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Economic and sensitivity analyses of dynamic distributed generation dispatch to reduce building energy cost

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ABSTRACT

The practicality of any particular distributed generation (DG) installation depends upon its ability to reduce overall energy costs. A parametric study summarizing DG performance capabilities is developed using an economic dispatch strategy that minimizes building energy costs. Various electric rate structures are considered and applied to simulate meeting various measured building demand dynamics for heat and power. A determination of whether investment in DG makes economic sense is developed using a real-time dynamic dispatch and control strategy to meet real building demand dynamics. Under the economic dispatch strategy, capacity factor is influenced by DG electrical efficiency, operations and maintenance cost, and fuel price. Under a declining block natural gas rate structure, a large local thermal demand improves DG economics. Increasing capacity for DG that produces low cost electricity increases savings, but installing further capacity beyond the average building electrical demand reduces savings. For DG that produces high cost electricity, reducing demand charges can produce savings. Heat recovery improves capacity factor and DG economics only if thermal and electrical demand is coincident and DG heat is utilized. Potential DG economic value can be improved or impaired depending upon how the utility electricity cost is determined.

1. Introduction

Distributed generation involves the use of small-scale electrical generators to provide power at the point of use. Shifting from centralized generation to distributed generation provides numerous benefits to individual customers, utilities, and society as a whole, including the potential for increased system efficiency, reliability, and power quality, as well as reduced grid demand, delivery losses, central generation investment, maintenance, expansion, and emissions [1]. Despite these benefits, it is estimated that distributed generation accounts for less than three percent of all installed generation capacity in the United States, with distributed generation smaller than 1 MW accounting for less than 1% [2].

It has been argued that this may be due to electrical standby rates associated with distributed generation (DG), which can effectively increase the cost of utility-supplied electricity whenever a customer installs DG [3] and potentially limit the long term benefits of DG [4]. However, any decrease in profitability caused by such rate structures has only been shown to be prohibitive for those serviced by utilities with moderate to low congestion grids [5]. It has also been argued that the small DG market may be due to mandatory regulatory and interconnection requirements that must be satisfied before DG may be utilized [6]. Regardless of specific causes, the primary barrier for DG installation and use is its cost; as a practical matter, customers will not consider DG in the first instance if it is not shown to be profitable [5,6].

DG is currently not a practical option for everyone, even if it appears to be profitable on average. The practicality of DG depends upon the magnitude and coincidence of electric and thermal demand as compared to the dispatch and control capabilities of available DG systems. DG is typically a more attractive option for commercial and industrial sectors that may be subject to relatively high electric rates and may have coincident heat and power demand. For example, despite the significant variation in rates between regions and providers [2], in California, commercial and industrial customers paid an average of $0.131/kWh and $0.098/kWh, respectively in 2010 [7]. Under these circumstances,

Abbreviations: CHP, combined heat and power; DG, distributed generation; FC, fuel cell; GT, gas turbine; HR, heat recovery; ICBA, installed capacity over average building electrical load; ICBM, installed capacity over maximum building electrical load; MTG, microturbine generator; Non-TOU, non time of use; O&M, operations and maintenance; SCE, Southern California Edison; SCG, Southern California gas company; TOU, time of use.

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DG has the potential to reduce the amount spent on energy when properly matched to the needs of a customer.

Numerous forms of DG that use natural gas are available today. These technologies include small gas turbines (GT), microturbine generators (MTG), and fuel cells (FC) [8]. In addition to electricity, many of these technologies can provide a source of high grade heat for combined heat and power (CHP) [9–11]. They are also capable of providing base load and load following power [12,13] as well as cooling through the use of absorption chillers [14–16]. They can also provide power quality support when used in conjunction with proper power electronics [17].

Investment risks associated with DG include the high volatility of natural gas prices. Predictably, studies concerning the impact of fuel price uncertainty show that the risk of investment increases as the volatility of fuel price increases [18]. It has also been shown that payback is more likely to increase than decrease when faced with electric rate, fuel price, or capital cost volatility [19].

Multiple business models have been developed and presented to take advantage of DG technology in an attempt to create business prospects, including demand shifting, demand response, providing reserve power capacity, and grid balancing. It has also been suggested that the ability to sell and trade on a power exchange market, feed in tariffs, and stable regulations may further improve the business prospects of DG [20,21].

Studies on the economics of DG and CHP establish that detailed information regarding the electrical load, thermal load, characteristics of the DG source, and applicable electric rate structures are necessary to estimate the profitability of a project [22,23]. Further studies demonstrate that both FCs and MTGs are best suited for situations with a large and consistent electrical and thermal load as they take full advantage of all the products of the FC or MTG, and that for situations without a consistent thermal load, it is better to employ a generator with higher electrical efficiency [24,25] or to abandon attempts to recover heat in the DG system design [26]. It was also shown that buildings with low electrical load factors and large heating demand were well suited for GT installation [24].

The current analysis determines when investment in DG technology makes economic sense based upon these considerations and, in particular, includes the new consideration of dynamic dispatch to meet real building demand dynamics. Using previously developed utility rate structure and building energy demand models coupled with the current economic dispatch strategy, a parametric study was conducted to help determine when and why DG investment makes sense. The following parameters are varied in the current study: generator capital cost, generator size, electrical efficiency, operations and maintenance costs (O&M), generator turndown, and heat recovery ability. These parameters were selected due to the significant impact they have on DG investment and DG operation. In addition, there are various DG technology options available on the market today (e.g., microturbine generator, fuel cell) that an investor can select with various values for these parameters. The cost of electricity and fuel also influence the decision to purchase and operate DG. However, it is unlikely that an individual investor can vary the cost of electricity or fuel beyond selecting a service rate provided by the applicable utility.

Only natural gas fired DG with the capability of supplying electricity and heat were considered as they involve less mechanical complexity and cost than systems that also provide cooling, reducing investment risk. Models of electric and natural gas utility rates in Southern California developed by Flores et al. [27] were used. Electric standby rates were included in the analysis. Real electrical and heating load data were extracted from various buildings located throughout Southern California and used to simulate industrial and commercial facility operations. A simple yet effective economic dispatch strategy presented by Flores et al. [27] was applied to the various building models. The cost of supplying building energy using DG and utility energy was then compared to the cost of building energy using only utility supplied energy, allowing for financial analysis of DG investment. Results from the study for generators supplying electricity only and generators supplying electricity and heat are provided. Finally, the effect of switching to the parent rate structure from the standby rate structure is discussed.

2. Models

2.1. Electrical rate structure

Electric rate structures are typically broken down into fixed, energy (aka volumetric), and demand charges. The methods by which these charges are calculated vary amongst utilities and rate structures (e.g., time of use, declining block, and fixed rate). As a result, the calculation of utility costs can vary drastically between utilities and depend strongly upon the specific tariffs that are applied. It is therefore important to capture the general characteristics of an electric rate structure and how it functions as a whole, as opposed to specific individual charges associated with a particular rate structure.

For example, some common rate structures can be broken down into non-time of use (non-TOU) and time of use (TOU) components. Individual charges can change between seasons, with the season that contains highest total utility demand typically comprising higher charges. Non-TOU energy charges consist of a flat rate that applies to all of the energy consumed by a customer while non-TOU demand charges are determined by the largest load recorded for that billing period. As for TOU energy charges, these typically depend upon the time of day in which the energy is consumed. TOU energy rates are generally highest during periods of high demand (“on-peak”), lower for periods of moderate demand (“mid-peak”), and lowest during periods of low demand (“off-peak”). Concerning the demand charges, TOU demand charges are typically determined by the largest demand that is recorded during a specific time period (i.e., time of day) during the billing period.

The electrical rate structures used in this work were based upon the structures used by Southern California Edison (SCE). SCE rate structures for commercial and industrial buildings have TOU energy charges and both non-TOU and TOU demand charges. Energy and demand charges are increased during summer months. For customers with DG, standby rates apply. These rates only affect demand charges and can be broken down into two charges: standby or backup charges which are applied to demand that could be met onsite but is purchased from SCE, and supplemental charges which are applied to demand that surpass onsite capacity and must be purchased from SCE. In addition to being determined by maximum utility demand, standby demand charge rates are also determined by the time of day when maximum utility demand occurs. All SCE utility rates used are further described by Flores et al. [27].

2.2. Natural gas rate structure

Natural gas utilities usually sell their gas in a block structure. These block structures can have a single price for all gas used or comprise up to a three tiered declining block structure, with gas typically becoming progressively cheaper as the customer reaches each new tier. The standard charge is in dollars per therm (unit of heat equivalent to 100,000 BTUs or 1.055×10^8 J). Southern California Gas Company (SCG) is a major provider of natural gas to most customers in southern California, providing a declining block structure for commercial and industrial users. Like many natural gas utilities, SCG’s rates take into account the distribution and fuel costs. While distribution costs have been observed to be