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Impact assessment of microgrid implementation considering complementary building operation: An Ontario, Canada case

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ABSTRACT

This case study presents the energy, emissions, and operating cost advantages and consequences of microgrid implementation. The buildings system considered in this study consists of commercial and residential components and exhibits complementary building use behavior between these two building types. This study investigates the advantages provided to the overall system by operating the buildings as a cluster in a microgrid as compared to standalone operation for each building unit. Variety of distributed electricity generation technologies were implemented and modelled to evaluate the behaviors of photovoltaic generation and seasonal micro co-generation of heat and power in each operational configuration. The results show that the buildings system was able to manage its distributed electricity generation and storage resources to meet the total system demand as a microgrid. This was achieved through the sharing of local energy generation and storage resources, which provided improved load-balancing and more efficient utilization of storage capacities within the buildings system. From the energy assessment, implementation of the microgrid configuration resulted in a reduction in total required storage capacity of up to 6.7% while also reducing consumption of grid electricity by up to 13.8%, as compared to standalone operation. Meanwhile, the emissions and operating costs assessments showed that, under scenarios with a high level of photovoltaic generation potential and seasonal micro-cogeneration of heat and power operation, a microgrid configuration reduces annual emission and operating costs by up to 1.29% and 61.2%, respectively.

1. Introduction

Sustainable development has become a major research focus due to emerging attention to climate change. As such, there is growing interest in the adoption of distributed energy resources (DER) into the power grid through the implementation of microgrids. In this context, a microgrid is a configuration of buildings with its own energy generation resources and consumption loads while also maintaining connection to an external power grid, from which it may import and export energy to suit its operational needs [1]. Transition of the centralized power grid infrastructure towards the implementation of microgrid communities has been considered due to several advantages of the microgrid configuration. The main benefits are the reduction of energy losses due power transmission and distribution, increased resilience and energy reliability and security, and reduction in greenhouse gas emissions.

In past studies, focus has been placed on evaluating the applicability of various distributed renewable resources and technologies in microgrid systems. The research aimed to assess the feasibility of certain technologies as distributed energy generation resources and their potential impacts on microgrid operation. In particular, micro-cogeneration of heat and power (μCHP) technology and solar photovoltaics (PV) has been considered for application within commercial and residential microgrids. Normazlina et al. [2] provide a literature review of the implementation of cogeneration systems in microgrids. Prehoda et al. [3] consider the role of PV applications in microgrids to enhance grid energy security. Camilo et al. [4] provide an economic assessment of PV adoption in residential microgrids considering the cost reduction potential of energy storage systems.

Studies have also been directed towards the methodology of technology selection for microgrid archetypes and the optimization of microgrid operation. Marnay et al. [5] examine the economic and environmental impacts of a microgrid operation in a commercial building system utilizing various technology configurations. The study discusses the potential for operating cost and emission reductions through technology optimization. Bahramirad et al. [6] examine the capacity sizing problem for ESS implementation in microgrids, considering an economic optimization based on capital and operating costs, as well as operational constraints for the function of the ESS. Nguyen et al. [7]

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Nomenclature

CHP	cogeneration of heat and power
DER	distributed energy resource
DHW	domestic hot water
ESS	energy storage system
FIT	feed-in tariff
GHG	greenhouse gas
HVAC	heating, ventilation, and air conditioning
ICE	internal combustion engine
PV	photovoltaic

present a power scheduling and price-based optimization approach to microgrid operation. Di Somma et al. [8] provide a stochastic programming model for the optimization of operation of a microgrid system with multiple DER technologies. The work also provides an economic and environmental evaluation of the performance of the microgrid system under a proposed operational method.

However, the successful implementation of microgrids and DER technologies is often subject to various geographic and economic conditions. As such, several studies have made efforts to consider the economic and environmental conditions of specific microgrid systems. Biglia et al. [9] present the potential implementation of micro co-generation within a microgrid in Sardinia, Italy, recognizing the economic conditions that proved unfavorable for μCHP implementation within the region. Perara et al. [10] present a case study for a Swiss microgrid consisting of both residential and commercial buildings. The study highlights the operational advantages of a microgrid configuration in integrating renewables and in achieving increased autonomy for the microgrid under Swiss conditions. In another Swiss case study, Kuehner et al. [11] consider the potential for full islanded operation in Cartigny, Switzerland microgrid. The study recognizes conditions that discourage full transition towards renewable generation, as well as the importance of daily and seasonal storage capacities in enabling a more reliable renewable integration within microgrids. In these studies [9–11], the effort is mainly directed towards recognizing the specific economic and environmental impacts that result from the adoption of DER technologies in microgrids.

In this paper, a microgrid system that consist of both commercial and residential components was modelled and simulated using a dynamic energy simulation approach. This microgrid takes advantage of the complementary commercial and residential buildings use behavior to demonstrate the microgrid's potential to reduce the required capacity of ESS and to improve energy security for the community. Various DER technology configurations were simulated for the microgrid system, which were evaluated for Ontario, Canada conditions to assess the energy, economic, and environmental impacts of each configuration under a Canadian context. This work is an extension to a previous study conducted using similar simulation scenarios [12]. However, it incorporates additional simulation scenarios to consider the role of distributed PV generation and battery energy storage within the buildings system. Additionally, the focus of this study is on the assessment of electrical power and the potential of the microgrid for islanded operation.

2. Case study

For this case study, a set of buildings that contains both residential and commercial components was considered. This was chosen to take advantage of the complementary building use behavior between residential and commercial buildings, in which residential buildings experience high energy demand in the early and later parts of the day, while commercial buildings experience high energy demand in the middle of the day. In order to maximize the effect of this complementary building use behavior, the number of building units of the residential and commercial building components were scaled such that the annual heating, cooling, and electrical loads of the two components are approximately equal. This resulted in a buildings system that consists of 20 residential buildings (i.e. single family homes) with an average total floor area of 200 m^2 and a single commercial building with a total floor area of 5110 m^2. This buildings system was set as the focus of this study and was investigated to explore the potential advantages and consequences that a microgrid configuration may provide in comparison to standalone operation of each building.

The context for this study was set to Ontario conditions to evaluate the potential benefits of microgrid application under a Canadian setting. Ontario was selected among other Canadian provinces because it has the highest relevance to the microgrid configuration proposed in this work. This is because Ontario has the potential to benefit from microgrid application for energy security and for reducing congestion in power transmission, since the Ontario electrical grid is highly reliant upon central power generation stations and it consists of many high power consumption regions. Furthermore, microgrids are less costly to implement in comparison to power distribution grid expansion for grid development.

Simulations for this building system were conducted using the Transient Systems Simulation (TRNSYS) software, which uses a time-step-based flowsheet simulation approach to perform transient energy balance calculations within simulation scenarios [13]. In this work, annual simulations were conducted using Canadian Weather data for Energy Calculations (CWEC) data for Ontario [14]. Within these simulations, the building system was operated both as a set of standalone buildings and as a cluster in a microgrid.

2.1. Operational configurations for building system

The two operational configurations considered in this study are as shown in Fig. 1. In the standalone configuration, buildings fulfilled their individual heating, cooling, and electricity consumption requirement using their own heating, ventilation, and air conditioning (HVAC) and electricity generation systems. In the microgrid configuration, these systems were operated such that all components in the system had access to the total heating, cooling, and electricity generation and storage capacities of the overall building system. In this approach, excess generation from distributed generation components of individual buildings may be directed to meet the electricity demand of its neighbors or stored within the ESS as backup power. The overall microgrid also maintains a connection to an external power grid for electricity imports and exports to support the overall operational needs of the microgrid.

Within the system simulation model, different HVAC components were implemented to provide heating, cooling, and electricity to the buildings in the system in each set of scenarios. The heating loads in the system were addressed using either a conventional boiler system or using μCHP implementation, which was considered for both residential and commercial components. The cooling loads in the system were addressed using only conventional, commercially available air-cooled, electric chillers. Lastly, the electrical loads in the system were met using PV generation, co-generated electricity from μCHP operation, or through energy imports from an external electrical grid. All of these options for addressing the heating, cooling, and electrical loads of the system were explored in this work in separate simulation scenarios.

The focus of the microgrid system model is on assessing the ability for islanded operation of the microgrid system in terms of its electrical consumption. Within the model, the heating and cooling components were incorporated to account for the heating and cooling needs of the