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Stochastic optimization for electric power generation expansion planning with discrete climate change scenarios

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ABSTRACT

This research is dedicated to the study of electric power system generation expansion planning considering uncertainty of climate change. Policy makers are increasingly concerned about the effects of climate change and its impact on human systems when making decisions. Electric power generation expansion planning (GEP) problems that determine the optimal expansion capacity and technology under particular technical constraints, given cost and policy assumptions, are undoubtedly among those decisions. The best approach to comprehensively model climate change uncertainties, and to optimize the generation planning under uncertainty needs to be rigorously studied. In this research, a preliminary GEP model is proposed with available input data from various sources. Discrete scenarios of possible climate change outcomes are defined and optimization models are formulated to specifically model uncertainty. Relationships between climate change and GEP parameters are defined for each scenario to consider their effects. The preliminary GEP model is then solved under each scenario to identify the climate change impact on generation expansion planning decisions. Two related optimization models are then presented and solved to find the optimal results under uncertainty: Model 1 is expected total cost minimization, and Model 2 is maximum regret minimization. Both models find compromise solutions that are suitable for all scenarios, which avoid the possible risk associated with a poor decision that is only optimal for one particular scenario, or only for an average climate change forecast.

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1. Introduction

An electric power system is a network of generation, transmission, distribution and load components. The electricity generation expansion planning (GEP) problem involves the selection of generation technology options to be added to an existing system, and when and where they should be constructed to meet the growing energy demand over a planning time horizon [1]. The problem is solved to ensure an economic, reliable and environmentally acceptable supply over a given planning horizon based on particular technical constraints, and cost and policy assumptions.

Climate change has generated significant research interest for electric power system planning as policy makers are increasingly concerned about its effects on this critical system. Various initiatives, policies and regulations have been launched to address this issue, such as Regional Greenhouse Gas Initiative (RGGI), Eastern Interconnection Planning Collaborative (EIPC), Renewable Portfolio Standard (RPS) and the most recent Environmental Protection Agency's Clean Power Plan (CPP). A regional GEP model provides a useful tool for power system uncertainty modeling as well as reliability and risk management for both market-driven and vertical integrated electricity generation. In countries and regions that have competitive electricity markets, solution of GEP may not be explicitly useful for a utility or government agency. That being said, there are still many parts of the world that do not have electricity markets and the GEP is still directly applicable, or if even they do have competitive markets, GEP solutions can help inform environmental policies such as greenhouse gas reduction policies (e.g., CPP) or renewable energy policies (e.g., feed-in-tariffs or RPS).

It must continually be assured that sufficient and flexible generation capacity is planned and constructed to meet anticipated growing demand and unpredictable climate disasters, recognizing that the costs associated with short-term variability are absorbed and passed on to consumers [2]. Therefore, we propose in this paper both risk-neutral and risk-averse approaches addressing different policy making considerations for GEP optimization under climate change uncertainty. There are several major climate variables that are relevant to the power system [3], including temperature,

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Nomenclature

Decision variables

$x_{y,t,r_1,i}$	generation amount of generation type i in region r_1 in time period t in year y (MWh)
$s_{y,r_1,i}$	investment amount of generation type i in region r_1 in year y (MW)
f_{y,t,r_1,r_2}	transmission flow from region r_1 to r_2 in time period t in year y (MWh)
$UD_{y,t,r_1,j}$	unmet demand in region r_1 in time period t in year y in scenario j (MWh)
$UG_{y,t,r_1,i,j}$	unavailable amount of generation type i in region r_1 in time period t in year y in scenario j (MWh)
$UR_{y,r_1,j}$	unmet reserve margin capacity requirement in region r_1 in year y in scenario j (MW)
$UT_{y,t,r_1,r_2,j}$	unavailable transmission amount from region r_1 to r_2 in time period t in year y in scenario j (MWh)
$Maxregret$	maximum regret

Indices

y, u	years
t	time periods in each year
r_1, r_2	regions
i	generation types
n	renewable generation types (subset of i)
e	emission gases
j	scenarios

Parameters

r	interest rate/discount rate
J	number of scenarios
Y	number of years
T	number of the time periods in a year
R	number of regions
I	number of generation types
N	number of renewable generation types
E	number of emission gases (CO_2, SO_2, NO_x,. . .)
$c_{y,i}$	generation variable cost for generation type i in year y ($/MWh)
$a_{y,i}$	investment cost for generation type i in year y ($/MW)
p_j	probability of scenario j
$init_{r_1,i}$	initial capacity of generation type i in region r_1 at the beginning of the time horizon (MW)
$fnew_{y,r_1,i}$	forced new capacity of generation type i in region r_1 on-line in year y (MW)
$fretire_{y,r_1,i}$	forced retirement capacity of generation type i in region r_1 with retirement year y (MW)
$g_{y,i}$	fixed operation and maintenance cost for existing generation type i in year y ($/MW)
$h_{y,i}$	fixed operation and maintenance cost for new generation type i in year y ($/MW)
φ_{y,t,r_1}, $\varphi_{y,t,r_1,j}$	demand in region r_1 in time period t in year y in scenario j (MWh)
$d_{y,t,i}$,$d_{y,t,i,j}$	outage rate of generation type i in time period t in year y in scenario j (i.e. the proportion of time when a generation unit is not available for service caused by equipment failures, weather disruptions or preventive and corrective maintenance activities, etc.)
$hours_t$	Hours in time period t
$cf_{y,t,r_1,i}$, $cf_{y,t,r_1,i,j}$	capacity factor for generation type i in region r_1 in time period t in year y in scenario j (i.e. the ratio of actual usable capacity of a generation unit to its nameplate capacity given its thermal efficiency or fuel availability)
$peak_{y,r_1}$, $peak_{y,r_1,j}$	peak load (demand) in year y in region r_1 in scenario j (MWh)
m_{y,r_1}, $m_{y,r_1,j}$	reserve margin for region r_1 in year y in scenario j
$MIN_{y,r_1,n}$	minimum generation percentage requirement of renewable type n for region r_1 in year y
$TMIN_{y,r_1}$	yearly minimum renewable generation percentage requirement for region r_1 in year y
$EM_{e,i}$	amount of emission gas e from generation type i (lbs/MWh)
$RLEM_{e,y,r_1}$	regional limit for emission gas e in region r_1 in year y (lbs)
TL_{y,r_1,r_2}, $TL_{y,r_1,r_2,j}$	transmission limit from region r_1 to r_2 in year y in scenario j (MW)
$CL_{y,r_1,i}$	yearly construction limit of generation type i in region r_1 in year y (MW)
VD_y	penalty cost of unmet demand in year y ($/MWh)
VR_y	penalty cost of unmet reserve margin requirement in year y ($/MW)
$Optimal_j$	expansion cost of optimal solution under scenario j ($)

precipitation and frequency of extreme events, which are fully addressed in this paper. Higher temperatures will increase demand for summer cooling, and thus peak loads, and decrease heating demands in winter. Seasonal and long-term changes in patterns of precipitation, river flow, runoff and snowpack will impact cooling water availability for electricity generation. Extreme events also affect electricity generation, transmission and distribution facilities. While the extent of climate change remains uncertain, the model results can provide valuable insights and lessons-learned for appropriate adaptation and mitigation in response to global climate trends.

1.1. *Background*

Greenhouse gas emissions, mainly carbon dioxide, associated with the production and use of energy are widely believed to be a primary cause of global warming, and in turn, broader climate change, will influence our production and use of energy [5]. The interaction of climatic, environmental and human factors makes the effects of climate change complex and uncertain. Refs. [5–10] provide background on climate change projections, implications of future risk management with possible mitigation and adaptation measures, as well as, comprehensively project and assess the impacts of climate change from a broader perspective of intergovernmental agencies/organizations and U.S. government.

Researchers have started to study those impacts on power systems recently, but according to [11], “there is a dearth of literature on assessment studies that focus on climate change impacts on electric power sector at a national, regional or state-level.” Chandramowli and Felder [11] summarize large amount of references that study the climate change impacts on electricity demand and supply, in which most reviewed papers such as [12–14] only adopt simple statistical regression based on historical data without fully considering the uncertainty of climate outcomes. The Sixth Northwest Conservation and Electric Power Plan [15] models climate change as a random variable and incorporate climate change

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