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Generation expansion planning by considering energy-efficiency programs in a competitive environment

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ABSTRACT

Restructuring of the electricity industry and the development of energy efficiency solutions are the two major developments of the recent power systems. Implementation strategies in the use of energy efficiency can be made by utilizing more energy-efficient equipment or increasing penetration rate of production of new sources of energy at the generating side. These new sources of energy can be renewable sources, especially wind resource and energy storage instruments such as grid-connected electric vehicles. The vehicles can be charged during the low load and discharged during peak load. In this study, wind resources and grid-connected electric vehicles are considered as an approach for energy efficiency strategies in generation expansion planning. But, because of high investment cost, great uncertainty of wind resources' productivity and uncertainty of their supportive policies no one will invest on them without proper supportive policies in a competitive environment. So support policies for wind resource are also considered. One of the fundamental problems of supportive policies is financial support in a competitive environment. Therefore, as an innovation of the paper, grid-connected electric vehicles is used to solve the problem. In the paper, the impact of these vehicles is considered in a way that they act integrated with wind resources and thus increases the capacity factor of wind resources.

Introduction

In spite of limitations and uncertainties, which many manufacturing companies are facing in the short term and long term, a framework is an essential requirement for planning. Uncertainties of forecasted load, fuel value of generating units and strategies of investment competing companies are major cases that manufacturing companies facing during the long term. In the mid-term, price fluctuations, due to the strategic behavior of market actors, have a considerable impact on the company's operating profits. Therefore, it is necessary to use appropriate methods to model the uncertainty in the planning [1]. Another solution that has been developed over recent years in the power industry is the implementation of strategies for energy efficiency [2]. Implementation of energy efficiency strategies can be applied by using more energy-efficient equipment at the consumption side or by the increasing penetration rate of new sources of energy at the generation side. These resources can be renewable resources, especially wind energy resources or energy storage instrument such as grid-connected electric vehicle. These cars can be connected to the grid and charge in low load and discharge during peak load [3].

In [4], the effect of the penetration of wind resources in the Thailand power system has been studied. In addition, the rate of return on investment is also specified by the help of economic analysis. It was noted that wind resources are free and with modern technology it can be captured efficiently; actually it is a domestic source of energy. Also, it's a clean fuel source. Wind energy doesn't pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas. Wind turbines don't produce atmospheric emissions that cause acid rain or greenhouse gasses. Wind power is cost effective. It is one of the lowest-priced renewable energy technologies available today. In this respect it can be noted that some of its disadvantages, the strength of the wind is not constant and it varies from zero to storm force. This means that wind turbines do not produce the same amount of electricity all the time. There will be times when they produce no electricity at all. Turbines may cause noise and aesthetic pollution.

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Although wind power plants have relatively little impact on the environment compared to other conventional power plants, there is some concern over the noise produced by the rotor blades, aesthetic (visual) impacts [4,5]. In [6] a strategy to invest on wind resources are presented. This problem has been analyzed by mixed integer programming that aims to increase the net present value of the project. The answer involves determining the number and size of wind resources. Screening and ranking method for determining the best investment method is used. Sensitivity analysis has also been used to assess the effects of investment. In [7] the problem of investment and the exploitation of wind resources is examined. Installation costs of wind resources are investment cost, exploitation cost, maintenance cost and the cost of land. The selection process is obtained by solving the optimization problem, while the classification process is conducted through the parameters of capacity index, energy density, benefit to cost ratio and the ratio of benefit to area. In [8] the impact of carbon reduction in generation expansion planning is studied. In this article, the use of wind resources is considered as one of the suggestions. Also, the random parameters are considered. One of the important issues in the generation expansion planning is determining an optimal combination of power resources. In reference [9] the use of large amounts of wind resources is examined. Some studies consider the effects of using clean fuels and storage technologies. Some researchers have impact on reduction of carbon and other pollution in different ways but it is necessary to develop a comprehensive plan for generation expansion planning model to reflect the effects of various factors on carbon reduction. These factors include the mechanisms of carbon exchange, the obligation and commitment to carbon reduction and also to consider tax on carbon. To model the uncertainty of carbon reduction, scenario analysis can be used. In [10] long-term planning with short-term operation is considered while investment candidates are the traditional and renewable sources of energy. In [11] the impact of prediction errors on load and wind resource production is studied by Monte Carlo simulation. During the last years NERC published a report on planning and operation of a power system by considering the large wind sources [12]. In [13] an integrated model for power system generation expansion planning is considered. In [14] investment on the wind resource is studied. The study was conducted by considering the random nature of load and wind resource through the various scenarios. Market structure is considered as a pull base and regional prices are calculated at each bus. The problem has two stages, the upper and the lower. The upper level represents an investment and operation decisions while the lower level determines how the market-clearing is. In [15] maximum penetration of wind resources in a power system with a fixed line capacity is determined by solving the optimization problem while network security standards are maintained at the predetermined values. In [16] the cost benefit analysis has been done for grid-connected wind resources. In [17] numerical algorithm to calculate the maximum amount of wind resources attraction in an independent network has been suggested. In [18] linear programming model is proposed to determine the optimum combination of technology where wind resources are considered as a negative load. In [19] a review of the computer tools have been made.

Based on a comprehensive review of the literature that has been done in this area it is obvious little work has been done on energy efficiency solutions. In this article, wind resource and electric vehicles have been considered as energy efficiency solutions. Note that in a competitive environment without implementing supportive policies for wind resources investors won't invest on these resources. This is mainly because of great uncertainty in wind resource productivity, investment costs and also uncertainty in supportive policies of the resources. So, supportive policies for wind resource are also considered. One of the major problems of these supportive policies is to supply costs in a competitive environment. Therefore, use of grid-connected electric vehicles is presented as an approach to reduce this problem in this paper. Effects of electric vehicles on the supportive policies are also examined. The car has the feature that can be charged in some hours and discharged in some other hours. Therefore, these vehicles can affect to designed supportive policies. In this study effect of these vehicles has been considered in a way that these vehicles act integrally with wind resources and thereby increase the capacity factor of wind resources. Green energy sources such as wind, solar and electric vehicles despite their advantage have high investment costs and high uncertainty. In order to develop these resources in the green industry, having a good plan for investment, operation and maintenance should be considered. The goal of this article is generation expansion planning considering wind resources and electric vehicles. On the other hand in today's power networks, intelligent networks are discussed. As seen in Fig. 1, the smart grid has three dimensions: environmental issues, operation issues and system reliabilities. Also, the role of electric vehicles, renewable resources and energy efficiency solutions are shown in Fig. 1.

Novelties of this study are to develop a framework for generation expansion planning problem with regard to energy efficiency solutions. As previously mentioned, utilization of wind resource and electric vehicles is proposed as a solutions in energy efficiency. Regardless of supportive policies for wind resources, investment risk for investors on the resources is increasing. On the other hand, determined policies shouldn't be inconsistent with a competitive market. Noting that financing cost of supportive policies for wind resources is difficult, especially in a competitive environment. The impact of electric vehicles on supportive policies has also been studied. The idea of using electric vehicles in this article is that through the integration of these vehicles increase wind resource capacity index so that investors with fewer incentives invest in these resources.

The remaining part of this paper is organized as follow. In section 'Wind resource modeling' wind resource modeling is done. The mathematical formulation of the generation expansion planning problem by considering the wind resource and electric vehicles has been done in section 'The mathematical formulation of the problem by considering wind resources and electric vehicles'. In section 'The proposed framework for integrating wind resources and electric vehicles', a framework for generation expansion planning problem considering wind resources as energy efficiency solutions is developed. Furthermore in this chapter, the impact of integrated electric vehicles with the wind resources on the generation expansion planning problem also would be studied. In section 'Numerical studies' simulation of generation expansion planning problem with regard to energy efficiency solutions have been conducted and the results have been analyzed. Finally, conclusions and recommendations of the study are presented in section 'Conclusion'.

Wind resource modeling

In this study the implementation of energy efficiency solutions with integration of wind resources and electric vehicles have been done. Therefore, it is essential to model wind resources. Wind resources have different outputs depending on the geographical locations. Electric power generated by wind resources is dependent on the speed and direction of wind and randomly changes over time and geographical locations. As previously mentioned, the wind has a random nature and any random phenomena can be modeled by using probability distribution function. Distribution of wind speeds can be described typically by using Weibull distribution. Wind speed probability density function ($f_v(v)$), can be calculated as follows: