Electrical Power and Energy Systems 80 (2016) 275–286

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Least cost generation expansion planning with wind power plant incorporating emission using Differential Evolution algorithm

K. Rajesh [a,*], S. Kannan [b], C. Thangaraj [c]

[a] Department of EEE, Kalasalingam University, India
[b] Department of EEE, Ramco Institute of Technology, Rajapalayam, India
[c] Vignan University, Vadlamudi, Guntur, Andrapradesh, India

ARTICLE INFO

Article history:
Received 28 March 2015
Received in revised form 11 January 2016
Accepted 27 January 2016
Available online 15 February 2016

Keywords:
Differential Evolution (DE)
Emission
Generation Expansion Planning (GEP)
Wind power plants
Reliability indices
Tamilnadu

ABSTRACT

Generation Expansion Planning (GEP) is a challenging problem as both the supply and the demand for energy have temporal and spatial variations. It also involves the integration of system elements with a complex mix of alternative candidate plants having different physical and production capabilities and characteristics. The integration of all such elements in a system framework makes the GEP a large-scale, long-term, non-linear, mixed-variable mathematical modeling problem. The accurate solution of such realistic models is essential to create an efficient and economic power system.

The aim of this study is to determine the GEP for the candidate system, integrating all critical system elements leading to the formulation of a realistic mathematical system and the employment of GEP in the model solutions. It also demonstrates the effectiveness of DE algorithm in finding efficient solutions to the identified problem. The planning is carried out for two different planning horizons of 6 and 14 years. An approach, which is balanced, is adopted to understand the long term impact of wind additions by imposing Total Emission Reductions Constraints (TERC) and Emission Treatment Penalty Costs (ETPC) on the remaining portion of pollution. As the system is expected to get an increasing proportion of wind power plants in future, a special focus is given to study the impact of such increase. The resulting variations in different cost components including the emissions and the variations in reliability indices are also reported.

Introduction

India is planning to curb the emission by major scaling up of the renewable energy to 175 GW by 2022 outlined in Intended Nationally Determined Contributions (INDCs). At the same time, if the renewables are to provide such a large quantum of power, there have to be other conventional sources, involving some emissions such as thermal to provide capacity to handle the fluctuation in the generation from renewable (Green) sources. In the absence of large storage, providing generation flexibility means fast ramping and short startup times and efficient partial load operation. Expanding the ability of these plants to ramp and cycle of varying degrees will negatively impact their operations, maintenance schedules, and expected operational lifetimes. In the State of Tamilnadu, the study region, the proportion of renewable energy technology (RET) plants, which hovers around 40–45% of the total installed capacity, is bound to increase with the addition of 1 GW solar plants planned in the next 3 years.

The problem of selecting the best expansion alternative for their system is one of the most significant problems confronting the electric utility system planners. In general, the Generation Expansion Planning (GEP) problem is the selection of the best expansion alternative for their system [1,2]. The important objectives of GEP can be summarized as

1. Where to construct the power plant?
2. When to construct the power plant?
3. Which type of power plant need to be constructed?
4. What percentage of fuel mix ratio and penetration of renewable energy integration will help the system to perform better?

The GEP Problem has been addressed by the system planners for more than 40 years. Solving the GEP problem allows the planners to determine the generation technology and the size of generation units to be built as well as the amount of energy that can be produced by new and existing plants, taking into account the

* Corresponding author.
E-mail addresses: k.rajesh@klu.ac.in (K. Rajesh), kannaneeeps@gmail.com (S. Kannan), thangaraj.vc@gmail.com (C. Thangaraj).

http://dx.doi.org/10.1016/j.ijepes.2016.01.047
0142-0615/

constraints on construction times, life-cycle duration and the total amount of investment [3].

Many countries throughout the world have been planning the use of wind and solar energy as major substitutes to the conventional energy derived from the fossil fuels due to its non sustainability and public environmental concerns. In the last decade, the growth rate of the global installed wind capacity has been about 30% per annum [4]. Denmark, Germany and Spain are the first few countries to generate 20% of their electricity from Wind turbines [5]. In developed countries such as China, 200,000 off-grid wind turbine generators had been installed by the end of 2004, ranking it as number one in the world [6].

Sustainable energy systems of the future likely to have an increased share of the renewable energy. Wind energy accounts for 94 GW (2.5%) of the world electrical power installed capacity in 2007 [7]. In many grids, the share of the wind is significant (22% in Denmark, 20% in Spain, 17% in Germany and Portugal, 8% in Netherlands) and growing [8].

Conventional power planning offers techniques for fossil fuel power and hydro power plants. The output of a wind power plant has daily and seasonal variations, depending on the site wind regime and machine characteristics. As the share of the wind energy increases and becomes significant, the issues related to the capacity expansion planning and dispatch become important. The impact of the wind energy in the grid has been studied in terms of the capacity credit. The capacity credit of the wind power has been defined as the level of conventional generation that can be replaced with wind generation [9].

Wind energy is considered to be a very promising alternative for power generation because of its tremendous environmental, social and economical benefits. Electrical power generation from wind energy behaves quite differently from that of conventional sources. Improvements in wind generation technologies will continue to encourage the use of wind energy in both the grid connected and stand-alone systems. Therefore, it is important for power system planners and engineers to carefully consider the reliability [10] issues associated with the wind energy sources. Wind is one of the fastest growing energies for human beings, and it is an alternative source of conventional energy production as well as fossil fuel generation. The impact of wind energy is cost free and requires less maintenance as well [11].

The electric power system based on the fossil fuels has been one of the major contributors to the global carbon emissions. In an effort to decarbonise the electric power systems, policy makers have adopted measures to promote the investments in low emissions renewable electricity generation. India has a vast supply of renewable energy resources. The proportion of RET in the power systems has increased from around 7.8% in 2008 to 12.3% in 2013 and it is expected to increase to 17% of the total installed capacity by 2017 [12]. The authors have completed the impact study of RET (solar only) [13]. This is a companion work deals with the impact of Wind inclusions and its impacts.

In this work, the GEP study is carried out for Tamilnadu State to study the impact of increasing penetration of the wind power technology.

The objectives of the present study are:

1. To formulate the solution to GEP model, a representative of the power system of Tamil Nadu, India for determining the long-term impact of the introduction of wind technologies into the system.
2. To study the effect of increasing proportion of wind technology on the future generation mix for the system under consideration.
3. To determine the investment spectrum associated with varying policy propositions on the level of wind induction into the system and to identify the control of the emissions from thermal plants.
4. To estimate the Loss of Load Probability (LOLP) and Expected Energy Not Served (EENS) factors and their impact on the reliability of the system.

This paper is organized as follows: Section 'Literature review' presents the literature review, Section 'Physical system' deals with the physical system, Section 'Problem formulation and solution methodology' gives GEP problem formulation and solution methodology, Section 'Results and discussions' gives the results and discussions and Section 'Concluding remarks' provides concluding remarks.

Literature review

Many countries have goals to reduce the greenhouse gas emissions and boost the energy security by reducing the energy imports. Renewable energy is the prime means to achieve these goals. The European Union has a goal of 20% renewable energy by 2020 [14], while the renewable energy industry in Europe claims 100% renewable energy is technologically achievable by 2050 [15]. China and India are striving toward the goals of 15% by 2020. In the US, 37 of the 50 states have standards or goals ranging from 10% to 40% over varying time periods [16]. Key findings of NREL [17] suggest that it is feasible for the US to achieve 80% renewable energy by 2050; however, this theoretical feasibility has only been backed by comprehensive studies that integrate 30% wind energy [18].

High wind power generation will have significant impact on system security, stability and reliability due to the fluctuation and the unpredictable characteristics of wind speed. The integration of a large number of wind farms can have either positive or negative impacts on the performance of the power system reliability. The impacts of wind power penetration on system reliability and security are usually studied from two aspects of system operation and system planning.

In short-term system operation, spinning reserve management with wind power generation has been developed [19–24], which illustrates that spinning reserve from conventional units has to be increased with the increased wind power generation to fulfill the specific reliability and security requirements.

The power system requirements of wind power depend mainly on the power system configuration, installed wind power capacity and variation of wind power production. Wind resource variation on time scales of seconds to years affects the power system. An analysis of this impact will be based on the geographical area of interest. The impact of wind energy in the grid has been generally represented in literature in terms of the capacity credit. The capacity credit of the wind power has been defined as fraction of installed renewable capacity by which the conventional capacity can be reduced without a loss in security of supply [25].

Many studies with respect of the effects of grid integration of wind power in European countries [25–29] have reported that the major challenges include impacts on power system operating costs, power quality, imbalances and transmission and scheduling planning. The reported results indicate that wind power impacts are small at low penetrations (about 5% or less) and the effects remain moderate with penetrations approaching 20%.

The wind energy as a promising and popular source of electrical energy has been considered as a substitution candidate for conventional fossil energy resources. Wind power is expected to have a significant portion in the total electrical energy production for