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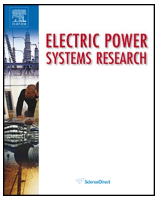

Managing solar uncertainty in microgrid systems with stochastic unit commitment

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ABSTRACT

As renewable energy becomes more prevalent in transmission and distribution systems, it is vital to understand the uncertainty and variability that accompany these resources. Microgrids have the potential to mitigate the effects of resource uncertainty. With the ability to exist in either an islanded mode or maintain connections with the main-grid, a microgrid can increase reliability, defer T&D infrastructure and effectively utilize demand response. This study presents a co-optimization framework for a microgrid with solar photovoltaic generation, emergency generation, and transmission switching. Today, unit commitment (UC) models ensure reliability with deterministic criteria, which are either insufficient to ensure reliability or can degrade economic efficiency for a microgrid that has a large penetration of variable renewable resources. A stochastic mixed integer program for day-ahead UC is proposed to account for uncertainty inherent in PV generation. The model incorporates the ability to trade energy and ancillary services with the main-grid, including the designation of firm and non-firm imports, which captures the ability to allow for reserve sharing between the two systems. In order to manage the computational complexities, Benders' decomposition is applied. The commitment schedule is validated with solar scenario analysis, i.e., Monte-Carlo simulations are conducted to test the proposed dispatch solution.

1. Introduction

With the increase in renewable energy resources, reliability and uncertainty have become essential issues facing system operators and planners. Solar photovoltaic (PV) generation is subject to a great deal of variability and uncertainty, depending on the size and location of the array. These factors arise from weather events, such as rain and dust storms, cloud cover and solar forecasts. A microgrid system is one resource that can help mitigate the effects of solar uncertainty. In addition to the ability to operate in an islanded mode, the control and management of a microgrid can be more sophisticated and complex than a larger, traditional grid system due to the small-scale topology.

The modeling of the microgrid in this paper involves many complexities, e.g., a stochastic mixed integer program, typically not used within a large-scale system. However, advances in stochastic programming are developing, and decomposition techniques like progressive hedging might soon be able to quickly handle problems of this magnitude [1].

Microgrids have the ability to rely on their neighbors since operating two grids together will further improve reliability and reduce costs. There are presently neighboring systems that trade power and depend on each other for ancillary services. The system described in this paper attempts to mimic the regional relationship between entities, as opposed to a small neighborhood and its system operator. For example, this neighboring system could compare to an entity, such as the Sacramento Municipal Utility District, who might trade with a larger entity, e.g., the California Independent System Operator (CAISO). For simplicity, we refer to the smaller neighboring system in this paper as a microgrid, though this developed work can be used by any single entity integrated into a larger network.

There are political and social factors that justify the use of microgrids to mitigate uncertainty. Military bases cannot always depend on the surrounding area for uninterrupted electricity support. In these cases, a microgrid with islanding capabilities can ensure that power remains online even if there is a blackout. Microgrids can also benefit communities that choose to promote solar energy, allowing them greater control over their power generation mix, especially with the addition of emergency generators and/or storage.

General optimization methods for dealing with uncertainty in many problems and industries are reviewed in [2]. The stochastic problem dealing with uncertainty in power demand and generation

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Nomenclature

Variables

E_T^*	power that is being sold (+) or bought (−) in hour T
$\mathrm{LS}_{i,t}$	load shedding in model two, stage two for bus i in period t
$P_{g,t,c}$	power output from generator g in period t for scenario c
$P_{k,t,c}$	power flowing in line k in period t for scenario c
$P_{g,t,c}^{\mathrm{NSP}}$	additional power reserve for generator g in period t for scenario c
PI_t^*	net firm (F) or non-firm (NF) power sold to (+) or purchased from (−) the main-grid in period t
$r_{g,T,c}^{\mathrm{SP/NSP}}$	spinning/non-spinning reserves from generator g in hour T for scenario c
$\mathrm{SU/SD}_{g,T}$	startup or shutdown commitment of generator g in hour T
$u_{g,T}$	commitment of generator g in hour T
$u_{g,T,c}^{\mathrm{NSP}}$	variable indicating if the non-spinning generators are on (1) or off (0) in model two, stage one for generator g in hour T for scenario c
$z_{k,T}$	variable indicating if intertie line k is closed (1) or open (0) in hour T
Δ_t^*	deviation from averaged firm (F) or non-firm (NF) power sold to (+) or purchased from (−) the main-grid in period t
$\theta_{k,t,c}$	voltage angle of line k in period t for scenario c
λ_z^y	the dual variables from the subproblem for iteration y and constraint z

Parameters

B_k	line susceptance for line k
b_z	the right hand side of the constraints in the subproblem for constraint z
C_T	maximum number of open lines in hour T
c_g	linear cost of generator g
$C_g^{\mathrm{SU/SD/NL}}$	startup, shutdown, or no load cost of generator g
C_T^*	cost of firm (F) or non-firm (NF) power sold to (+) or purchased from (−) the main-grid in hour T
$d_{i,t}$	demand in microgrid at bus i for period t
$g(i)$	set of generators at bus i
$M_{k/\zeta}$	big M value for intertie line k for total cost of main-grid
$P_g^{\max/\min}$	maximum or minimum power capacity for generator g
$\overline{P_{g,T}}$	power flow fixed from model one used in constraint (29) from model two
$P_k^{\max/\min}$	maximum or minimum line rating for line k
$\overline{P_{g,T}^{\mathrm{MAIN}}}$	total power in main-grid fixed from model one
$\mathrm{PV}_{i,t,c}$	power from PV at bus i in period t for scenario c
$\mathrm{RR}_g^{*/\mathrm{SU/SD}/5}$	hourly, startup, shutdown, or five-minute ramp rates for generator g
$\overline{u_{g,t,c}^{\mathrm{NSP}}}$	fixed $u_{g,T,c}^{\mathrm{NSP}}$ used in stage two for generator g in period t for scenario c
k_t^*	penalty for deviating from average firm (F) or non-firm (NF) power sold to (+) or purchased from (−) the main-grid in period t
$\theta_{\min}^{\max}$	maximum or minimum angle rating
τU_g, τD_g	minimum generator up and down time
ρ_c	probability that scenario c will occur
$\delta^{+/-}(i)$	set of lines defined as connected to (+) or from (−) bus i

outages was formulated in [3] using scenario trees and [4] using a variety of produced scenarios. Demand uncertainty and random outages were also modeled in [5] using Lagrangian relaxation to decompose a security-constrained unit commitment (SCUC) problem. They recommend utilizing a scenario reduction strategy due to the large computational burden of stochastic programming. The combination of stochastic UC and reserve requirements is analyzed in [6], where the resulting schedules were found to be more robust. Additionally, some have analyzed uncertainty in the UC problem with robust optimization [7], noting that the information needed about the uncertain variable is reduced.

These techniques have also been applied to uncertainty in renewable energy generation. The authors in [8] study the impacts of wind uncertainty on UC using rolling planning with scenario trees and they find a reduction in costs compared to deterministic modeling. The California system was examined in [9] using stochastic wind and solar forecast errors from actual historical data and a statistical model described in [10]. In [11], they use particle swarm optimization to demonstrate cost and emissions reductions when modeling grid-tied vehicles, renewables, and demand side uncertainty.

Renewable generation in the microgrid is also handled through the use of transmission switching, which facilitates additional flexibility in operations. Past research has shown that switching can be used to reduce losses [12], improve the voltage profile, and reduce line overloads [13]. In recent years, it has become an area of increased research with analysis of economic indicators and policy [14], production cost minimization [15,16], economic efficiency and reliability [17,18], different topology control policies [19], and methods to reduced computation time [20]. PJM hosted a day-long workshop on the topic [21], which highlighted new research and recent developments. These benefits can be valuable assets for microgrid operators, since they can utilize switching for the coordination of imports and exports if multiple interconnection points exist. As the references above show, systems of all sizes can take advantage of the variety of benefits transmission switching offers, including bolstered coordination among neighboring entities.

In order to manage PV uncertainty, this paper presents a stochastic mixed integer program, which is decomposed into two stages to reduce the computational burden. In addition to the two stages, which compose "model two," an initial UC model is run in order to incorporate the complex relationship between two interconnected systems that can trade and switch the intertie lines. The two models are intended to capture existing flexibility between systems while also ensuring scalability for larger electric grids.

The contributions of this work are:

- A modeling framework describes the complex interactions between neighboring electric grids while ensuring Pareto improvements for each system. The model includes the trade of ancillary services and energy (firm and non-firm imports) in order to improve efficiency and provide each system the opportunity to anticipate the operating conditions of the other.
- A two-stage stochastic programming problem for day-ahead scheduling, incorporating solar uncertainty at the 5-min level. Unlike previous work, the 5-min interval expresses detailed variability about solar generation in a day-ahead framework, instead of using hourly averages that do not capture the imposed ramping requirements of solar.
- A transmission switching model to allow the neighboring system to decide to disconnect intertie lines in order to minimize loop flow and wheeling through its system.
- Solar scenario analysis is conducted to confirm the approach. The results from this research were validated against many other