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CVaR-based energy management scheme for optimal resilience and operational cost in commercial building microgrids

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ABSTRACT

This paper aims at enhancing the resilience of a photovoltaic-based microgrid equipped with battery storage, supplying a typical commercial building. When extreme weather conditions such as hurricane, tsunami and similar events occur, leading to islanding of the microgrid from the main power grid, it is not expected that the microgrid would be taken out of service for a long time. At the same time, it is not cost effective to make the electrical system to be absolutely reliable to provide service for the customers. The main contribution of this paper lies in its ability to determine the optimal point between the operational cost and grid resilience. In other words, this work proposes an optimal management system of battery energy storage in a way to enhance the resilience of the proposed microgrid while maintaining its operational cost at a minimum level. The optimization is achieved by solving a linear optimization programming problem while the Conditional Value at Risk (CVaR) is incorporated in the objective function. The CVaR is used to account for the uncertainty in the intermittent PV system generated power and that in the electricity price. Simulation analyses are carried out in MATLAB to evaluate the performance of the proposed method. Results reveal that the commercial building microgrid resilience is improved remarkably at a slight increase in the operational cost.

1. Introduction

Nowadays, the number of events related to severe weather conditions such as hurricanes, sandy storms, tsunami, blizzards and similar incidents which affect the operation of the power grid has increased significantly. This problem is linked to power systems resilience, which simply means the capability of the grid to resist, recover and minimize the undesirable effects from unfavorable accidents, attacks, or natural events that occur erratically [1]. It should be noted that the concept of power system resilience is different from reliability. A reliable system is essentially one that functions as desired and expected to, while resilience is the ability of the system to withstand certain types of failure and yet remains functional from the customer's point of view. In other words, reliability is the outcome and resilience is the way to achieve it. While reliability generally affected by events with high possibility but a fairly small effect e.g., different faults in power system, resilience is associated to low probability events with large influence such as thunderstorm, hurricanes, floods, blizzards, etc.

The main features and differences between resilience and reliability as applied to power grid are shown in Table 1 [2]. The benefits of resilience as it applies to power grids have been investigated in [3]. The coordination approach proposed by the authors demonstrate that it is capable of exchanging power once a microgrid experiences a power shortage and at the same time keep their frequency and voltage at the rated values. In [4], a design and configuration for a resilience power grid is presented and discussed. Nevertheless, there are some physical limitations such as voltage and power generation limits that must be considered in resilience studies.

Traditional power grids were designed in a way to allow only unidirectional power flow from the generation units to the load centers. However, in recent years, the need for a flexible power system which could be expanded and that is able to use renewable energy resources (RERs) in an effective way, has necessitated the development of microgrids to enable a bi-directional power flow between generation and consumers [5]. Microgrids are usually operated in a small geographical zone and may be integrated to the main grid. Because it is more stable

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Nomenclature

Indices

t	index of time step

Abbreviations

SOC	state of charge
VaR	value at risk
CVaR	conditional value at risk
RERs	renewable energy resources
SARIMA	seasonal autoregressive integrated moving average

Variables

S_t	the charging level of battery at the t^{th} step time
C_t^{GD}	cost of energy transferred from grid to load
C_t^{GS}	cost of energy transferred from grid to battery at the t^{th} step time
C_t^{SG}	cost of energy transferred from battery to grid at the t^{th} step time
C_t^{PVG}	cost of energy transferred from PV to grid at the t^{th} step time
$\mathrm{Cos}\ t_t(X_t^{ij},C_t)$	total operational cost of the commerial bulding microgrid
B	confidence level
P_{PV}	the output power of PV module at irradiance G_{ING}
T_c	cell temperature
D_t	the load of commercial building microgrid at the t^{th} step time
P_t^{PV}	total generated power by PV at the t^{th} step time
P_t^{ij}	the power transfered from unit i to unit j at the t^{th} step time

Parameters

ΔS^C	maximum amount for charging rate
ΔS^D	maximum amount for discharging rate
$SOC_{\min}$	minimum SOC of battery
SOC_{max}	maximum SOC of a battery
$S_{Battery}$	battery capacity
η^C	charging efficiency of the battery
η^D	discharging efficiency of the battery
w	weighting factor for the price risk consideration
S_{min}	minimum allowable charge level of the battery storage
S_{max}	maximum allowable charge level of the battery storage
P_{STG}	the maximum power of module at standard test condition
G_{STG}	irradiance at STC 1000 W/m^2
G_{ING}	incident irradiance
k	temperature coefficient of PV power
T_r	reference temperature
T_N	number of step time

Table 1
Main features of resilience compared to reliability.

Resilience	Reliability
Reaction to unfavorable events which affect the system	Response to frequency and duration of faults
Affected by power grid design, operational circumstances and control actions	Capability of distribution systems to supply the load demand
Has no evaluation metrics yet	It is generally measured by interruption indices such as SAIFI, SAIDI, ENS, CAIDI and CAIFI
Usually calculated before or after an event	Often calculated over a specified length of time
Focuses mainly on critical loads	All load demands are regarded
All power outages, regardless of time and duration, is necessary to study resilience assessment	Small interval of power outages (usually lasting less than 5 min) are ignored

and resilient, it usually decreases the power outages or demand curtailments remarkably. For this reason, using microgrids where the power generation units are close to the customers is one of the most practical options to enhance the resilience of the power grid [6]. In [7], a policy based on managing the accessible resources in an effective way is suggested in order to reduce load shedding during islanded mode. The study uses mixed integer linear programming to model the normal and resilient modes. Similarly, the merits of hierarchical DC control system in microgrids to enhance resilience and economic performance compared to AC microgrids are investigated in [8]. Three types of control including primary, secondary and tertiary are used and studied for DC microgrids. In addition, it is demonstrated that when there are outages, the operation of a power grid is improved by using a number of microgrids located in places precisely calculated. A novel restoration service plan for the distribution power system is presented in [9] while there is a big insertion of dispersed generation. It is shown that the requirement for more equipment of remotely controlled switches which is contingent on the dispersed generation capacity and its location will be beneficial in reconfiguration and restoration of service after a significant incident in the main grid.

In [10], a two-stage algorithm which models predictive control in the first stage with the aim of planning the existing resources and power from unexploited capacities of microgrids is exchanged among different microgrids in the second stage to supply the rest of the demands, is proposed. In the same vein, ref [11], a self-healing strategy is used to improve the resilience of overloading microgrids using centralized and decentralized method. The frequency of each migrogrid is used in the decentralized stage in order to specify the requirement or probability for interconnection of different microgrids. Generation of power by all microgrids is also calculated in the centralized stage. To describe the behavior of the PV generation, joint predictive distributions based on marginal densities was proposed in [12] and space-time trajectories of the PV generation assessment was modelled. It is verified in the work that when historical data is not available, it is possible to regard covariance matrix recursively as an alternative approach to determine the PV generation.

In [13], the wind power generation is explained at several locations from space-time trajectories including paths sampled from high-dimensional joint predictive densities. In [14], a multi-objective optimization programming is employed in an integrated building and microgrid system. The proposed control scheme in the study is able to preserve energy in sustainable homes and microgrid system in order to reduce operational costs and satisfy consumers. In [15], networked microgrids are considered for a study and the optimal planning approach is examined with respect to the unpredictable nature of the generating units and load demand. In [16], in order to minimize the system risk against incident occasions, new hybrid market framework involving emergency transactions and a bilateral contract is suggested