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Economic and emission-saving benefits of utilizing demand response and distributed renewables in microgrids☆

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ABSTRACT

The authors present several scenarios of demand response actions based on adjustments to a building's temperature management system in combination with renewable DER integration in microgrids. Economic benefits from $9,000 to $167,000 appear possible when implementing demand response in a microgrid of 30 to 50 additional buildings. The scenarios also demonstrate the potential emission-saving effects of demand response at the grid level.

1. Introduction

With increasing integration of renewable energy resources in power generation, the challenges associated with their variability, such as dispatchability, grow. In the state of California, increasing penetration of solar electricity in the grid extends the risks of over-generation and large ramp-up needs during peak hours or when the solar irradiation is not available, as shown in the California Independent System Operator's "duck graph" (CAISO, 2012), Fig. 1. The resulting ramping needs are typically met by fossil-fuel-fired generation, which can be expensive, complicated, and inefficient. When thermoelectric power plants have frequent startups, this is also more harmful to the environment than steady operations (CAISO, 2012; de Groot et al., 2017).

Commercial buildings are responsible for 18% of total U.S. emissions, and a building's operational emissions can be categorized into direct and indirect sources (U.S. Department of Energy, 2012). Direct sources of emissions include all combustion at the building site, generally produced by burning natural gas or other fuels for heating, hot water, or kitchen needs. Indirect sources of emissions are not located at the building site and include all emissions associated with the electricity purchases. Depending on the location of the building and the grid network to which it is connected, emission factors will vary in time with the electricity production (Harris et al., 2015). The time when electricity is purchased correlates to some total demand on the grid and a certain set of generators being used to meet this load. To accurately calculate the indirect emissions of the building, the electricity use trend on an hourly or sub-hourly basis is needed (Harris et al., 2015).

Reducing the emission production by electricity use can be seen as adding more clean and renewable sources of electricity to the fuel mix. At the same time, various building certificates such as LEED and LBC encourage building owners to integrate some features of on-site renewable electricity production in the building design and/or renovation plans, for example, rooftop PV. The optimal size of rooftop PV is will depend on the annual load of the building as well as solar irradiation availability in the site of the building (Bianchi and Smith, 2016).

In larger buildings, with lower skin ratios, usually the maximum available area on the rooftop is used for PV arrays; however, this source of electricity production may not be sufficient for the building's load. On the other hand, in smaller buildings electricity production may be higher than the actual building loads in some hours of the day. In this case, some buildings may be able to sell the excess electricity back to the grid. Although this may be financially beneficial for the building owner, in places such as California this will amplify the problems with the duck curve, which is undesirable for the ISO or balancing authority. Different ways of storing the excess energy are more beneficial in this case.

Energy storage can be provided in a variety of ways, such as by using batteries. However, batteries are expensive and degrade after a certain number of charge and discharge cycles. Another way of storing energy is using the thermal mass of the building. In this case, during the hours of excess energy production, "coolth" (a lack of heat) or warmth can be stored in the building thermal mass and used when on-site energy production is low (Kreith, 2014). In this work, storing coolth is investigated using demand response mechanisms. A signal will inform

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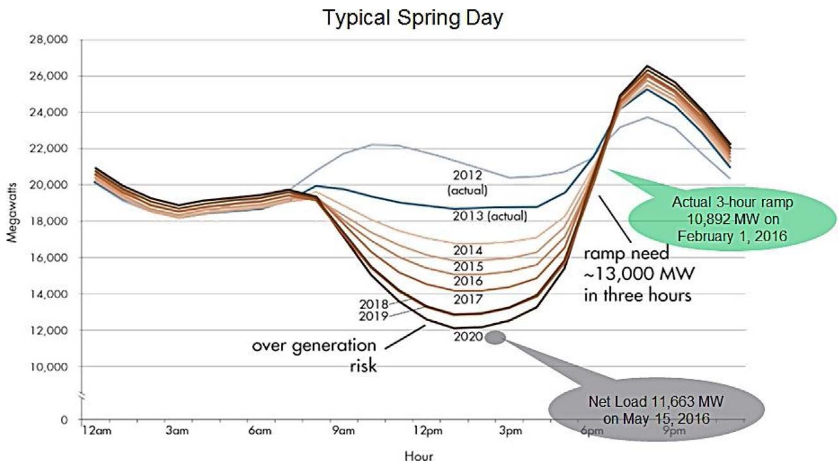

Fig. 1. Duck Graph representing over generation and ramp up risks, California ISO (CAISO, 2012).

the building automation system (BAS) to increase the load on AC units and decrease the room temperature as soon as solar electricity generation is higher than the building load. Later, the stored energy in the thermal mass of the building will keep the rooms at a suitable temperature and will decrease the need for air conditioning when on-site electricity production is not sufficient.

These changes in the operational schedule of the building will change the electricity use trends of the building and can affect the amount of purchased electricity from the grid (Srikantha et al., 2012). We investigate this variability in this paper. At the same time, due to temporal nature of emission factors linked to electricity production, the changes in electricity use trend of the building will affect the total indirect emission production of the building (Harris et al., 2015; Fallahi and Smith, 2016).

In this work, simulations of four types of commercial buildings are performed. Large, medium, and small office building as well as stores, typically seen on campuses, are simulated using EnergyPlus, the building energy consumption simulator developed by DOE. This software helps researchers to investigate and estimate the annual buildings energy consumption in an hourly and sub-hourly level both for natural gas and electricity. In this work, typical commercial buildings in the DOE climate region of 2 B is simulated (Ernest Orlando Lawrence Berkeley National Laboratory, 2015). The weather data are acquired from TMY3 weather files recorded in San Diego International Airport. Although a demand response event should be triggered based on live weather conditions, TMY3 data for irradiation is used to show the typical rooftop PV production and building consumption and the potential for using DR measures in commercial buildings (Wilcox and Marion, 2008).

2. Methods

In this work, four commercial building models are simulated to evaluate the potential benefits of a demand response action on building-related emissions. Use of the thermal mass of the building, as a mean of energy storage may be beneficial in load flexibility in the building. This kind of storage and load change due to generation and consumption patterns can be implemented in every commercial building without the need of capital cost. In this section, the methods used for assessment and implementation of DR are discussed.

2.1. Building energy modeling

One of the most difficult factors in building energy modeling is the operational schedule and transient load changes in the building. Prediction of the consumer behavior is not an easy task as it involves a great deal of uncertainty. In a commercial building, due to central adjustment and management of the operation as well as pre-determined operational hours of the building and number of occupants, operational schedule modeling can be more reliable compared with the residential sector. For this reason we are focusing on commercial building demand response in this article.

Four commercial building models are studied: examples of small, medium and large office buildings, as well as a retail stores. These represent common building types within the U.S. building stock, and similar buildings can be seen on university campuses. In this work, the building energy modeling (BEM) is performed using EnergyPlus software. EnergyPlus, developed by the U.S. Department of Energy, is a tool for energy researchers to simulate buildings' energy consumption in hourly or sub-hourly ranges for different time periods up to a full year. EnergyPlus uses two main model pieces. One is the actual building information containing the geometry and orientation of the building, material used for construction, occupancy, and operational schedule. The other is the weather file associated with the location of the building, informing the software about the ambient temperature, solar irradiation, humidity, wind speed, and other relevant information (DOE, 2014; NREL, 2017).

In this work, building models are obtained from the prototype building database provided by DOE, and all construction is designed to satisfy the 90.1-2010 standard. The prototype commercial buildings are modeled based on the location of the building and consider the typical building construction and features in the buildings climate zone (Fig. 3) (Deru et al., 2011; Baecheler et al., 2010).

Typical meteorological year (TMY) Version 3 weather data is used; TMY3 represents an average of weather data from a pool of 30 years of information. Although it does not show the most recent weather conditions and does not consider extremes in the weather features, it is a useful resource for showing the typical weather information and affected building energy consumption. The weather data in this work are obtained from San Diego International Airport (Wilcox and Marion, 2008).

2.2. Demand response

A simple option for shifting electricity use of a building's HVAC system, a *managerial retrofit*, is used to provide electrical load shifting. Both the building's electricity demand and the rooftop PV system's electricity production are used to signal the appropriate times for demand response actions. Pre-calculations are performed using EnergyPlus to predict the energy consumption of the building, designed to meet the 90.1-2010 standard, and also to estimate the rooftop PV production in hourly time steps during the year. These initial calculated values will later on help to determine the relations between generation and consumption of electricity in a building. As mentioned above, the