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Energy Storage Enabled Microgrid Design for Critical Infrastructure

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SUMMARY

Uninterruptible power supply is indispensable for critical infrastructures like hospitals, industries, and military sites. Failure to serve the critical loads at these facilities could cause loss of millions of dollars, or damage to invaluable human life, or can affect the mission criticality at defense sites. Since the value of lost load is extremely high at these facilities, they are often supported with local microgrids to serve critical loads during outages. Traditionally microgrids consists of diesel generators (DG). In the recent times, there are more incentives towards having microgrids based on low emission and clean energy sources like long duration energy storage (ES) technologies and solar photovoltaics (PV). This paper proposes a DER based microgrid design methodology to address the recent requirement, specifically adapted for critical facility. The paper also proposes performance metrics to compare with the traditional DG based microgrids in both reliability performance and in terms of total project economics.

A microgrid design case-study is presented in this paper to validate the proposed methodology. Traditional microgrid design for the given site has 7 diesel generators along with the existing PV capacity. The proposed DER rich microgrid design is energy storage enabled. The primary objective of the design is to provide same or better reliability performance than the DG based microgrid. The final design for the site has 4.4MW 4 hr energy storage, existing PV and 5 diesel generators. As expected, the reliability performance of the designed microgrid is greater than the traditional DG based microgrids for all outages upto 168 hours. It is to be noted that the state of charge (SOC) reservation required to achieve the reliability target is only 5% of its energy rating.

Further, detailed economic analysis is carried to compare the proposed microgrid design with the traditional design. The metric used for the comparison is an annualized $/kW value which indicates the annual net cost of the microgrid on a 20-year analysis horizon divided by peak critical load in kW. Costs include capital costs, O&M expenses, energy storage replacement and augmentation costs throughout the analysis horizon. Benefits include the economic revenue estimated from stacked services that is obtained from StorageVET
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dispatch optimization. The analysis accounts for technology escalation rate, inflation rate and discount rate. This analysis for the given site data shows that the designed microgrid has 37% lower net cost per peak critical load ($/kW) compared to the traditional DG based microgrid.

For the considered case-study, the analysis shows that the DER-rich microgrid can provide superior performance both in terms of reliability and cost-effectiveness. But the conclusion can vary for other case-studies depending on factors like service territory restrictions, wholesale market structure, etc. Key inference from this paper is the analysis methodology and the performance metrics to compare microgrid designs. They can be widely applicable for similar studies that is focused on designing economically feasible microgrids for critical facilities, where reliability is the main objective.

KEYWORDS

Microgrids, Energy Storage, Solar Photovoltaics, Diesel Generators, Reliability, Economics.

INTRODUCTION

There is an increasing need for uninterrupted electric power supply at all sectors. Electric utilities strive to achieve it by maintaining high power-quality and reliability standards. Yet, planned or unplanned power outages do happen due to equipment failures or natural disasters. While it may be acceptable at residential level, a 100% power supply is indispensable for some critical infrastructures like hospitals, industries, and military sites. Failure to serve the critical loads at these facilities could cause loss of millions of dollars, damage to invaluable human life, or can affect the mission criticality at defense sites. Since the value of lost load is extremely high at these facilities, they are often supported with local microgrids to serve critical loads during outages.

Traditionally microgrids are based on diesel generators (DG). In the recent times, there are more incentives towards having microgrids based on low emission and clean energy sources like solar photovoltaics (PV) and long duration energy storage (ES) technologies [1, 2]. One of the reasons contributing to this change is recent reduction in capital costs of renewable energy technologies and their performance improvements. Further, field demonstrations and studies have shown that DERs can provide additional economic revenue from stacked services. So, DER based microgrid can be cost-effective compared to the traditional DG based microgrid. Detailed analysis and study are required to compare the performance metrics and study the economically feasibility of DER based microgrid.

This paper proposes a DER based microgrid design methodology that is adapted specifically for a critical facility. The designed microgrid is then compared with the traditional DG based microgrids in both reliability performance and in terms of total project economics. Primarily, the ability of both the designed microgrids in serving critical load during outages are studied. As it is the main objectives of the microgrid, DER based microgrid is designed to provide the same or better reliability performance than the DG based microgrid. Then detailed economic analysis is presented in this paper to compare the microgrid designs. The methodology and the results could help other stakeholders do similar analysis and draw conclusions.

Another contribution in this paper is the metrics used to quantify the effectiveness of a microgrid. Two metrics are used – One for reliability quantification and another for the economic cost effectiveness. To compare the reliability performance of the microgrids, a probabilistic metric is used. A microgrid with higher probability percentage metric would provide better serve critical coverage during outages than the microgrid with a lower metric. The other metric is net cost of serving critical load and it is based on detailed economic analysis on a 20-year analysis horizon. It provides an annualized net present value of the microgrid considering all the capital costs and economic benefits of the microgrids. Capital costs include specific life-cycle costs of each DERs and their assumptions. While benefits are calculated from detailed DER dispatch optimization subject to service territory restrictions and market signals.

Organization of this paper is briefly described here. First, methodology used to design DER-rich microgrid is presented. Then the site data used in the analysis are discussed and the traditional DG based microgrid design results are presented. Followed by DER based microgrid design results and discussion. Finally, the two microgrid designs are compared in terms of reliability performance and economic feasibility.

METHODOLOGY APPROACH

This paper presents a novel DER-based microgrid design methodology. The primary goal of the design methodology is to meet or exceed the reliability performance of traditional microgrid consisting of diesel generators. While satisfying the primary goal, the microgrid is made cost-effective by maximizing the net benefits. The analysis steps for the microgrid design are illustrated in Fig. 1.

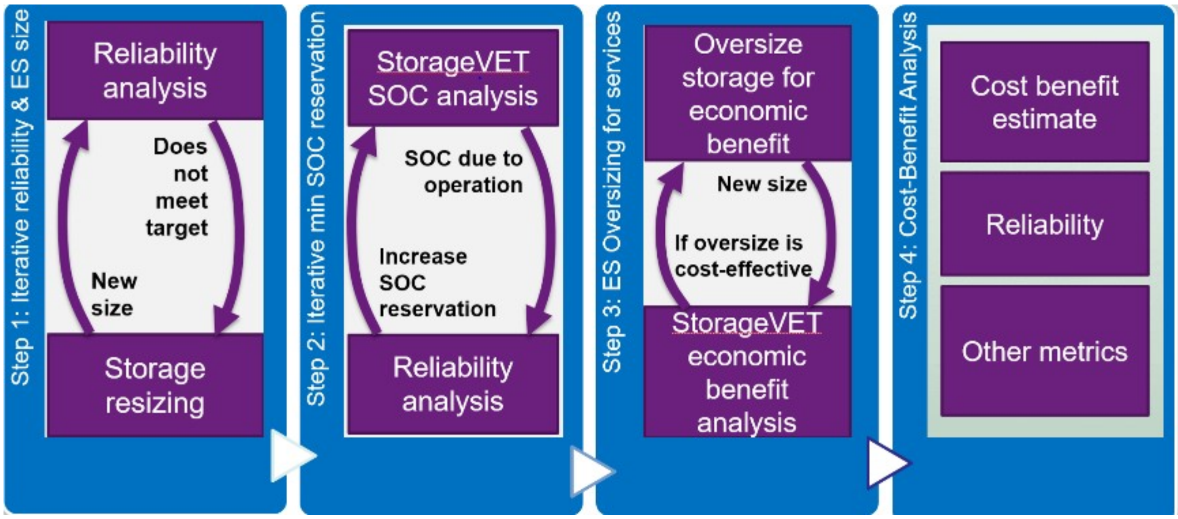

Figure 1. Illustration of the Technical Approach Developed for DER-Based Microgrid Design

Energy storage is the key component in this proposed microgrid design. Every analysis step in this methodology deals with energy storage - energy storage sizing, soc reservation and dispatch optimization, energy storage oversizing and sensitivity analysis. The analysis steps are briefly described below.

Step 1: Sizing and Reliability Analysis: The battery storage system is designed to meet the reliability objective at the least possible cost. This step involves finding the smallest battery storage system that meets the reliability requirement. To that end, a Monte Carlo [3] reliability simulation is combined with a binary search algorithm that updates the battery size at each iteration is used in this step.

Step 2: Iterative SOC reservation design: Once the minimum battery size for reliability has been found, the focus of the analysis is to maximize the economic benefits from the DERs without affecting the ability to meet the reliability objective. This analysis step is carried out using StorageVET® [4].

In the previous step, the SOC of the energy storage is assumed to 100% i.e., energy storage is used only to provide back-up for critical loads. This step of the modeling process however finds the minimum % SOC reservation required to satisfy the reliability objective. To this end, this step combines Monte Carlo reliability simulation with the EPRI-developed energy storage valuation tool StorageVET. StorageVET models the revenue of a storage system providing various grid services, subject to specific operational constraints. Various case studies with StorageVET have been performed to estimate the maximum benefits that a energy storage can provide [5]. These constraints can be due to interconnection requirements, or prior operational commitments. As an outcome, StorageVET will provide hourly dispatch profile, hourly SOC evolution, and annual operational costs/benefits associated to the grid services provided by the battery. Cycling due to economic objectives could make the battery

SOC to be low during some hours of the year. If an outage happened at any of those hours, the battery would not be able to supply the critical load. This raises the question on how much can the SOC decrease without deteriorating the system reliability. In this step, a minimum SOC reservation is determined. This reservation guarantees that the battery will always have at least a given amount of energy stored for reliability purpose.

Step 3: Oversizing analysis: Sensitivity analysis over storage size identifies the potential value of storage oversizing. Once the battery system has been designed, it would be important to understand whether it makes sense to increase the system size to get higher revenues. A sensitivity analysis is carried out to iteratively oversize the energy storage along with StorageVET. From this analysis, a suitable energy storage size is chosen that provide higher economic revenue and also better reliability performance.

Step 4: Final results: Analyze the reliability performance and economic performance of the designed microgrid with the traditional DG based microgrid. The final design selected as the one that provides the best cost/benefit metric while meeting the reliability target.

SITE DATA

Details on the critical facility that is used in this paper are included in Table 1. Yearly load profile at hourly resolution is used in this analysis. Peak load of the facility is 14.9 MW. For this analysis, a fixed percentage of site load is regarded as the critical load. A microgrid has to be designed to serve the critical load profile during any possible outage scenario during the year. Peak critical load is 4MW. The site has 800kW existing installed PV capacity. Yearly PV profile at hourly resolution is also considered in the analysis. Traditional DG based microgrid designed for this site has 7x750kW rated DGs.

Table 2. Critical Facility Load and DER Size Details

Parameters		Site Data
Peak load (MW)		14.9 MW
Critical Load (MW)		4 MW
Max PV gen. (kW)		800
Traditional Microgrid Design	**# of Diesel Gensets**	7
	Genset Size (kW)	750

Stacked services benefits at this site can come from either wholesale market or demand/bill reduction. Wholesale market services include are day ahead (DA) energy time shift, and frequency regulation. Bill reduction components include energy cost reduction, and demand charge reduction. It is to be noted that service territory regulations at the site location restricts DGs from participating in either of the above-mentioned value streams. DGs can only provide back-up services. Energy storage can offer both the services. While PV capacities can only be optimized to support battery's operation for bill reduction service. However, while calculating the NPV of the project in the economic analysis only the incremental value offered by the ESS was considered since the PV was already a part of the baseline microgrid.

RESULTS AND DISCUSSION

The microgrid configurations with the most feasible design and best financial performance for the critical facility is determined using the four-step design methodology as described in Fig. 1. The final design configurations for a Li-ion battery technology based microgrid is provided in Table 2. The table includes storage size in terms of power and energy and SOC reservation of the designed microgrid. The table also identifies the secondary grid services that energy storage can provide for best additional revenue. It can be observed the designed microgrid has only 5 diesel generators and has removed 2 DGs from the baseline microgrid design. Also, note that the energy storage's SOC reservation required is only 5.16%. It is a very minimal soc reservation required to provide the desired reliability performance.

Table 2. Proposed DER Based Microgrid Design with Li-Ion Energy Storage

Microgrid Parameters		Values
Li-ion ES Microgrid Config.	Power and Duration	4375kW 4hr
	SOC Reservation	5.16%
	# Gensets	5
	Secondary Services	Bill reduction

The performance of the designed microgrid is studied as follows. The primary objective of the microgrid is to provide acceptable reliability coverage during outages and to continuously serve critical loads. While achieving it, the cost effectiveness of the microgrid is also studied. The performance metrics for both the aspects of the microgrid are described below.

- **Reliability Performance**

The first step of the analysis methodology ensures that the DER based microgrid at least meets or exceeds the reliability performance of traditional DG based microgrid. The reliability metric used for the comparison is derived from probabilistic Monte-Carlo based approach. The probabilistic numbers for both the microgrids are included in Fig.2 for outage lengths ranging up to 168 hours. It can be observed the reliability metric for the DER based microgrid is always higher than the DG based microgrid.

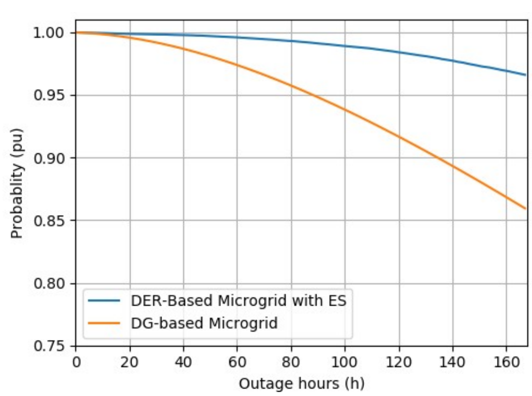

Figure 2. Reliability Performance of DER-based microgrid and DG-based Microgrid

From all the 168-hour outages analyzed in the study, the designed DER based microgrid can successfully serve 96.6% of the scenarios while the DG based microgrid can only serve 85.9% of the scenarios. Thus, the proposed methodology has designed a microgrid with superior reliability performance (~10% more probability of covering any 168-hour outage).

- **Economic Performance**

Detailed economic analysis for both microgrids considering both costs and benefits is carried out. Cost inputs include capital expenditures (CapEx) and operational expenditures (OpEx). Economic benefit for the traditional DG based microgrid is zero, since DGs are restricted by the service territory to provide only reliability service. The economic benefits from a Li-ion storage-enabled microgrid are estimated using StorageVET. In addition to economic benefits from lowering the site bills, the reduction in two generators from the traditional design is also accounted as the avoided cost in the economic calculation. Based on the net benefits, the annual net cost of Critical Load Coverage ($/kW) is calculated by annualizing the total NPV of installing and operating the microgrid over a 20-year period and then normalizing it based on the peak critical load served. The annual cost of serving each kW of peak critical load for the Li-ion based microgrid and the DG based microgrid are compared in Figure 2. The proposed DER based microgrid provides 37.12% improvement in critical load coverage cost compared to the DG only microgrid. The economic performance of the designed microgrid is also superior to DG based microgrid.

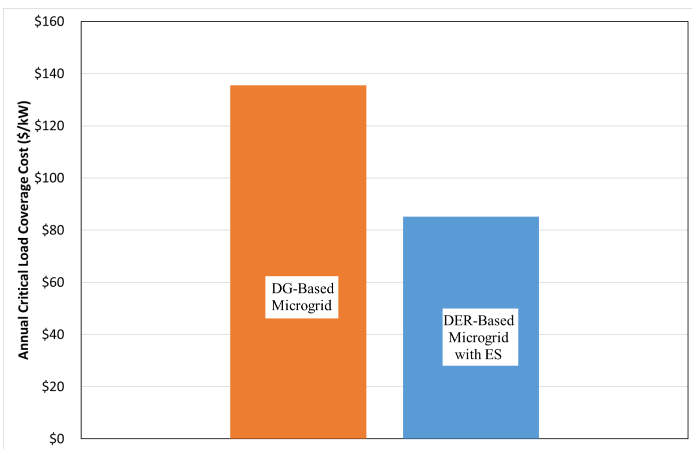

Figure 3. Economic Performance of DER-based microgrid and DG-based Microgrid – Annual Critical Load Coverage Cost

CONCLUSION AND INFERENCES

This paper proposes a novel DER-rich microgrid design methodology. The methodology is tested with an actual critical infrastructure load data. The final microgrid design consists of a 4.4MW 4hour energy storage, in addition to the existing PV and a few diesel generators. Performance of the designed microgrid is compared with the traditional DG based microgrid in terms of reliability and economic metrics. The designed DER-rich microgrid has been demonstrated to provide better performance than the traditional microgrid. Reliability performance of the storage-enbled microgrid is equal to or greater than the reliability targets for all outage durations ranging up to 168 hours. For 168 hour outage, the designed microgrid provides ~10% more probability of covering critical load than the DG based microgrid.

Further, the designed microgrid provides about 37% reduction in annual critical load coverage cost compared to the traditional microgrid.

For the considered case-study, the analysis shows that the DER-rich microgrid can provide superior performance both in terms of reliability and cost-effectiveness. But the conclusion can vary for other case-studies depending on factors like service territory restrictions, wholesale market structure, etc. Key inference from this paper is the analysis methodology and the performance metrics to compare microgrid designs. They can be widely applicable for similar studies that is focused on designing economically feasible microgrids for critical facilities, where reliability is the main objective.

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