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Generation expansion and retirement planning based on the stochastic programming

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ABSTRACT

This paper develops a mathematical model based on the stochastic programming for simultaneous generation expansion and retirement planning. Retirement decision of the existing generating units is accommodated since these units are aging more and more. The proposed method is formulated as an optimization problem in which the objective function is to minimize the expected total cost consisting of the investment required for commissioning new units, operation and maintenance costs, the retirement salvage cost, and the system risk cost. The problem is subjected to a set of generating unit and system physical and operational constraints. The modeling of energy limited units is also devised in a probabilistic manner as an underlying requirement in practical studies. The Monte Carlo simulation approach is used to consider the component random outages. A large number of scenarios are simulated and the scenario reduction technique is applied to tailor the computational effort within a tractable range, which is essential for large-scale problems. Numerical studies are conducted on the IEEE-RTS79 and the performance of the proposed model is investigated. As expected, the retirement option could be beneficial particularly when the contribution of aged units in the system unreliability becomes more severe.

1. Introduction

Demand growth in power systems necessitates Generation Expansion Planning (GEP) in which the type, size, location, and commissioning time of new generating units in a planning horizon are to be determined. The final solution of GEP is based on the minimum cost and/or optimum reliability taking into account various constraints such as capacity of units and lines, operating constraints, and budget restrictions. Generally speaking, GEP is a combinatorial large-scale, mixed-integer, and non-linear problem; accordingly a wide range of heuristic and classical optimization approaches have been applied.

The GEP problem has been coped with several heuristic optimization approaches among them are genetic algorithm [1,2], particle swarm optimization technique [3], and a combination of heuristic approaches [4]. However, there is a tendency in formulating the planning problems as a mathematical optimization model as there is no guarantee for optimality of the results in heuristic approaches and they request extremely long execution times particularly for real-scale problems. Among classical optimization techniques, the Mixed-Integer Programming (MIP) [5] has been recognized with a satisfactory performance. MIP method offers a great flexibility in modeling different aspects of the problem and could guarantee a solution that is globally optimal or one within an acceptable tolerance. Decomposition techniques have been also employed in GEP problem to overcome its extreme dimensionality. A simple but effective decomposition method for calculating the Loss of Load Probability (LOLP) with a strict budget constraint was elaborated in [6]. Reference [7] investigated the application of Bender's decomposition technique based on the genetic algorithm to achieve the GEP optimum solution. In [8,9], Bender's decomposition was exploited in the GEP problem and in the concurrent generation and transmission planning, respectively. The GEP problem, although has been primarily defined for the planning of bulk generation facilities mainly connected to the transmission level, is also being applied in the distribution networks for specifying the capacity, type, and location of distributed generation units [10].

One of the key requirements in the GEP problem is the reliability concern and its impact on the planning decisions [11]. Inclusion of reliability criteria additionally expands the GEP problem and if not considered would result in uneconomic overdesign or cost-effective vulnerable schemes. In fact, random nature of power system elements has a great effect on the system performance. In this manner, three categories of approaches are identified:

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deterministic, probabilistic, and scenario based. In [12], the outage possibility of components is modeled as a deterministic criterion in expansion planning. Probabilistic approaches for modeling the uncertainty are also incorporated in expansion planning in which stochastic parameters are not described by unique values, but rather by probability distributions [13]. Reference [14] assumes a probabilistic distribution function for each stochastic parameter and solves the problem using genetic algorithm approach. In [15], a decomposition method for reliability modeling in expansion planning is proposed. In [9], the stochastic programming is used to model the uncertainty. Even though the probabilistic approaches are more accurate, they put computational burden to the expansion planning problem. Scenario based approaches overcome this difficulty by assessing a selected set of scenarios generated according to the probabilistic distribution of stochastic parameters [16]. To date, scenario-based techniques have been successfully applied in the various power system planning problems [17–19]. In these references, a large number of scenarios generated by Monte Carlo simulation are reduced in an optimal way to overcome the numerical complexities.

A less-investigated issue in the GEP problem is the incorporation of equipment retirement decisions in the problem. As a matter of course, power systems are getting older and more generating units are facing the aging deficits. Besides, new technologies are of desirable features such as the high production efficiency. To the best of authors' knowledge, there is no thorough study emphasizing the aging and retirement of generation facilities and their concurrent assessment in the GEP problem. Reference [20] discussed a case study conducted in 1999 in which the retirement of a generator located in the north region of an island has been discussed. However, the GEP is not covered in the proposed model. As a result of increasing operation cost of aged facilities and their significant role in the system unreliability and risk cost, the retirement of aged units could be an economic option in the GEP problem. Furthermore, owners of retired units could earn more profits with selling the equipments and/or the field. Generation Expansion and Retirement Planning (GERP) is accordingly introduced in this paper as an open research area.

This paper derives an efficient mathematical model for the GERP problem in which all analyses are conducted in a probabilistic way through the stochastic version of MIP. Recourse-based stochastic programs employ a discrete distribution of the random parameters and therefore can be solved by effective optimization algorithms. The proposed model is expanded over a number of scenarios which simulate the random outage of both generating units and transmission lines. The scenario reduction, as an essential means for solving practical large-scale optimization problems, is employed here for decreasing the model size in an optimal way. The proposed approach is applied to both Hierarchical Levels I and II (HLI and HLII) [20]. The first level (HLI) focuses on the generation sector and its adequacy in satisfying the corresponding load. The second level (HLII) refers to the composite generation and transmission system and its compound ability in delivering energy to the major load points. The performance of the proposed model is thoroughly discussed based on numerical evidences.

The rest of the paper is organized as follows. Section 2 provides the uncertainty modeling of generating units and transmission lines. Section 3 presents the proposed methodology and formulation. Section 4 elaborates simulations on the IEEE-RTS79 network. Concluding remarks are drawn in Section 5.

2. Uncertainty modeling

Over recent decades, deterministic approaches have been gradually replaced by probabilistic ones in power system planning studies [20]. Probabilistic approaches, however, bring about heavy computational burdens on the optimization problem of expansion planning. The solution is either to use the parallel processing approach or to employ the scenario-based technique. The former necessitates hardware facilities which are not usually accessible while the latter could be generally applicable. This section discusses a scenario-based approach by which component random outages are effectively taken into account.

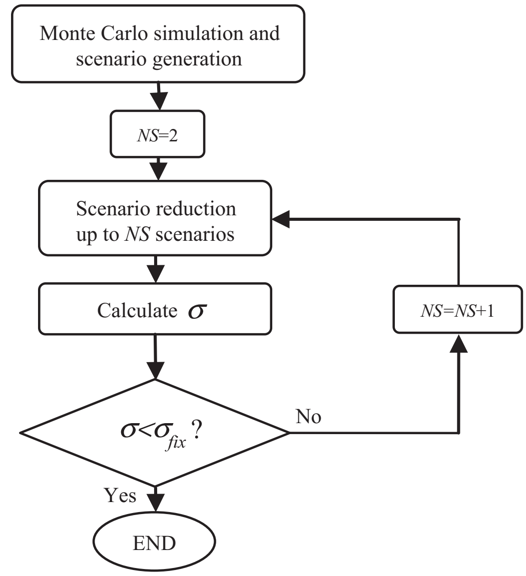

Fig. 1. Flowchart of the scenario reduction algorithm.

Uncertainty modeling initiates with generating a large number of scenarios by the means of Monte Carlo Simulation (MCS). In fact, these scenarios are 0/1 strings that determine the state of components in each scenario. The number of scenarios in MCS is irrespective of the system size, and this characteristic makes it applicable in large-scale problems. In its most plain form, Simple Sampling approach is used in MCS with the predefined variance of 0.05.

Next, similar scenarios are determined and the probability of each scenario is calculated with respect to the number of occurrences experienced. The final step is to take a scenario reduction technique which is essential for solving scenario based optimization problems in large-scale power systems. Among various algorithms of scenario reduction are fast backward, a mix of fast backward/forward, and a mix of fast backward/backward methods [21]. Also, several efficient algorithms based on backward and fast forward methods were developed in [22]. In general, these methods are different from the results accuracy and execution computational time perspectives. For a large number of initial scenarios, the fast backward method is the fastest one, while the results of the other two methods are more accurate but at the expense of higher computational times.

Fig. 1 depicts the flowchart of scenario reduction algorithm. The number of retained scenarios, namely *NS*, is determined based on a stopping criterion, σ_{fix}, which is adopted as the maximum estimated standard deviation of loss of load expectation (LOLE) [18], namely σ. The formulation of the deviation index, σ, is:

$$\sigma = \frac{1}{NS}\sqrt{\sum_{s=1}^{NS}\frac{(LOLE_s - \overline{LOLE})^2}{NS-1}} \tag{1}$$

Typical values for σ_{fix} are of 0.05 or 0.01 [18] and it is assumed here to be equal to 0.05. Therefore, both the predefined variance for simple sampling in MCS and σ_{fix} are set to 0.05 in this study.