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Least cost generation expansion planning with solar power plant using Differential Evolution algorithm

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ABSTRACT

The issue of balance between the benefits of greater renewable penetration with the cost of adapting conventional base load systems is drawing the attention of power system planners across the globe. The study region, State of Tamilnadu, India, faces acute power shortages and frequent power cuts, though the installed capacity of the state is higher than the peak demand and is planning more solar additions. The impact of the inclusion of solar power plants is analyzed, for 6-year and 14-year planning horizons, using the model formulated, integrating all critical elements of the system, employing Differential Evolution (DE) algorithm. A balanced approach is adopted to understand the long term impact of solar additions by realistically imposing Total Emission Reductions Constraints (TERC), and Emission Treatment Penalty Costs (ETPC) on the remaining portion of pollution. The sensitivity of the system generation mix and the system reliability, to different solar power development and emissions reduction scenarios is also studied. The resulting variations in different cost components are also reported. The study will have greater utility for the planners who are currently involved in the long term planning of systems expected to have increasing proportion of RET plants.

1. Introduction

Starting with the United Nations Conference on Human Development held in Stockholm in 1972, the formation of Intergovernmental Panel on Climate Change (IPCC), the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) at the Rio Summit in 1992, there has been an increasing concern among all countries about the climate change and emissions. This has led to the formulation of Kyoto Protocol and the Bali Action Plan (BAP). The threat of climate change due to man-made emissions is now a serious global concern. It is reflected in the action plan for development of all countries across the globe.

The Planning Commission of India set up an Expert Group, ahead of the Twelfth Five Year Plan, to advise and help evolve low carbon strategies for inclusive growth. The Interim Report [1] outlined a menu of options that could help reduce India's emissions' intensity by 25% over the 2005 levels, by 2020. The Final Report [2] of the Expert Group made a number of recommendations to make the renewable energy sector viable and provide long term stability for its growth in the country.

Apart from wind power energies, solar energy has been growing very rapidly during the last decade. The country's large land mass receives one of the highest levels of solar irradiation in the world. In tune with the global trend India has adopted policy measures to promote investments in low emissions renewable electricity generation. The Indian government has launched Jawaharlal Nehru National Solar Mission (JNNSM) with a target of achieving 20,000 MW by 2022, achieving 15 million sq. meters solar thermal collector area by 2017 and 20 million by 2022 [3].

In India, only a limited number of research studies have been carried out on estimation of the solar energy potential based on irradiation data, impact of Solar PV and CSP technologies, and on market potential for investment. Moreover, no organized study in India has been carried to explore the potential mixes of electricity-generating technologies under varying future scenarios of solar energy development as the special characteristics of solar technologies require unique data and modeling capabilities. While

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conventional thermal generators generally can be dispatched within some operational limits, solar-electricity output is subject to the temporal uncertainties and spatial heterogeneity of solar irradiance [4]. While solar systems can generate emissions-free electricity, the limited ability to store electricity, forecast generation, and control the availability of solar energy is expected to have impacts at all levels of electric power system regulation, from economic dispatch in the short term to generation capacity addition in the long term.

Effective capacity-expansion models consider how solar deployment interplays with the electricity system's resource adequacy and operating reliability. Advanced models account for a solar generator's capacity value (and its erosion with increasing solar penetration) and contribution to resource adequacy as well as the improved capacity value of CSP with hybrid backup or TES [5].

In this work, a Generation expansion planning (GEP) modeling study is carried out, for a candidate region, which is typical of the State of Tamilnadu, India, to study the impact of increasing penetration of solar power technology. The Solar energy portfolio analysis is carried out using conventional technology capacity-expansion modeling technique investments in the long term. The GEP model formulated is used to determine an optimal system generation mix for a set of presumed solar penetration levels. The impact study of RET is planned in two parts before a combined study. A companion work deals with the impact of wind plants inclusions and this study is carried for the impact of inclusion of solar power. The GEP model solutions are carried employing DE algorithm. The sensitivity of the system generation mix to different solar power development and emissions reduction scenarios is also carried out. The resulting variations in different cost components and the variations in reliability indices are also reported.

This paper is organized as follows: Section 2 deals with literature review, Section 3 gives physical system, Section 4 deals with GEP problem formulation and solution methodology, Section 5 gives the results and discussions and Section 6 provides concluding remarks.

2. Literature review

A clean energy future demands greater investment in renewables, which in addition to environmental benefits could provide attractive dividends such as job creation, economic growth, energy security and greater insulation from price volatility. Hence, renewable energy is gaining traction as an important area of focus for governments across the globe [6].

The electric power systems based on fossil fuels have been one of the major contributors to global carbon emissions. In an effort to decarbonize electric power systems, policy makers have adopted measures to promote investments in low emissions renewable technologies based electricity generation. The increasing penetration of the RET require adopting different, and more costly, measures to balance load and generation and to maintain system reliability. This leads to two major issues: (i) increase in total system costs due to mandated renewable dispatches and (ii) the offset of emission benefits due to renewables by the ramping and cyclic operations of other plants in the system [7]. As each generation technology has different technical and economic characteristics, the challenge of capacity expansion planning is the proper integration of these issues in a system framework.

The incorporation of renewables into existing conventional electrical power system creates three distinct challenges for generation and grid operations: Non-controllable variability, Partial unpredictability and Location dependence [8]. Whereas conventional thermal generators generally can be dispatched within some operational limits, solar-electricity output is subject to the external factor of solar irradiance. This irradiance is temporally variable and uncertain and geographically heterogeneous [5].

Knowledge about the performance of solar power plants will result in correct investment decisions, a better regulatory framework and favorable government policies [3]. Cellura et al. [9] presented an excellent methodology for the assessment of the photovoltaic potential in urban areas using Google Earth™ tool that provides either satellite images of the roofs of buildings or their number of floors by means of the Street View function. The applicability of the methodology has been tested on a selected urban area of the city of Palermo in the South of Italy. The first step towards positioning rooftop solar energy as a solution is to understand its potential. An in-depth assessment [10] of the opportunities and challenges for the effective adoption of rooftop solar of Delhi city was carried out.

Effective capacity-expansion models consider how solar deployment interplays with the electricity system's resource adequacy and operating reliability. The variability and uncertainty of the solar resource and operational characteristics adds to the system's operating-reliability burden and costs associated with additional need for ancillary services. Some of these remain difficult to address with current models and thus represent an area for future research [5]. An important and unanswered question, though, is how this additional capacity will be composed and its optimal geographical distribution. In particular, the available literature gives no or only vague information concerning transmission grids, the supply of reserve capacities and the geographical allocation of plants [10].

Capacity expansion models to determine the optimal generation technologies mix with solar or other renewable technologies as a choice was carried out by many research workers. A survey [5] of four general methods for integrating non-dispatch able technologies like solar into capacity-expansion modeling, ranging from simple screening-curve calculations to simultaneous capacity-expansion modeling of dispatchable and non-dispatchable generators was presented. Capacity expansion models with renewables were also carried by many others [11–15,10,16–21].

The GEP models fall into three major categories: i) simple GEP models, which make decisions about what technology plants to induct into the system, when and in what quantities. They do not include detailed operational procedures as model decisions [11,12,14–17,21], ii) models which consider capacities of candidate plants given *a priori* and give detailed operational procedures as model solutions [13], and iii) models which offer both capacity and operational decisions simultaneously [19,20]. These models have considered both capacity and operational decisions at varying levels of approximations. These approximations were either system or situation specific. There were wide variations in terms of spatial and temporal resolutions in incorporating both capacity and operational issues. Models which went for finer resolution of spatial decisions have incorporated investment decisions on transmission systems in addition to location, timing and capacity decisions of different technologies plants [17,21]. Similarly, models which incorporated detailed operational issues also had varying spatial and temporal resolutions, one at the cost of the other. Of late, models incorporating RET as a choice have brought in additional operational issues like emissions, ramping and cyclic issues, in addition to other issues related to conventional plants. While system specific issues have been the force behind the selection of specific model for analysis, situation specific issues like availability of data, computational capabilities and purpose of model analysis were also reasons for the selection of model type and solution