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Generation Resources Planning Based on the Nodal Model

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Abstract

Generation resources planning also known as generation expansion planning (GEP) is mainly performed to denote the place, capacity, time, and technology of new installed generation units in the power system. This paper presents generation resources planning based on the nodal model. In the proposed model, all generation units are installed on one bus and network in not included. The planning is managed as an optimization programming and solved by using genetic algorithms (GA).

Keywords: Genetic algorithms; generation resources planning; nodal model; power system planning.

Introduction

In recent decays, along with increasing the electricity demand and load, the electric power systems have been expanded and new power plants and lines have been build and installed[1,2]. In this regard, it is important to denote the place, time, capacity, and technology of new installed units. Generation expansion planning (GEP) denotes the best and optimal planning to expand the power system capacity. GEP mainly deals with costs and minimizes the cost or maximizes the profit, because cost is an important item in decision-making. GEP mainly consider different issues in the planning such as costs, risks, and benefits, in order to denote the best planning among the available options. GEP mainly denotes the place, time, capacity, technology of new units, which should be added to the system over a long-term or mid-term planning horizon 10 to 30 years[3-12]. Demand and electricity price are also very important in deregulated electricity market[13].

A reliability constrained generation expansion planning (GEP) in the presence of wind farm uncertainty in deregulated electricity market has been presented by Hemmati R. et.al.[14]. In this paper, the expected profit of all GENCOs is maximized subject to security and reliability constraints and wind farm uncertainties are also included in the planning. The uncertainty is modeled by probability distribution function and Monte-Carlo simulation is used to deal with such a situation. The proposed GEP is solved by using particle swarm optimization (PSO) method. Tohidi Y. et.al.[5] presents a mathematical model based on the stochastic programming for simultaneous generation expansion and retirement planning, where, retirement planning deals with aging phenomena. This paper aims at minimizing 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. Energy limitation is modeled by a probabilistic method and Monte Carlo simulation is used to deal with it. A Multi-period Multi-objective GEP incorporating sustainable energy sources is presented by Aghaei J. et.al.[15]. This paper considers costs, environmental impact, and reliability in the objective function and denotes the optimal size, time, and technology types of the generating units through a multistage planning horizon. This paper presents an analytical probabilistic approach to evaluate the system reliability and a Corrected Normal Boundary Intersection (CNBI) method is implemented. Pereira A.J.C. et.la.[6] addresses a GEP model based on the system dynamics to find the relationship between the variables and parameters. Regarding the proposed method presented by this paper, the demand and electricity price can be estimated in the future. These estimated parameters are used by private companies such as GENCOs and these GENCOs denote their individual plans. These plans are sent to coordination level, which is managed by ISO. At coordination level, some global indexes such as reserve margin and reliability are checked by ISO. This paper tests the approach based on the realistic generation system of Portuguese/Spanish system. The planning objective is to find the most adequate expansion plans in the presence of renewable generation units such as wind farms and evaluation of CO_2 emission costs. Three objectives[12] are defined for GEP as maximizing the economic return of the planning, minimizing the environmental emission, and minimizing the risk of fuel price. In additions, renewable energy sources such as wind farms and solar are considered in the planning and their effects is evaluated. In order to consider the realistic conditions, some incentive systems such as carbon tax, emission trade, quota obligation, and feed-in-tariff are incorporated in the planning. Modified Normal Boundary Intersection method is used to solve the problem. Pantos M. et.al.[16] considers the relationship between electric power system (EPS) and natural gas system (NGS) in GEP problem. In this regard, a stochastic GEP is proposed. This paper aims at supplying the load with acceptable level of reliability as well as expanding the system with minimum cost. This paper considers several constraints in the EPS and NGS. The uncertainties are taking into account by using Monte Carlo simulation. Yonghan Feng et.al.[17] presents a heuristic scenario reduction technique in GEP. Electricity demands and fuel prices are considered as uncertainty and two sets of scenarios are randomly generated for them. The first set is limited through applying increasing length time periods in a tree structure and the second set is controlled through its lattice structure with periods of equal length. In additions, a heuristic scenario reduction technique namely forward selection in wait-and-see clusters has been applied.

In this paper, generation expansion planning is presented based on the nodal model. Several generation types such as hydro, nuclear, coal, oil, and combustion turbine are considered in the planning as expansion candidates. The planning is managed as a constrained mathematical programming and solved by using genetic algorithms. Simulation results demonstrate the effectiveness of the planning at minimizing cost and satisfying the constraints.

Mathematical Formulation: GEP problem is a constrained optimization programming and can be mathematically formulated as below:

$$\text{Max}\left[\sum_{t=1}^{T}\sum_{j=1}^{C}\left(IC_t^j \times XT_t^j + OC_t^j \times XT_t^j\right)\right] \tag{1}$$

s.t.

$$XT_t^j \le Max\_XT_t^j \qquad t=1,2,3,...,T; \tag{2}$$

$$\sum_{j=1}^{C} XT_t^j \le XC_t \qquad t=1,2,3,...,T; \tag{3}$$

$$RM^{\min} \le RM \le RM^{\max} \tag{4}$$

$$\sum_{t=1}^{T}\left(IC_t\right) \le Max\_IC \tag{5}$$

$$\text{t} = 1,2,...,\text{T}; \tag{6}$$

$$\text{j} = 1,2,...,\text{M}; \tag{7}$$

The proposed set of equations provides a constrained optimization programming. In this programming, equation-1 shows the objective function-2 to 7 indicate the constraints. The objective function-1 minimizes the planning cost at all stages. Where, the investment and operation costs are minimized. The first term shows the investment cost (IC) of the installed technology *j* at stage *t* of the horizon planning *T*. The second term shows the operation cost (OC) of the installed technology *j* at stage *t* (XT^j_t) of the horizon planning *T*. Constraint-2 demonstrates that the installed technology *j* at stage *t* should be smaller than a specified value at all stages. Constraint-3 denotes the total installed capacity at stage *t* should be smaller than a specified value at all stages. Constraints-4 shows the reserve margin and constraints-5 represents the maximum invest cost of planning as a constraint. Relationship-6 indicates the stages of the horizon planning and constraint-7 shows the number of included technologies in the planning.

Genetic algorithm: Optimization algorithms have been developed to deal with the mathematical problems based on a new procedure[18,19]. Genetic algorithm (GA) is a heuristic optimization method that follows the natural process. This method is mainly used to solve the optimization problems. GA belongs to evolutionary algorithms (EA) which use the natural evolution in their solving process such as inheritance, mutation, selection, and crossover[20].

In GA, at first, an initial population is randomly generated and this population is moved toward the best solution by using crossover and mutation during the optimization process. Each row of the population is called an individual. The new population in each iteration is called a generation. In each generation, a fitness function or objective function is calculated for each individual. The best individuals are chosen from the current population, and the rest individuals are modified based on the crossover rule and a new generation is formed. This process is iterated until the convergence of algorithm. A standard representation of each individual is as an array of bits and each bit is defined between its minimum and maximum allowable ranges. During the optimization process and following the mutation and crossover, the bits should not breaks the minimum and maximum allowable limits and should lie between the defined areas. Therefore, it is necessary to consider this limitation in the programming.

Initialization: In order to generate the initial population, a random number is generated for each bit. The population is a matrix and each row of this matrix is an individual, and each element of an individual is a bit. The population size depends on the nature of the problem and mainly defined by the planner. Each bit is generated in the allowable limits which are defined by the planner based on the nature of the problem.

Selection: During the optimization, the fitness function is calculated for all individuals and the best individuals are chosen to form the new generation. In fact, the selection process is a fitness-based process, where fitter solutions are typically more likely to be selected. The better individuals are combined to form the new individuals and formation of new generation. This issue is a realistic phenomenon in the real world, where the stronger animals can save their generation and weaker ones become extinct.

Crossover and Mutation: Crossover and mutation are two importance parts of GA. After selection process and choosing the better individuals and removing the bad individual form the current generation, it is required to form the new individuals instead of the removed ones. The crossover procedure produce the new individuals based on the selected individuals. There are many methods to produce the new individuals such as calculation of mean and etc. However, the new individuals are formed equal to number of the removed ones.

Termination: This optimization process is iterated until a convergence condition is reached. Common convergence conditions are: satisfying minimum criteria; fixed number of iterations; computation time is reached, manual inspection and so forth.

Test System

In order to evaluate the proposed method, a test system is considered and data are provided in table-1[21]. The proposed test system comprises five generation types as hydro, nuclear, coal, oil and combustion turbine and each generation type contains several units. The total capacity before planning is 4100 MW and peak demand is 3550 MW. The load levels over the horizon planning are presented in table-2[21]. Where, three stages are considered for expansion. The other necessary data for planning are provided in table-3[21].

Simulation Results

The proposed planning is simulated based on the test system given in the previous section. The simulation results are provided in table-4. It is seen that different generation units are installed in all stages in order to cope with the system conditions and satisfying the constraints.

It is seen that the units with high investment cost are installed in initial stage and on the other hand, the units with low investment cost and high operation cost are installed in last stage. This procedure minimizes the total cost of planning. In addition, the system constraints are satisfied at all stages of the horizon planning.

Conclusion

In this paper a generation expansion planning based on a nodal model was presented. In the proposed planning, several generation types such as hydro, nuclear, coal, oil, and combustion turbine were included and each generation type contained several units. The proposed planning was managed as a constrained mathematical programming and solved by using genetic algorithms. Simulation results showed that the proposed methodology can successfully minimize the total cost of planning and satisfy the constraint.

Table-1
The data for generation units

Unit Type	Number of Units	Capacity (MW)	Fuel Cost ($/kWh)	Operation Cost ($/MW)	For
Hydro	4	200	0	235	0.12
Nuclear	2	650	2.41	113.75	0.055
Coal 1	2	400	4.21	450	0.09
Coal 2	2	200	4.21	516	0.15
Oil	2	300	11.3	195	0.36
Combustion Turbine 1	2	50	12.16	235	0.015
Combustion Turbine 2	4	25	12.15	140	0.0075

Table-2
Forecasted peak demand

Stage	0	1	2	3
Peak Demand (MW)	3550	5500	6800	8200

Table-3
The technical and economical data of generation units

Unit Type	Capacity (MW)	Capital Cost ($/kW)	Fuel cost ($/kWh)	Operation Cost ($/MW)	Life time (year)
Nuclear	650	625.5	2.41	113.75	30
Coal 1	400	635	4.21	450	25
Coal 2	200	595	4.21	516	25
Oil	300	255.75	11.3	195	25
Combustion Turbine 1	50	152	12.16	235	5
Combustion Turbine 2	25	100	12.15	140	10

Table-4
The installed technologies in stages of horizon planning

Stage	1	2	3
Hydro	1	0	0
Nuclear	1	0	0
Coal 1	0	1	0
Coal 2	0	0	0
Oil	0	1	0
Combustion Turbine 1	0	0	1
Combustion Turbine 2	0	0	1

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