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Optimal design and financial feasibility of a university campus microgrid considering renewable energy incentives

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HIGHLIGHTS

- Microgrid decision support model is developed.
- Incentives, tax benefits, and grid ancillary services are considered in the model.
- Incentives, tax benefits, and grid ancillary services affect both optimal sizing and financial feasibility.
- Optimal microgrid was found to decrease energy cost by 42% and emissions by 15%.

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ABSTRACT

Microgrids are gradually being recognized as an important option for sustainable and reliable energy, especially in university and military campuses. In this paper, we investigate the technical and financial feasibility of deploying a microgrid in a university campus. We consider various incentives such as renewable energy investment-based incentives, tax benefits, and grid ancillary services. In this study, we developed a microgrid planning model, called Microgrid Decision Support Tool (MDSTool). The model is structured into two sub-models—performance and economic models. Performance model simulates the optimal operation of the microgrid and is used to analyze energy usage and investigate technical feasibility. The economic model calculates all the system cash flows, its purpose is to determine the optimal sizing of distributed energy resources and financial feasibility. The overall model is used to design a campus microgrid at Seoul National University, South Korea. The results show that renewable energy incentives, tax benefits, and grid ancillary services influence both the financial feasibility and renewable energy penetration in a microgrid.

1. Introduction

Microgrids are becoming increasingly popular in university campuses seeking reliable and cost-effective energy solutions because of their economic, technical, and environmental benefits [1] such as energy bill savings, energy security, resiliency, and emission reduction. A microgrid is a group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries and acts as a single controllable entity with respect to the grid. It can connect and disconnect from the grid to enable it to operate in either the grid-connected or the island mode [2]. A typical microgrid comprises: renewable energy resources (RER), which are not dispatchable; distributed generators (DG), which are dispatchable; energy storage system (ESS); and controllable load (CL), which can be shifted or curtailed.

Microgrids are relatively new and complex, and because they usually involve more than one energy source, their planning and analysis remain a challenge. The planning process includes a selection of technology; sizing of DER; simulation of the optimal operation to ensure all reliability criteria and constraints are met; investigation of the financial feasibility of the system; and analysis of uncertainty to manage risks.

As the industry is searching for an ideal microgrid business model, capturing all benefits associated with microgrid investment is important for microgrid planners [3]. These benefits include renewable energy incentives and grants, emission reduction credits (EMRC), net metering, feed-in tariff, demand response, grid ancillary services, and tax benefits such as tax credits and accelerated depreciation. Although these benefits have been widely recognized [4], they are often not captured in the microgrid planning problem, and currently, no single commercial microgrid planning tool considers all of these benefits. We noted this gap in the literature and developed a Microgrid Decision

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Nomenclature

Acronyms

DER distributed energy resources
RER renewable energy resources
DG distributed generators
ESS energy storage system
TOU time-of-use
NPV/LCC net present value/lifecycle cost
PP/IRR payback period/internal rate of return
ALCS/B-C annual lifecycle savings/benefit-to-cost ratio
IBI/PBI investment-based/production-based incentives

Variable and parameters

RU^{max}/RD^{max} ramp-up/ramp-down power limit [kW]
P^{min}/P^{max} Minimum/Maximum power of DER [kW]
P^{OUT} output generated power of DER [kW]
P^{RATED} rated power [kW or kWh for ESS]
P^{PUR}/P^{SALE} utility purchased/sale power [kW]
P^{DR}/Φ^{DRR} demand response power/rate [(kW)/($/kWh)]
P^{AS}/Φ^{ASR} ancillary service power/rate [(kW)/($/kWh)]
P^{PEAK}/Φ^{DM} peak power/demand charge [(kW)/($/kW)]
P^{LOAD} load demand [kW]
P^{ESSD} ESS discharge power [kWh]
C^{FIX} fixed operating cost of DG [$/h]
C^{FC} fuel consumption cost of DG [$/kWh]
C^{ESS} ESS variable cost [$/kWh]
C^{SUC}/C^{SDC} startup cost/shutdown cost of DG [$]
MFix utility fixed monthly charge [$/month]
EP/ES utility purchase/sale price [$/kWh]
Φ^{CAP} unit capital cost [$/kW or $/kWh for ESS]
$\Phi^{O\&M}$ unit operation & maintenance cost [$/kW, $/kW/h]
Φ^{REP} unit replacement cost [$/kW or $/kWh for ESS]
Φ^{FUEL} unit fuel cost [$ per unit, e.g. liters, m^3etc.]
F^{OUT}/F^{IN} cash outflow/cash inflow
$F^{PTC}F^{ATC}$ pre-tax cost/after-tax cost
$F^{PTCF}F^{ATCF}$ pre-tax cash flow/after-tax cash flow
C^{CAP}/C^{REP} total capital/replacement cost [$]
$C^{INSTALL}$ total installed cost [$]
$C^{FIXcap}/C^{FIXo\&m}$ fixed capital cost [$]/annual fixed o&m cost [$/yr]
$C^{O\&M}/C^{FUEL}$ annual o&m cost [$/yr] / annual fuel cost [$/yr]
C^{PUR}/C^{SALE} annual utility purchased/sale [$/yr]
C^{INS}/C^{PRT} Annual insurance/property cost [$/yr]
C^{EMP}/C^{EMRC} annual emission penalty/annual emission reduction credit [$/yr]
C^{IBI}/C^{PBI} annual IBI [$]/annual PBI [$/yr]
C^{DEP}/C^{SALV} annual depreciation payment [$/yr]/Salvage value [$]
$C^{SAVINGS}$ annual energy savings [$/yr]
C^{TAXin}/C^{TAX} annual taxable income/annual income tax due [$/yr]
$C^{DEBT}/C^{DEBTint}$ annual total debt payment/annual debt interest payment [$/yr]
r_{pav}/r_{prt} property assessed value [%]/property tax rate [%/yr]
r_{ins} annual insurance rate [%]
N^{REP} A vector of replacement years of DER technologies
R_j/N_j remaining lifetime/lifetime of DER technologies
τ/d effective tax rate/nominal discount rate [%/yr]
f_d/r debt fraction [%]/inflation rate [%/yr]
γ^{IBI} IBI rate [$/W]
γ^{PBI} PBI rate [$/Wh]
φ^{GRID} utility tariff escalation rate [%/yr]
φ^{FUEL} fuel cost escalation rate [%/yr]
φ^{EMRR} emission reduction credit escalation rate [%/yr]
φ^{EMPR} emission penalty escalation rate [%/yr]
φ^{PAV} property value declination rate [%/yr]
φ^{PBI} PBI escalation rate [%/yr]
q_0/q_1 fuel curve intercept/Fuel curve slope

Support Tool (MDSTool) that employs an integrated approach to the microgrid planning problem and use the model to investigate the effects of considering all these benefits on the optimal sizing and financial feasibility of the microgrid.

1.1. Literature review

Numerous studies have been conducted on microgrid planning. The problem is typically approached in either of the following two ways: by using commercial software tools or using mathematical models and various optimization algorithms. Several commercial software tools for microgrid planning have been developed over the last two decades. A clear understanding of the features, capabilities, and limitations of these tools is necessary in order to apply them in microgrid planning. A comprehensive review of these tools has been given [5,6]. The most widely used include HOMER, iHOGA, DER-CAM, SAM, and RETScreen. HOMER [7] is a sizing tool that is extensively used by researchers for microgrid sizing and analysis. It uses an enumerative optimization to find the optimal sizes of DER components. Studies that have used HOMER for DER sizing have been comprehensively reviewed [8]. iHoga [9] is a simulation and optimization model for microgrid and hybrid energy system. The model uses a genetic algorithm to find the optimal sizes of DER components. DER-CAM [10] is an optimization tool used to support DER investment decisions, typically by minimizing total annual costs or CO_2 emissions. It uses mixed-integer linear programming (MILP). Unlike HOMER and iHoga, DER-CAM can consider passive improvements within the optimization process holistically. Recently, studies have been conducted using DER-CAM [11–14]. Remarkably, both HOMER, iHoga, and DER-CAM did not consider renewable energy incentives. In addition, they use before-tax cash flows in their economic analysis, thus excluding tax benefits such as renewable energy tax credits, tax deductions for debt interest payment, and accelerated depreciation. This is appropriate for non-tax-paying entities investing in microgrids, such as the government or non-governmental organizations (NGOs). However, for private entities, taxes and tax benefits are real costs that will impact the investment. The effect of income tax can vary widely from one microgrid configuration to another, so comparing alternative configuration on an after-tax basis is imperative to ensure valid economic analysis [15].

The tools that include incentives and use after-tax cash flows are System Advisor Model (SAM) [16] and RETScreen [17]. They are performance and financial models designed to facilitate decision making for renewable energy investment. They contain an extensive library of various DER technologies and a detailed economic model that accounts for taxes, incentives, and tax benefits. However, both SAM and RETScreen are not sizing tools and cannot model the operation of hybrid energy systems, thus limiting their application to microgrid planning.

The limitations of these tools motivate many researchers to develop their planning models using various optimization algorithms. A comprehensive review of these works has been reported [18,19]. In [20], a heuristic optimization technique, harmony search, is used to plan a stand-alone microgrid in Kerman, Iran. The authors report the optimal sizes of DER