



Reliability constrained generation expansion planning by a modified shuffled frog leaping algorithm



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ABSTRACT

This paper introduces a modified shuffled frog leaping algorithm (MSFLA) to solve reliability constrained generation expansion planning (GEP) problem. GEP, as a crucial issue in power systems, is a highly constrained non-linear discrete dynamic optimization problem. To solve this complicated problem by MSFLA, a new frog leaping rule, associated with a new strategy for frog distribution into memplexes, is proposed to improve the local exploration and performance of the SFLA. Furthermore, integer encoding, mapping procedure and penalty factor approach are implemented to improve the efficiency of the proposed methodology. To show the effectiveness of the method, it is applied to a test system for two planning horizon of 12 and 24 years. For the sake of methodology validation, an ordinary SFLA as well as a Genetic Algorithm (GA) are both applied to solve the same problem. Simulation results show the advantages of the proposed MSFLA over the SFLA and GA.

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Introduction

Generation expansion planning (GEP) is a problem to determine when, where, what type, and how much capacity of new power plants should be constructed over a long-term planning horizon to meet a forecasted demand within a pre-specified reliability criterion [1]. GEP is an important decision-making activity for electricity industry as well as utility companies. The main objective of a conventional GEP problem is to minimize the total fixed and variable costs of power systems. Long-term GEP model is a non-linear and highly constrained discrete dynamic optimization problem. The high non-linearity feature of a GEP problem is regarded to the nature of the production costs, associated with a set of non-linear constraints [2,3]. So far, several methods have been applied to solve such complicated problem. In the classic optimization approaches, dynamic programming (DP) is one of the most used algorithms in GEP [4]. Because of high dimensionality of practical power systems, however, DP is not an efficient method. Overcoming this difficulty in commercial packages like WASP [5], heuristic tunnel-based techniques are employed in DP routine, where users specify the configurations in advance, and the modified tunnels are successively considered to arrive at local

optimums. Recently, among classical optimization techniques, the mixed-integer programming is widely used in the GEP problem modeling [6–8]. In [7], a mixed-integer linear programming (MILP) model is developed for solution of the centralized GEP problem. A monthly time step is employed to consider mid-term scheduling decisions. In [8], demand response programs are incorporated in the GEP problem and formulated as a MILP model.

Over the last decades, there has been a growing concern in heuristic algorithms inspired by the observation of natural phenomena. It has been shown by many researches that these algorithms are good alternative tools to solve complex computational problems [9–14]. In [12], an improved Genetic Algorithm (GA) with stochastic crossover technique and elitism are applied to solve the GEP problem. In [13], the meta-heuristic techniques such as Genetic Algorithm, Differential Evolution, Evolutionary Programming, Evolutionary Strategy, Ant Colony Optimization, Tabu Search, and Simulated Annealing are applied to solve the GEP problem and compared with DP. Results show that drawbacks of DP can be overcome by these meta-heuristic techniques. Particle Swarm Optimization (PSO) algorithm is used in [14] to solve the GEP problem in the deregulated electricity market. A comprehensive review of the GEP problem from different aspects and views such as modeling and solving methods is presented in [15].

Among the evolutionary procedures, Shuffled Frog Leaping Algorithm (SFLA) is a meta-heuristic optimization method inspired from the memetic evolution of a group of frogs when seeking for food [16]. SFLA was originally developed by Eusuff and Lansey in

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2003 [17] for optimal pipe network expansion problem. It is implemented to many research areas [18–22] because of the advantages of the algorithm, and some modifications are proposed to overcome the difficulties associated with the basic SFLA. In [23], a search-acceleration parameter is used to formulate the basic SFLA and implemented to optimize the construction projects' time–cost trade-off decisions. An efficient multi-objective modified SFLA is used to solve distribution feeder reconfiguration problem in [24]. In [25], a modified SFLA is presented by adding a new mutation operator to the algorithm to reduce the processing time and avoid trapping in local optimum. In [26], the leaping rule is improved by extending the leaping step size and adding a leaping inertia component to account for social behavior. In [27], a modified SFLA with GA crossover is introduced to solve economic dispatch problem by combining the SFLA and GA techniques. A hybrid algorithm called Shuffled Differential Evolution are presented in [28], using the benefits of SFLA and Differential Evolution algorithm and integrated with a novel mutation operator to solve economic dispatch problem.

In this paper, a Modified SFLA called MSFLA is proposed to overcome the drawbacks of the basic SFLA, in which a new way of frog distribution into memplexes, and a new frog leaping rule are used to improve the local exploration and performance of the SFLA. In order to demonstrate the effectiveness and feasibility of the proposed algorithm, it is applied to solve a reliability constrained GEP model. The numerical results are presented on a test system used in [12,13,29] with two different 12-year and 24-year planning horizons. Furthermore, integer encoding, mapping procedure, and penalty factor approach [13] are deployed to increase the efficiency and ease of implementation for solving GEP problem. The obtained results by applying MSFLA are compared with the ordinary SFLA for the same systems; also with GA results, as in the most reported applications in solving GEP problem [3,12,29–31].

Optimal GEP problem model

Solving the GEP problem is equivalent to determine the optimum expansion plan over a planning period that minimizes total costs, including investment, operating, and outage (energy-not-served) costs minus the salvage value of the new units under several constraints. In the following, detailed description of each objective function part is provided.

Capital investment and salvage value costs

Denote the capital investment cost of the k th ($k = 1, 2, \dots, N$) unit type as Cl_k . If the capacity vector of all candidate unit types in the stage t is U_t , the present value of total investment and salvage value costs are given by:

$$\bar{I}(U_t) = (1+i)^{-t'} \times \sum_{k=1}^N [Cl_k \times U_{t,k}] \quad (1)$$

$$\bar{S}(U_t) = (1+i)^{-T'} \times \sum_{k=1}^N [\delta_{k,t} \times Cl_k \times U_{t,k}] \quad (2)$$

in which

$$t' = t_0 + s \times (t - 1) \quad (3)$$

$$T' = t_0 + s \times T \quad (4)$$

where i is discount rate, $\delta_{k,t}$ is the salvage factor of unit k added in stage t ; t_0 is the number of years between the reference date for discounting and the first year of study, s is the number of years in each stage and T is the length of the study period (total number of

stages). Calculating the present values of the cost components of (1) and (2), it is assumed that the capital investment for a candidate unit, suggested by the expansion plan, is made at the beginning of the stage in which it goes into service, and the salvage value occur at the end of the planning horizon.

Operating and maintenance costs

This objective function part is the total present value sum of the generation costs for existing and new candidate units and assumed to occur in the middle of the corresponding planning stage,

$$\bar{M}(X_t) = \sum_{y=0}^{s-1} \left[(1+i)^{-(t'+0.5+y)} \times \sum_{k=1}^N [FOM_k \times X_{t,k} + VOM_k \times G_{t,k}] \right] \quad (5)$$

where $X_{t,k}$ is the capacity and $G_{t,k}$ is the expected energy produced for all existing and candidate units of type k in stage t ; FOM_k and VOM_k are fixed and variable operating and maintenance (O&M) costs, respectively. For each generation units, fixed costs are proportional to their capacity, where variable costs are calculated by the amount of energy that is produced in each planning horizon stage. Therefore, proper estimation of expected energy, produced by each unit, is required to provide more accurate estimation of the variable costs. Power system Probabilistic Production Simulation (PPS) is a tool that considers the relevant uncertain factors like the future demand fluctuation, the random outage of generating units, etc. in power system production process [2]. By considering the random factors, not only the production costs are estimated more reasonable and more accurate, but also the generating system reliability indices such as Loss of Load Probability (LOLP) and Expected Energy Not Served (EENS) are obtained. In this paper, the PPS is performed using the equivalent energy function (EEF) method [2], which is described in Section The equivalent energy function method.

System outage cost

In recent years, deregulation changed the traditional GEP paradigm and encouraged new challenges in the era of power systems planning. In such environment, customer satisfaction with better supply will greatly influence the utility's competitive ability. Hence, it is highly desirable that the utilities find ways to reflect customer satisfaction in their planning procedure. In this paper, by using reliability index, EENS the power system outage (energy-not-served) costs are considered in the proposed objective function. Then, it is attempted to consider the customer satisfaction level in generation planning by minimizing the system outage costs,

$$\bar{O}(X_t) = \sum_{y=0}^{s-1} \left[(1+i)^{-(t'+0.5+y)} \times EENS_t \times CEENS \right] \quad (6)$$

where $CEENS$ is the cost of $EENS$ in dollars per megawatt hour. In order to calculate the present values of the cost, it is assumed that the cost occur in the middle of the corresponding stage.

Objective function

The GEP objective function is to minimize the total present value of investment, operating and outage costs minus the remaining value of the new units at the end of the planning horizon. The objective function of the GEP problem can be represented by the following expression:

$$\min C = \sum_{t=1}^T [\bar{I}(U_t) + \bar{M}(X_t) + \bar{O}(X_t) - \bar{S}(U_t)] \quad (7)$$

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