COST-BENEFIT ANALYSIS: CASE STUDIES OF COMMUNITY MICROGRID

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ABSTRACT

Microgrids are receiving increased attention from a variety of stakeholders for their potential to deliver multiple benefits. Despite their upside, microgrids are, however, not currently widely commercially deployed. Lack of understanding of the value proposition(s) that microgrids present, and the appropriate use cases and business models that can support their commercial viability are additional contributing factors.

EPRI's previous work presented a Cost-Benefit Analysis Framework for evaluation of individual microgrids [1]. Utilizing the framework, this paper presents a real-world case study focused on a community microgrid in the southeastern U.S., where the local utility is interested in better understanding economic drivers for customer adoption of microgrids. The paper also provides key insights on microgrid design and operational parameters and their impact on costs & benefits.

INTRODUCTION

Recent developments in microgrids have led to various challenges and opportunities to be dealt in the area of techno-economic analysis. Developing a consistent basis to estimate the potential values that can be realized from a microgrid presents great challenges that include identifying associated costs, regulatory issues, and other non-trivial values such as avoided costs of reliability and resiliency. Regulatory issues comprise of polices related to ownership, obligation to provide adequate quality of service, availability, coordinated equipment control, etc. Various control methods are essential for maintaining the reliability, resiliency, and adequacy constraints of the grid to ensure adequate economic margin in the microgrid operation as well as ability to serve critical loads in case of upstream network faults. A microgrid's cost may depend on the location, energy prices, DER costs, cost of emissions, amount of outage duration to supply power to critical loads, etc. In order to holistically address all these factors, a techno-economic analysis framework is essential for the evaluation of a microgrid. The framework accounts for the objective, operational use cases, constraints, optimal DER dispatch for analysing the feasibility of the microgrid.

This paper outlines this framework while provides description of the key elements within this framework. A case study from a commercial owned community microgrid is presented. Within the case study, sensitivities around microgrid design and operational parameters (e.g. customer type, single vs aggregation of loads, electricity rate & structure, islanding duration) are explored and insights are highlighted into how economics drive microgrid design, and vice versa. The case study also demonstrates how utilizing a CBA framework that is consistent, repeatable and transparent can help demystify a microgrid's value (i.e. where microgrid costs arise and how benefits are derived).

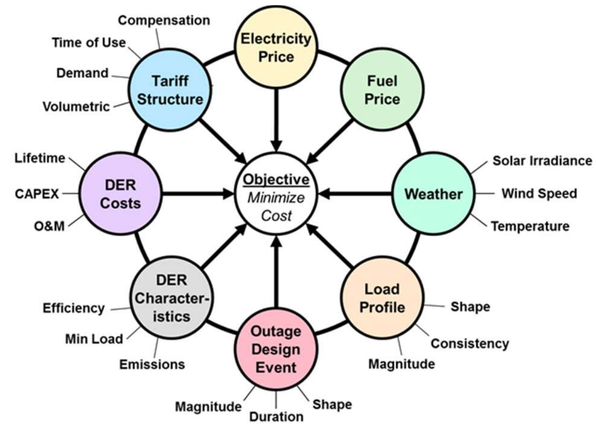


Figure 1. Factors that Impact Microgrid Design & Economics

DESIGNING A MICROGRID

The design of a microgrid, often driven by project economics, is complex. A conceptual system design often seeks to define three main elements:

1. Resource selection (e.g., generation, storage, controllable load)
2. Resource sizing (e.g., energy, capacity)
3. Resource dispatch (i.e., economic dispatch).

These three design elements are intertwined and impact the resulting economics of a system, pursuant to an assigned objective (e.g., to minimize costs or environmental impacts). System economics are also subject to design constraints that may be physical (e.g. available space), preferential (e.g. microgrid island-able period), or regulatory (e.g. direct access) in nature.
As shown in Figure 1, there a variety of design factors that can impact the overall economics of a microgrid, and therefore its design. Many of these factors are interconnected and their combinations can have a non-trivial effect on project economics. Running a series of sensitivity analyses is often useful for evaluating the impact of a given factor to a proposed project's overall system cost. EPRI has also evaluated and utilized several commercial modeling/simulation tools that aid in microgrid design and evaluation [2].

ANALYSIS METHOD

The study employs EPRI's Microgrid Cost-Benefit

Framework [1] while utilizing the DER-CAM model as the optimization engine. Develop by Lawrence Berkeley National Laboratory, DER-CAM is a mixed-integer linear program (MILP) mathematical model for modelling a system of distributed energy resources and loads. Given a set of inputs (e.g. load profile, weather, capital costs, electricity/fuel costs), the DER-CAM model returns an optimal combination of DER types (e.g. solar PV, energy storage, gas-based generation, CHP), DER sizes, and economic dispatch that minimizes the cost (or maximize savings) of the system over time.

COST-BENEFIT FRAMEWORK

Economically, a microgrid can be examined from a variety of perspectives, including those of internal microgrid customers, external customers, and owners/operators. As a result, the economic picture is more complex than for typical utility investments.

A cost-benefit analysis framework establishes a list of impacts or effects that will be included in an analysis. It also specifies the perspective that an analysis will assume. The cost and benefit items are often expressed as specific impacts, or physical changes that are caused by a project, whether directly or indirectly. Lists of impacts may include easily identified macro effects known to regulators or policymakers, but utility engineers and technical analysts may need to translate these into more specific power system impacts or economic results. Further, a framework may outline a sequence of steps or modules intended to answer certain intermediate questions.

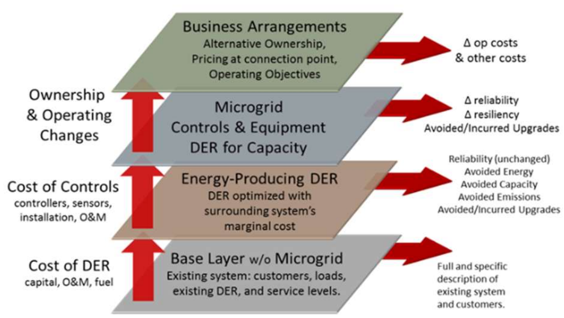


Figure 2. Multi-Layer Cost-Benefit Framework for

EPRI's conceptual framework, presented above, is designed to provide a general process in which one can evaluate the cost and benefit of a particular proposed microgrid system. The framework's underlying, staged analysis can be imagined as a sequential *layering* of a microgrid's assets and functions, and a subsequent evaluation of the incremental costs and benefits at each layer. The layers are not independent; as each layer is added, the growing stack is evaluated in terms of incremental cost and incremental benefit. Each layer addresses different economic questions. The base layer establishes the initial conditions, a "do nothing" (business-as-usual) scenario with no microgrid. The second layer adds on generating and storage resources, considering purely their economic attractiveness. The third layer then adds any costs associated with the controller/communications infrastructure as well as any additional generation/storage *needed to make the system island-able*. In the framework's fourth and final layer, a microgrid's proposed operating strategy is put into place to evaluate its incremental costs or benefits, with an eye to any impacts it may have on other entities.

CASE STUDY: CUSTOMER-OWNED COMMERCIAL CAMPUS MICROGRID

Cherokee Farms Innovation Campus located in Knoxville, Tennessee is a newly redeveloped, 200-acre commercial business park focused on fostering state-of-the-art science and technology research as well as stimulating local economic development. The target customers for the business park included interdisciplinary research and business in the areas of data science, energy research, materials research, and biomedical research. As part of the redevelopment plan at Cherokee Farms, a possible microgrid system built around the new campus was evaluated.

The primary objective of the study was to explore cases where a microgrid can be economic for a single or group of utility customers. A variety of factors, many interconnected, impact the overall design and cost of a microgrid. These include factors such as local electricity and fuel prices, customer load profiles, cost and characteristics of DER, and reliability/resiliency targets. Within this study, certain factors are considered fixed inputs (i.e. assumptions) while other factors are varied in order to evaluate the sensitivity of their impact on microgrid cost and feasibility.

Specifically, this study explores four different microgrid design and operational factors and their impact on the overall cost to build and operate.

I. *Microgrid Islanding Capability* – the duration for which a microgrid is able to sustain in islanded mode (separated from the grid).
II. *Electricity Price & Rate Structure* – the electricity price and rate structure seen by the customer owning/operating the microgrid.
III. *Load Profile & Magnitude* – the type of customer load and number of customers encompassed within the microgrid.
IV. *Renewable Penetration* – the required level of renewable generation within the microgrid's generation capacity.

These four sensitivities make up the modeled scenarios:

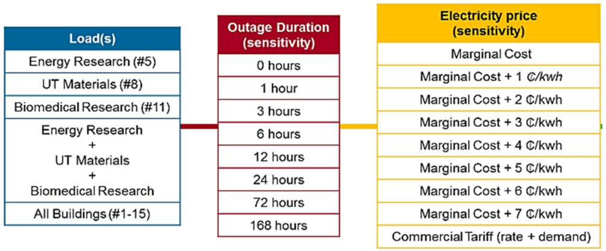


Figure 3. Modeled Microgrid Scenarios

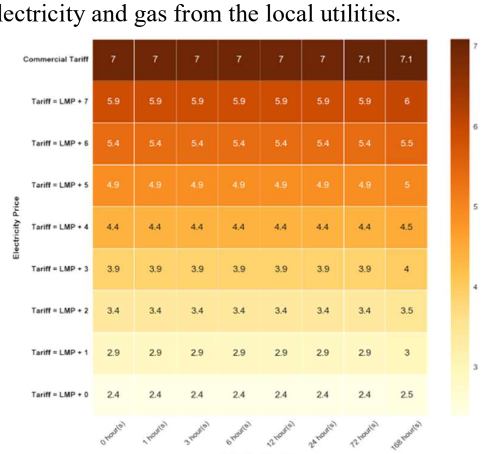
Number of Microgrid Cases = 4 x 8 x 8 = 256

Notes:
***Load** – The load profile utilizes DOE's database for commercial load profiles (e.g. school, office building, etc.)*
***System Marginal Cost** – The utility's real-time cost of energy.*
***Outage Duration** – Outage is assumed to occur at the peak hour of the customer's load, representing the "worst case" scenario.*

RESULTS

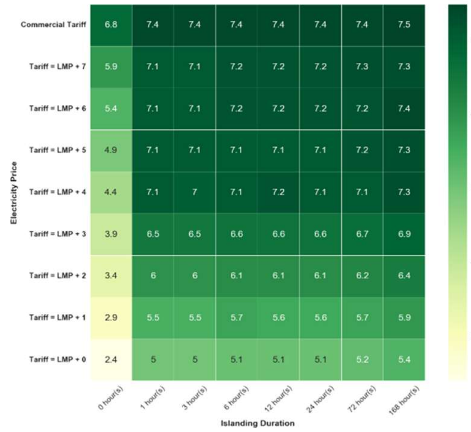
The scenarios in the previous section are further broken down in two types of cases – *base case* (representing "business as usual", i.e. a typical utility customer) and *investment case* (new assets are installed based on economic attractiveness and/or to satisfy reliability/resiliency objectives). The utilization of heat maps is helpful in analyzing results across many modeled microgrid cases.

An example of base cases is presented in the orange heat map below. In total, 81 cases are shown and explores two sensitivity dimensions – electricity price (y-axis) and the islanding duration (x-axis). Each box represents a modeled microgrid case while the number represents the normalized cost, in $/kWh, of serving the load using available resources. For base cases, the only available resource to service load is the electricity grid; therefore, the cost only includes operational cost of purchasing electricity and gas from the local utilities.



For base cases, the results show two simple trends:

1. The cost increases as electricity price increases
2. The islanding duration has no impact on cost, i.e. no options to increase reliability/resiliency.

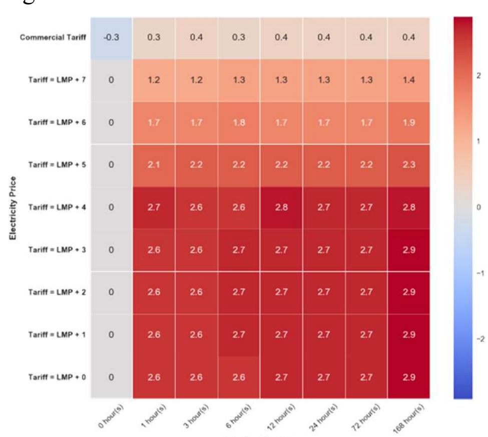


Next, the investment cases are presented in the green heat map, with the same sensitivity dimensions as above. For the investment cases, the DER-CAM model selects the optimal set of resources such that the cost to serve load is minimized while meeting any reliability/resiliency objectives. The pool of available resources includes PV, battery storage, combustion engines & turbines, combined heat & power (CHP), thermal storage as well as the utility grid. For investment case therefore includes both the operational cost (electricity, gas, O&M) as well as the capital cost (annualized) of installed assets.

For investment cases, the heat map shows two trends:

1. The cost increases as electricity price increases.
2. The cost increases as islanding duration increases, i.e. additional resources needed to meet increased islanding requirements.

Finally, the true cost of microgrid is the *difference* between the investment case and the corresponding base case. Thus, if we find the difference between the two heat maps, we can find the *marginal cost* of installing a microgrid.

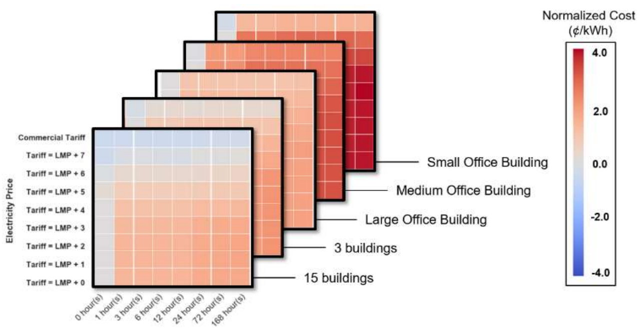


For marginal cases, the heat map shows two trends:

1. The cost is highest (red) when islanding duration requirements are high and when electricity prices are low.
2. The cost decreases as both and islanding duration electricity price.

Note the first column of these marginal cases. The islanding duration is 0 hours, i.e. an always grid-connected system. These represent *layer two* in the cost-benefit framework where DER may exist but not a microgrid. It can be observed that for all but the highest electricity price, the marginal cost is zero. This calls out the fact that it does not make economic sense to install and operate on-site resources (e.g. PV, storage) if there is no reliability/resiliency requirements that need to be met. For the highest electricity price (a commercial tariff with a demand charge component), the normalized cost is negative. This indicates that there are on-site resources installed and that some savings are generated from the investment case when compared to the “business-as-usual”, or base case.

KEY FINDINGS



Red = More Expensive. High premium for customer to build/operate a microgrid (compared to typical utility customer).
Blue = Less Expensive. Potential cost savings for customer that builds/operates a microgrid (compared to typical utility customer).

Figure 1. All Cases – Marginal Cost Heat Maps

1. For major of cases, absent any reliability/resiliency need (i.e. system does not need to have ability to island from the utility grid), DER alone do not make sense to install and operate, i.e. represents a net cost to the customer.
2. Under a net metering scheme, as electricity price is increased, DER become increasing attractive to install and operate; customers are incentivized to self-generate/consume instead of purchasing power from the grid.
3. Designing a microgrid for longer islanding durations adds to the cost. However, the correlation is not linear. For example, in many cases, a microgrid capable of islanding for 72-hours costs about the same as one designed to withstand 24 hours. This is mainly due to the model selection of gensets whose cost and size are dependent on capacity rather than energy.
4. Of the 256 modeled scenarios, 17 cases resulted in a net savings to the microgrid customer. In all other cases, the customer would pay a premium for installing the microgrid system. The two biggest contributing factors to these results are:
   a. *Size of Microgrid* – In general, microgrids become more economical as the amount of load increases. For example, the results showed that building three individual microgrids is ~20% more costly than building a single, three-building microgrid.
   b. *Demand-Based Tariffs* – In most cases, the cost of electricity ($/kWh) did not have a significant impact on microgrid design or cost. However, the addition of a demand charge component ($/kW) made microgrid investments significantly more attractive.
5. Given the low cost of natural gas, gas-based generation units are most economical in the majority of cases. In addition, combined heat and power (CHP) technology is especially favored for larger microgrids with more consistent day-to-day loads.
6. A solar PV and storage combination can make sense for small microgrids designed for short islanding durations (e.g. 1-3 hours).
7. There is unknown value to the customer for the additional reliability and resiliency a microgrid provides when operating separately from the grid. This analysis reveals what the cost, or cost premium, to the customer is under various scenarios.

Note: The key findings presented in this paper are specific to the set of assumptions used in the study – e.g. loads, weather conditions, electricity/gas prices, cost of DER. While some findings may apply to microgrids under similar design and operational conditions, they should not be interpreted as broadly applicable to all microgrid studies.

REFERENCES

[1] EPRI Report 3002010288 “A Cost-Benefit Analysis Framework for Evaluating Microgrids”, December 2017.
[2] EPRI Report 3002009721 “Assessment of Software Tools for Microgrid Simulation: Benchmarking and Case Studies”, December 2016.