:

- Perform a valuation study to ensure that well-informed energy project decisions can be made These methods are demonstrated in a case study for a tribal community that seeks economic benefits, improved reliability, and energy independence.

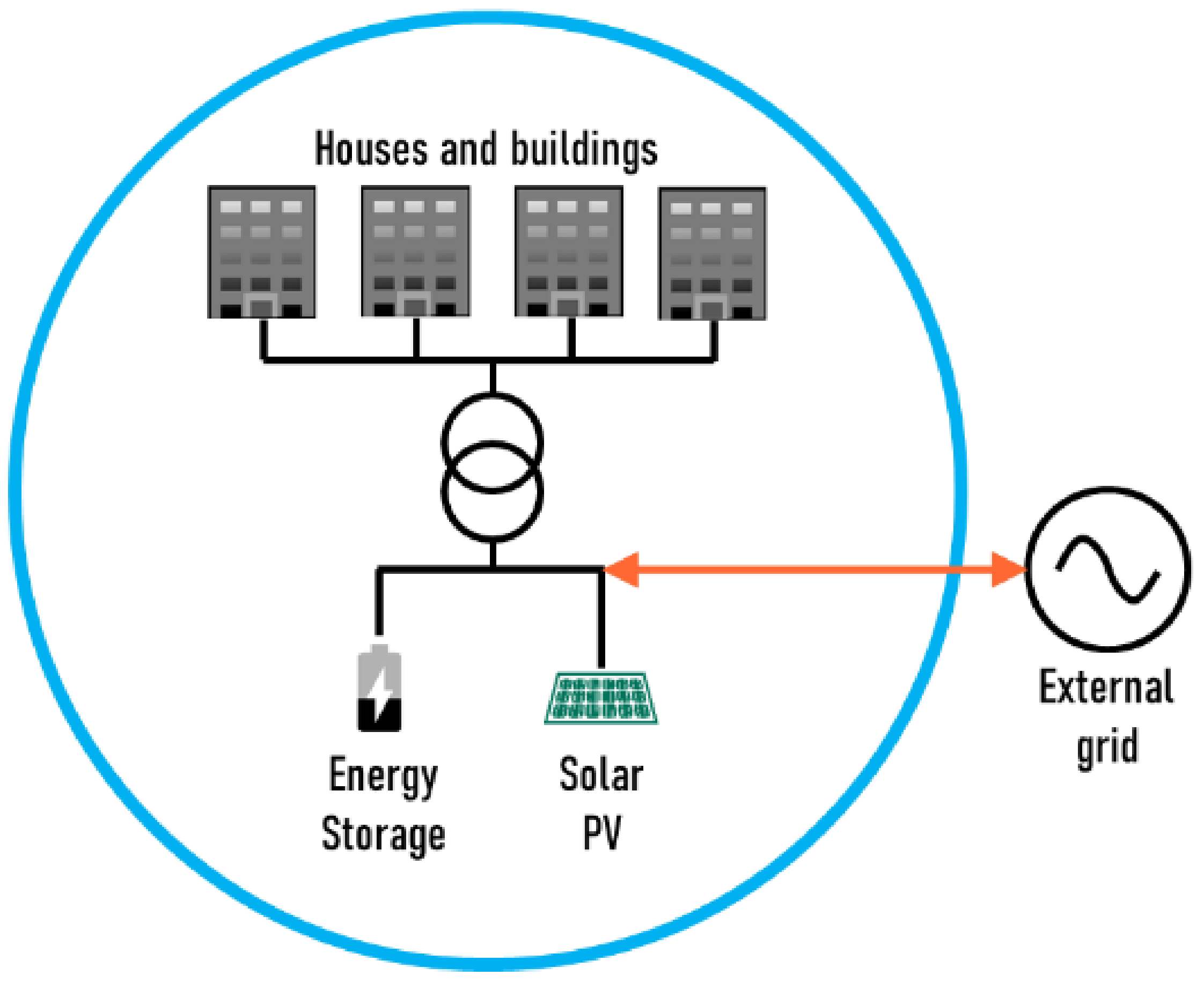

Fig. 1 The tribal microgrid serves its loads with a CESS, 1 MW of solar PV generation, and through power exchanges with the external grid.

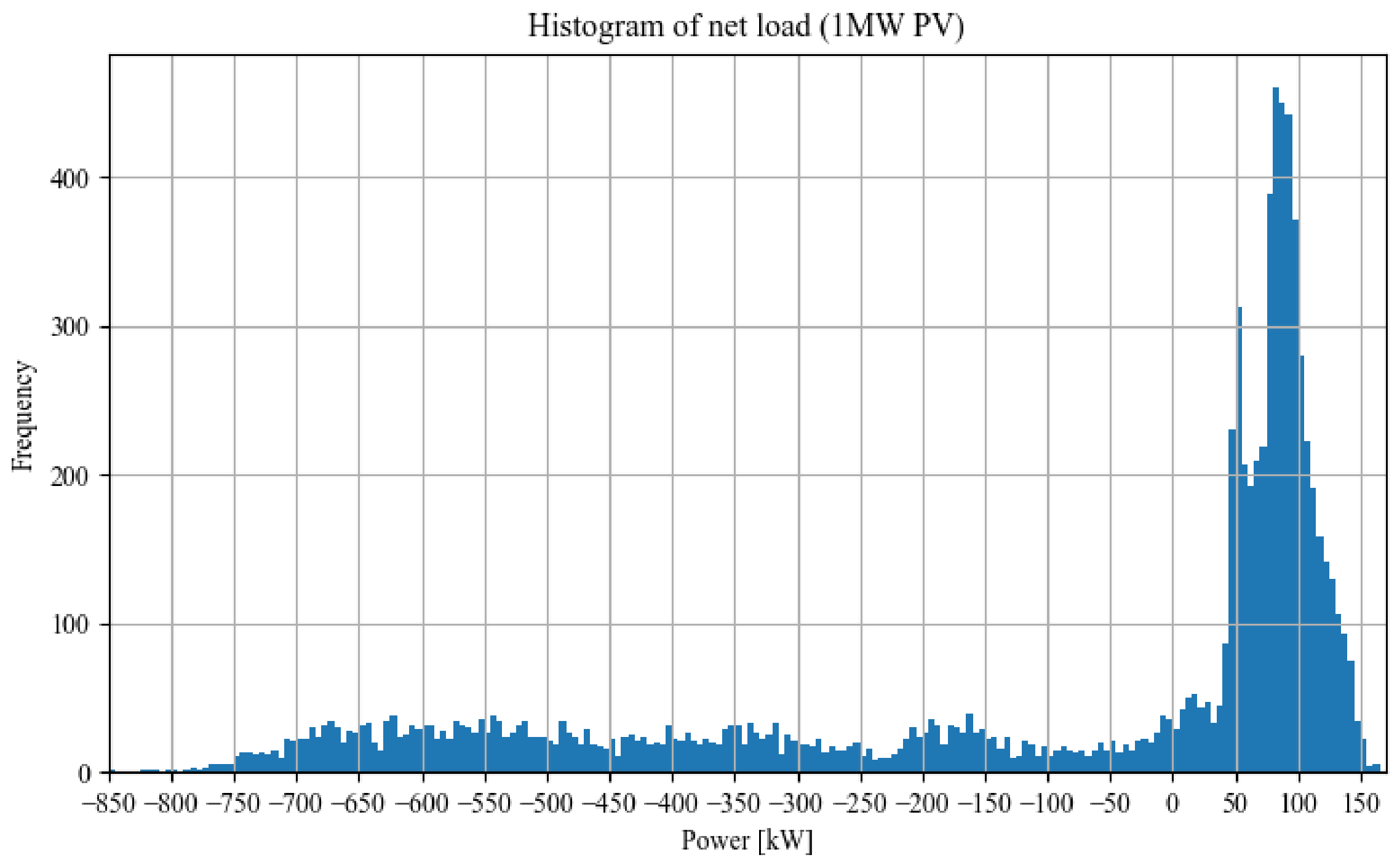

Fig. 2 Histogram of the microgrid's net load without CESS.

Assumptions

- CESS round trip efficiency: 86%[1]
- CESS throughput is less than the equivalent of 3,500 cycles at 80% depth of discharge over its life (10 years)[1]
- CESS and photovoltaic (PV) array are AC connected
- CESS costs from pricing survey/projections[1]
- Historical monthly energy (kWh) for 2 years is known and assumed constant over 10 years
- Interest rate of 3% per year
- 7% annual peak load growth
- Grant might be available to cover capital costs
- Time between failures to follow an exponential function with mean equal to the number of hours in a year divided by the SAIFI
- The backup power system must be capable of

  i) supplying the demand at any time, as well as

  ii) providing backup time for the load considering a desired reliability level

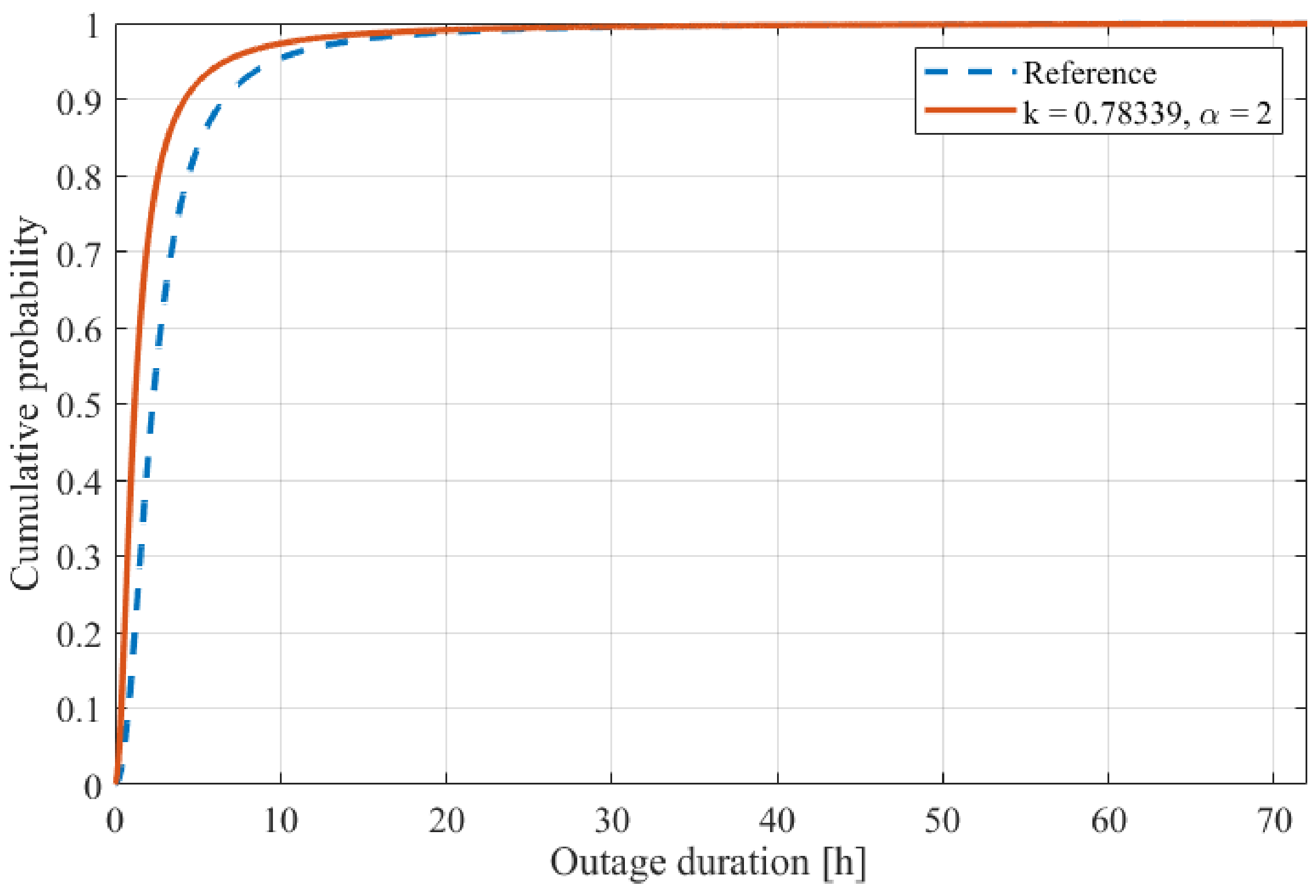

Fig. 3 Cumulative distribution of power interruption durations modeled using a Burr distribution.

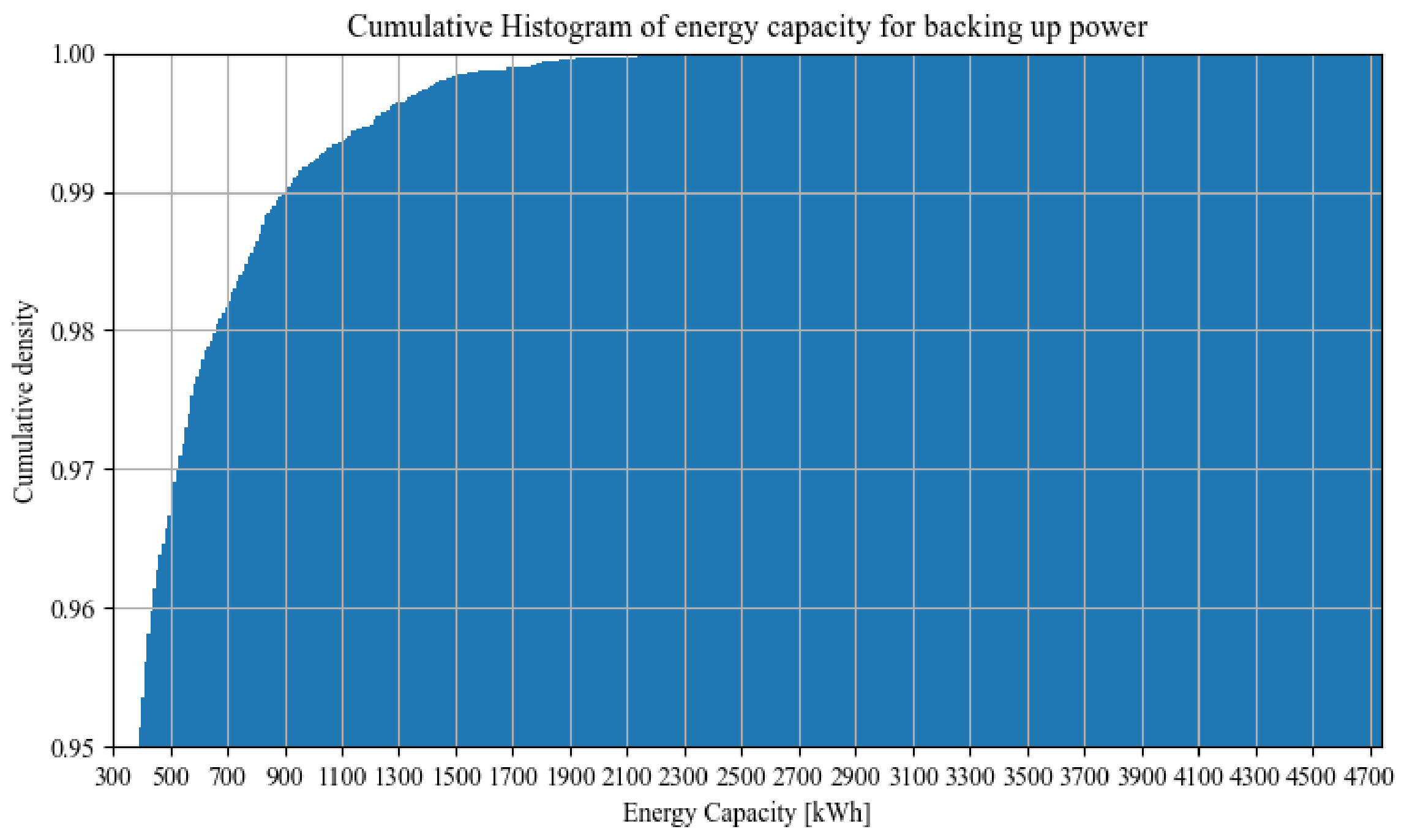

Fig. 4 Cumulative probability of capacity for energy backup of the microgrid.

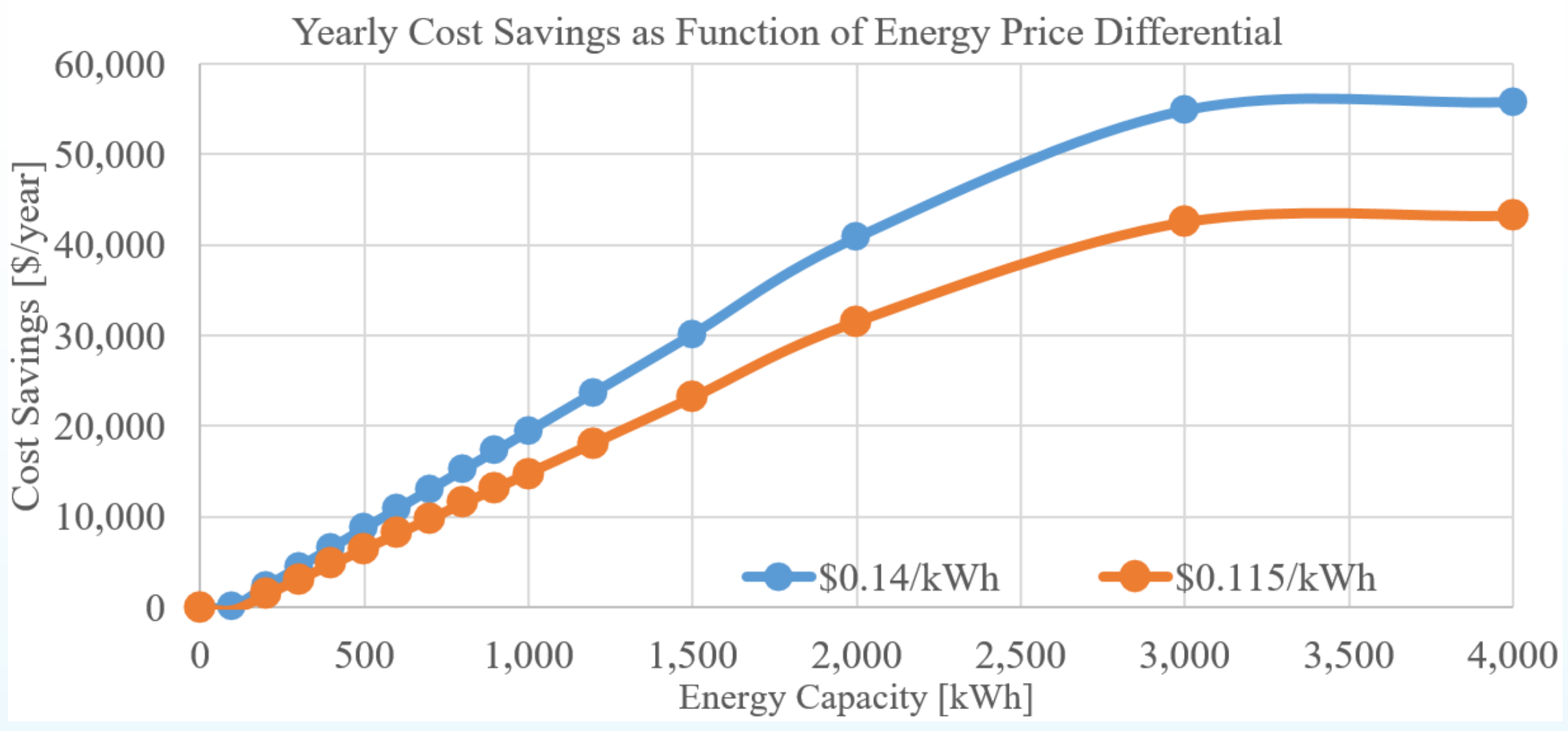

Fig. 5 Yearly cost savings as a function of energy capacity applied to energy trading for a power capacity of $\overline{q^m} = 400\ kVA$.

Case Study

- Microgrid in tribal lands
  - 1 MW solar PV array
- Two applications
  - Energy arbitrage: sell excess solar power and reduce net load of community loads
  - Reliability: backup power in microgrid mode
- Data inputs:
  - smart meter demand with 15-minute resolution
  - monthly kWh data of all loads;
  - hourly profiles with estimates of solar irradiation or solar production (kW) for the solar PV site
  - load profiles for loads without smart meters normalized by their monthly consumption
  - estimates of prices of energy
  - estimates of loads yet to be built or just built.
- Power capacity sizing
  - Larger than projected peak power in 10 year
- Energy capacity sizing
  - Arbitrage: result of optimization
  - Emergency backup power: defined by requirements, limited by cost
- Monte Carlo simulation repeated over the estimated net load profile with 8760 hours of data until the convergence criterion is reached
- **Goal:** Maximize net present value of cost savings by scheduling of CESS and PV, and sizing CESS
- **Solution:** script written in Pyomo and solved by Gurobi

$$NPV = \sum_{k=1}^{n_y} \frac{R_k}{(1+i_r)^k} - (C_{in} - G)$$

$$C_{in} = p_{kW}\overline{q^m} + p_{kWh}\bar{S}$$

- R_k: cost savings in electricity with BESS (per year)
- i_r : interest rate (per year)
- n_y: number of years (10)
- p_{kW}: price of BESS per kW
- $\overline{q^m}$: power capacity of BESS
- p_{kWh}: price of BESS per kWh
- $\bar{S}$: energy capacity of BESS
- C_{in}: cost of capital investment
- G: grant for investment

Table 1. Estimated power and energy capacity required as function of percentage of backed up interruptions.

Backup	**95%**	**99%**	**99.9%**	**99.99%**	**100%**
$\underline{q}^m$	127 kW	145 kW	161 kW	167 kW	169 kW
$\underline{\overline{S}}$	400 kWh	900 kWh	1.7 MWh	3.7 MWh	4.7 MWh

Conclusions

- BESS can improve resilience and generate revenue
- Project viability relies on a grant paying capital costs
- Spending in excess of a grant does not yield profit
- Resilience benefits are difficult to quantify, but can be obtained if supported by a microgrid, which means more capital investment and maintenance costs
- Power capacity: 400 kW
- Energy capacity: as much as the grant can provide
- Demand management can extend emergency backup
- Energy reserves can be increased to preempt events causing power interruption (e.g., weather, wildfires)

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