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Development of an open access tool for design, simulated dispatch, and economic assessment of distributed generation technologies

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ABSTRACT

The design and deployment of DG systems requires an integrated assessment of the building and generator dynamics including the time-variant energy costs and emission factors. Static design optimizations are unable to consider the physical generator operating constraints, seasonal variability and non-coincidence in electric, heating, and cooling demands. This paper introduces the Distributed Generation Build-out Economic Assessment Tool (DG-BEAT) which combines building, utilities, and emissions databases with a library of simplified generator and building models in a user-friendly interface. Five control strategies are presented for the dynamic dispatch of distributed generation technologies at commercial buildings. The control approaches stem from the physical limitations of different generator types. Methods are also outlined for the dispatch of complementary technologies (e.g. energy storage) and accommodation of on-site renewables (e.g. solar PV) which could further improve the economic or environmental benefits of distributed generation. This paper details the methodology of sizing and dispatching distributed generation components, outlines eight databases that are employed to capture regional variations in pricing and building dynamics, and discusses the myriad of customizations available to provide a tailored analysis for a single building or national impact studies.

1. Introduction

Electric power generation in the United States is undergoing a transformation in pursuit of lower electrical costs, lower emissions, and improved reliability and sustainability. Distributed generation in the form of electrical generation on the user side of the meter can refer to a host of small-scale technologies that can enable higher efficiency, lower emissions, and lower costs. In this context, distributed generation (DG) does not refer to systems used exclusively for emergency backup power generation, but rather those systems designed to offset a portion of grid electricity purchases on a continuous basis. Commercial buildings represent the bulk of early-adopters of DG due to the high cost of energy for businesses, concerns for electric reliability, and bulk purchasing power [1–3]. The shift into on-site generation for businesses has been driven primarily by environmental concerns, generous incentive programs in some regions [4,5], and the increased reliability of redundant supply from on-site and centralized generation.

A variety of technologies including reciprocating combustion engines, micro-turbines, fuel cells, and solar power have been deployed at sites around the world. The capability to recover waste heat from on-site generation is an effective means of improving efficiency of these small scale system while simultaneously reducing emissions and costs. Additional features including electric and thermal storage, centralized cooling systems, and on-site renewables are often considered as additional elements in the design and deployment of these DG systems at commercial buildings.

The dispatch and control of the distributed energy resources is integrally linked with the optimal system design problem, and must be considered simultaneously. Within the dispatch problem, dynamic performance characteristics of generation and storage technologies, present constraints that cannot be neglected [6]. The work detailed herein outlines the methodology underling an analytical software tool for the design and deployment of most types of DG systems at commercial building installations. A focus on a user-friendly graphical user interface design is summarized in the 8-step process of Fig. 1. The steps include specifying the characteristics of the building where DG will be applied, selecting the DG system and complementary technologies, entering the local energy costs, and deciding upon a control strategy.

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Nomenclature

DER-CAM Distributed Energy Resources Customer Adoption Model
DG distributed generation
DG-BEAT Distributed Generation Build-out Economic Assessment Tool
kW kilowatt
MW megawatt
NFCRC National Fuel Cell Research Center
NPC net present cost
NREL National Renewable Energy Laboratory

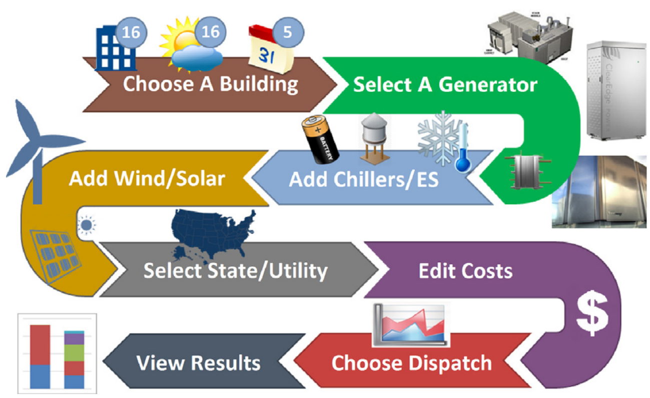

Fig. 1. Process of module specification for DG-BEAT software.

The open-access[1] software named the Distributed Generation Build-out Economic Assessment Tool or DG-BEAT packages previous research and development results and capabilities in building dynamics [7,8] and distributed energy resource dynamics and control [9,10]. Combined with detailed historical data on energy costs and emissions, DG-BEAT provides a powerful analysis tool for small stationary power installations. An included library of additional generator technologies (e.g. micro turbines, diesel generators, solar) are readily simulated and assessed for economic and emission benefits.

Previous analyses of the prospects for stationary power have tended to employ a simple market model that neglects the details of regional fuel and electricity price variations and the applicability of combined heat and power (CHP) integration with the dynamics of heat and power demand of a commercial building [11]. Some previous studies have evaluated a variety of building CHP systems (i.e. gas turbines, gas engines, diesel engines and phosphoric acid fuel cells) applied to four generic commercial buildings in Japan [12] or four commercial buildings in California [13].

The most comprehensive analysis tool available for distributed generation, DER-CAM, has been developed by Berkley Labs (LBNL) for more than 10 years [14–16] and provides some analyses that are similar to DG-BEAT in addition to analyses not addressed by DG-BEAT. The DER-CAM model provides multi-variable optimization of cost and emissions while simultaneously optimizing the system design using commercial DG systems.

DG-BEAT differs from DER-CAM in several keys areas of methodology and application. DG-BEAT was developed to investigate the impacts of system control rather than performing basic economic optimization. As such, it constrains the dispatch using physical characteristics such as off-peak performance curves, ramp rate constraints, and variable charging efficiencies. The design optimization used in DG-BEAT employs a full year of building load data with 15-min resolution. DG-BEAT applies one of the two algorithms (i.e. energy shifting or peak shaving) for utilizing either batteries or thermal energy. The flexibility and automation of DG-BEAT readily allow for comparative studies in addition to case studies. Specifically of interest during the development of this tool was the economic viability of specific DG technologies under both base-load and dynamic dispatch strategies while considering region specific weather impacts and energy costs.

DG-BEAT integrates multiple databases to accomplish these comparative studies including detailed 15-min demand profiles for 1280 simulated building types, state-specific hourly grid emission profiles for CO_2, SO_2, and NO_x [17], state specific wind and solar insolation profiles [18–21], a library of regional specific utility rate structures for electricity and natural gas, historical gas and electric rates by state for a variety of end-users [22,23], and a state-by-state building inventory of commercial buildings developed from a number of on-line sources.[2]

Section 2 will describe the simplified methodology for modeling the performance and dynamic response of distributed generation systems. Section 2 will detail many of the user-specified input parameters and outline options included for simulating and conducting comparative analysis on multiple case studies. Section 3 describes the algorithms used to dispatch the generation, energy storage, and complementary technologies to meet the electric, heating and cooling loads of a building. Section 3 also describes the method of dynamically sizing the generation under different design objectives. Section 4 provides a description of the building models and historical energy costs, unique datasets which bring additional validity to the analysis.

2. Model and interface description

The DG-BEAT interface was designed to be a user-friendly tool for building managers, distributed-generation stakeholders, and energy and environmental policymakers. Data visualization is a key aspect in applying perspective to results and allowing rapid feedback to the user with results automatically updated after any change in parameter selection. Behind the visual interface are a series of local electric utility rate structures and emission databases that eliminate guesswork when determining local costs and emissions impacts. Physical building and generator models, specialties of NREL and the NFCRC, are integrated into the tool through the insights and results of both the physical building models developed in Energy Plus [7,8] and the physical energy systems models [24] of the respective research centers. The control strategies are reflective of the dynamic limitations presented by different generators and complementary technology systems.

2.1. Component models

A library of 1280 building profiles generated using *Energy Plus* is used to represent the spectrum of commercial buildings in the United States. Each profile represents a year of detailed energy

[1] A simplified web-only version of the tool is available from http://fctac.nrel.gov/about.html, while access to the source code can be requested from the corresponding author at dustin.mclarty@wsu.edu.

[2] State building totals for restaurants and supermarkets are available from the USDA Food Environment Atlas, schools from the 2002 Census, office buildings from the Bureau of Labor Statistics, apartments from the National Multi-family Housing Council, hotels from http://www.factual.com/products/hotels, hospitals and clinics from the American Hospital Directory, retail stores from http://www.targetmap.com/viewer.aspx?reportId=2902, and warehouse data from a number of state and company specific websites.