Application of Metaheuristic techniques to generation expansion planning problem (1)

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ABSTRACT: This paper reviews Metaheuristic techniques utilized in solving the generation expansion planning (GEP) problem. GEP isa large scale constrained nonlinear optimization problem. The best expansion plan could be found through comparison of every available plan. Considering the expanded dimensions of this problem concerned with the calculation times, this issue is not feasible. Therefore, in order to reach the ultimate optimal solution, different techniques are used for shortening the calculation times and also reducing the number of variables. Throughout the first part of this paper, different techniques of generation expansion planning including Particle Swarm Optimization (PSO), Tabu Search (TS), Artificial Neural Network (ANN), Cross-Entropy (CE) and finally the Non-dominated Sorting Genetic Algorithm (NSGA_II) are introduced. Also the majority of reported literatures based on the above mentioned techniques are reviewed.

Key Words: Generation Expansion Planning (GEP), Metaheuristic Techniques

INTRODUCTION

Generally speaking generation expansion planning is defined as a response to the question that what type of power plants and with what capacity should be constructed and where and when these power plants should be installed and join the network in a long-term time period. In the beginning process of planning, the sole considered criterion was minimizing the general costs (constant and variable costs). Later on other criteria such as safety, quality of supply and reliability were added (Meza et al., 2009; Wuet al., 2004) presently another criterion, i.e. minimizing the spread of the air pollutant gases has been added to the overall of the mentioned criteria (Delgado et al., 2007). In addition to the stated criteria for the system, certain limitations including limitation of capacity, generation and operation should be considered as well (Zhu and Chow 1997). At first glance, the behavior optimization of a large system, which covers diverse parts, can be regarded as a concentrated problem and solved through the available techniques and tools. But in practice and in most cases this is not possible. The point is that solving such problems demands comprehensive data about the targets and principles of every element. Since these parts and segments are distinct both geographically and functionally, possibly collecting their related data is either impossible or time consuming. In order to optimize the determined goals for the restructured power systems, one should also consider the aspects related to coordinating within the decomposition techniques. In other words one should be able to coordinate the system elements through limited data in order to have access to the optimized solution (Shahidehpour and Marwali, 2000)

The problem regarding generation expansion planning has always encountered challenges due to different reasons (Phuphaet al., 2012). The first issue is uncertainty in parameters and input data as a result of the long term nature of the problem. In this relation one can point to uncertainty in demand of unpredicted loads, fuel cost, technical and economic features, modern techniques of generating electrical energy, time for the establishment of utilized devices and also the environmental rules and regulations. The second problem appears when several objectives are considered simultaneously. These objectives could be minimization of final cost, destructive environmental effects, and maximization of system reliability and the safety of supply (Meza, 2006). Generation expansion planning includes two processes; calculation of generation costs, and figuring out the best and most affordable design for expansion. Considering coincidental factors such as demand, stop of generation units and etc., generation costs could not be calculated precisely. Besides, a noticeable portion of system costs is linked to generation costs (Wang and McDonald, 1994). Meanwhile, the cost function is a nonlinear function due to the nonlinear features of generation units.
Different optimization methods are applied to find the best expansion plan including; linear programming, nonlinear programming, complex integer programming, and dynamic programming. The major principles of the problem are surveyed through two approaches; stochastic method and deterministic method (Shahidehpour and Marwali, 2000). In the former method factors bearing uncertainty are considered implicitly, while in the deterministic method the function of system within various scenarios which will possibly take place, are surveyed. Therefore due to the high number of simulations, a rapid optimization method is required.

The comprehensive achievement of GEP and finding the absolute optimized solution is carried out by thorough calculation and comparison of the general cost of the plan. This is true while in a problem we have an N type of variant units and T years of study durations, yet from each type of units in each year n units are constructible and as a result the number of types reaches \( n+1 \). Clearly enough, in a practical problem a long time is needed for the comparison of all potential plans. As a result the NLP, LP and DP methods are problematic in figuring out the optimized solution.

**Implementation of Generation Expansion Planning Problem**

Metaheuristic methods can be defined as a research repetitive method. A combination of different concepts uses within the search area for both the survey and exploitation of solutions in the search space (Glover and Laguna, 1997). Before solving, the problem is changed and they are compared with various metaheuristic techniques (Kannan et al., 2005). These changes are as follows:

1. Method of virtual mapping procedure (VMP)
2. Penalty factor approach (PFA)
3. Duration of intelligent initial population generation
4. Implement by applying individual techniques

**Metaheuristic Techniques**

The optimization algorithms and methods are divided into two categories; exact algorithms and approximate algorithms (Wu et al., 2004). Exact algorithms have the potential to obtain the optimal answer very accurately, but they are inefficient about difficult optimization problems and the time of their solution increases in such problems exponentially. Approximate algorithms can find good answers (close to optimized one) within a short period for difficult optimization problems. Meanwhile the approximate algorithms are also divided into two groups; heuristic algorithms and metaheuristic algorithms. Heuristic algorithms bear two major problems; their position within local optimizations and their incompetence for application in various issues. Metaheuristic algorithms are a good candidate for the purpose of solving the problem related to heuristic algorithms. As a matter of fact, metaheuristic algorithms are one of the types of approximate optimization algorithms which have output mechanisms from the local optimization and are applicable in vast fields of problems.

**PSO Algorithm (Particle Swarm Optimization)**

The particle swarm optimization algorithm was introduced as one of the most recent algorithms inspired by nature in the middle of 1990. After that, PSO has been utilized as an optimization tool in variety of optimization program such as; biologics, medicine, engineering, computer graphics and music composition (Sedighizadeh and Masehian, 2009). In this method, the movement toward the optimal point of function is carried out based on the data of best spot obtained through each of the available swarms in the initial population and also the best found point by the neighbor points. The stages of execution of this algorithm are as follows:

1. The formation of the initial population accidentally
2. Calculation of fitness function
3. Updating the local and global optimum values according to the results of evaluation function
4. Change in the speed of each swarm
5. Updating the values of swarms
6. Repetition of algorithm from stage 2 until convergence occurs.

The basis of developing this algorithm is the possible solutions in an optimization problem which are considered as birds without any volume and qualitative characteristics; which are in here recalled as swarms. These birds fly in an n-dimensioned space and change their path in the search space based on their past experience and also the experience of their neighbors. Application of PSO for solving the GEP has been reported in many references, including the following:

(Shayeghi et al., 2009). have presented a new approach for minimizing the generation costs in competitive market environment using PSO algorithm and then compared their results with genetic algorithm (GA). The suggested method is tested on a system with different power plants accompanied with 3 independent power supplies. The results of tests show that the PSO method is very flexible and is not aimed just at one solution. Meanwhile, the cost of generation expansion planning with the suggested PSO based method has improved to a high extent in comparison with the GA based method.
In (Kannana et al., 2004) the application of the particle swarm optimization technique and its various types has been offered for the purpose of minimizing costs in issues related to GEP. A new method known as VMP has been introduced for increasing the efficiency of PSO method, in which the penalty factor approach (PFA) is used for the purpose of reducing the number of impractical solutions in future repetitions. In this paper in addition to the regular PSO, other methods are also used for testing the system, including: CFA (constriction factor approach), the best model, hybrid PSO (HPSO), stretched PSO (SPSO) and C-PSO (composite PSO). PSO and its various types are applied in one test case, combined of 5 candidate units with a programming horizon of 6 and 14 years. The obtained results are better in speed and functionality compared with dynamic programming (DP). In the 6-year-period programming horizon, the time for executing the PSO method is more than the DP method, but in the programming horizon of 14-year-period, the DP method spends 45 hours on finding the optimized solution. Among all the PSO methods, the CFA method has been more successful in comparison with other methods regarding the execution time and limitation of errors.

In the other paper the improved particle swarm optimization (IPSO) algorithm has been used for solving the problem of generation expansion planning. The suggested algorithm is a combination of GA and PSO. In this paper the real electrical load and the data of electrical loads is predicted for some systems and then the suggested algorithm has been compared with GA, PSO and the traditional DP algorithm, which shows that the IPSO algorithm presents better behavior regarding optimization and speed compared to the other mentioned algorithms (Xiang et al., 2006).

**Taboo Search (TS) Algorithm**

This algorithm applies a comparative procedure for solving the combined optimization problems (da Silva et al., 2008). This algorithm starts its act through an initial answer in order to reach the optimal answer in an optimization problem. In the next phase the algorithm selects the best neighbor answer among the current neighbor answers. If this answer is not put in the tabu list, then the algorithm proceeds towards the neighbor answer, otherwise the algorithm will check a criterion known as the aspiration criterion. Based on the aspiration criterion if the neighbor answer is better than the best solution obtained up to that time, then the algorithm will move towards it even if that answer lies within the tabu list. After the algorithm moves toward the neighbor answer, the tabu list is updated. The stages involved in a TS optimization algorithm are summarized as follows (Seifi and Sepasian, 2011):

1. Producing the initial solution
2. Selecting the procedure track
3. Updating the solution

The application of TS for solving the generation expansion planning has been reported in so many references, among which these can be mentioned:

In (Nualhong et al., 2005) the improved tabu search algorithm was used for minimizing the costs of the GEP, including the biomass energy considering the environmental impacts. The tests were carried out on a test case with 15 power plants, 5 types of fossil fuels and 2 kinds of biomass energy within the horizon programming of 14-years-period. The simulation results show that the suggested ITS method provides a better solution in comparison with the dynamic programming and standard TS during a reasonable computational time period.

In another paper the combination of TS algorithm and optimization method were provided through using dynamic programming for solving the problem of generation expansion planning considering reliability in the multi-regional power system. Instead of choosing an initial solution for the tabu search accidentally, the optimization of a problem is done using DP and the technique of reliability evaluation known as global decomposition. The suggested method has been tested on a real power system consisted of 12 regions (Jirutiljaroen and Singh, 2006).

**ANN**

The Artificial Neural Networks are parallel computational devices which are formed by a group of interconnected processing elements known as neurons (Niculescu, 2003). This network attempts to simulate the brain neurons through taking an appropriate model from the neurons available in the human brain by defining mathematical functions inside the cells and afterwards create a model of the functioning synapses by the existing estimated weights in the communication lines of artificial neurons in the natural neurons. Experimental and flexible essence of this method makes it quite useful and applicable in problems like the issue of prediction which are nonlinear and have wild behavior.

The ANN techniques were used for evaluating the limits of load potential of power systems due to its sensitivity (Jahromi et al., 2012). In this paper first of all the load model of a power system with six buses has been improved. Then the best bus has been selected for increasing the charge which maintains the static voltage stability of the system. Afterwards the strategic interaction between transmission companies and generation companies for transmission expansion planning and generation expansion planning has been...
offered in a competitive electricity market using the game theory. The suggested algorithm has three optimization stages for the purpose of Nash equilibrium. The results show that the most benefiting scenarios for GENCOs and TRANSCO are the simultaneous execution of GEP and TEP.

Cross-Entropy (CE)

Many of the daily tasks become complicated in administrative studies including solving the problems of optimization. The travelling salesman problem (TSP) and the quadratic assignment problem (QAP) are samples of identifying and static combinatorial optimization problems (COP). Cross-Entropy is a general method for combinatorial optimizations and also the simulation of rare incidents. The CE method has a repetitive method in which each repetition can be divided into two stages (Rubinstein and Kroese, 2004).

Establishment a sample of accidental data (trajectories, vectors, etc.) considering the defined number of mechanisms. Updating the parameters from the accidental mechanism based on data for generation of a “better” sample in the next repetition.

The significance of the CE method lies in defining an accurate mathematical framework for quick calculation and in certain cases optimal updating of learning the rules based on progress simulation theories. In (Kothari and Kroese, 2009) the CE method was used for solving the problem of generation expansion planning. The present paper has utilized the C++ software for the simulation. The maximum demanded power is 1600 megawatt in a year, with a 10% annual increase. The results are carried out on a 10 year sample. The simulation results show that the CE method provides more repetitions within a comparable time period.

NSGA-II

Multi-objective optimization has several differences with single-objective optimization. Within single-objective optimization, the best design or plan is usually the absolute extreme of the objective function, yet in the multi-objective optimization the basic problem goes back to the contradiction of objectives. In other words, there is no unique answer which would simultaneously optimize all the objectives. This means that the optimal solution to each single objective differs. The non-dominated sorting genetic algorithm (NSGA) is one of the most prominent and functional algorithms in the field of multi-objective optimization. After the first version of this algorithm was offered in 1995, its second version was given out in 2002 under the abbreviated name of NSGA-II. This algorithm is one of the quickest and most modern multi-objective genetic algorithms which enjoy suitable time complication for regulation and organization, besides possessing a selective operator which creates a mating storage through the integration of the parent population and the child population together. Then it selects N of the best answers considering the value of fitness and expansion. Algorithm includes the following stages:

1- Generation of the initial population based on scale and regulations of the problem
2- Evaluation of the generated population from the perspective of the defined objective functions
3- Applying the undefeated organization method
4- Calculation of controlling parameters known as crowding distance
5- Selection of the parents’ population for reproduction
6- Execution of mutation and convergence

In (Kannan et al., and Murugan et al., 2009) the multi-objective algorithm with undefeated organization was used for solving the problem of the generation expansion planning. Two different formulations were considered for the problem. In one formulation the first objective was to minimize the costs, while the second objective was to minimize the violation of normalized limitations. In the other formulation the first objective was to minimize the investment costs and the second objective dealt with minimization of power outage for customers or maximization of reliability. This paper has introduced the VMP cartography for improving the NSGA-II performance. The generation expansion planning problem has been considered for a test case with a programming horizon of 6 years and 5 candidate units. This is a very flexible method in which the application of other formulations with different objectives or even a higher number of objectives will be practically possible and finally leads to the reduction of costs and the increase of reliability.

The NSGA-II algorithm was used for solving the problem of transmission constrained generation expansion planning in (Murugan et al., 2009). The TC-GEP problem is a large-scale challenging problem which usually consists of one objective with a series of restrictions. The problem of using this method is that the TC-GEP problem is a single-objective problem while the NSGA-II algorithm is a two-objective method which the first objective is the reduction of costs while the second objective is minimization of violating the normalized limitations. This paper shows that the multi-objective method can be applied as a tool for solving single-objective optimization problems. The NSGA-II algorithm has been applied for solving the TC-GEP problem in a 30-bus-IEEE system which has a 6-year programming horizon. The obtained results of this method have been compared with single-objective genetic algorithm and dynamic programming which shows that the NSGA-II algorithm has a better performance compared to single-objective genetic algorithm.
**Immune Algorithm (IA)**

The immune algorithm is a search algorithm based on natural and genetic selection. Antigens and antibodies can be considered as the objective functions and practical solutions. All of the elements diagnosed by the body immune system are named antigens. The basic task of this search system is finding the ruined cells (tumors and cancer cells) and external factors of illness such as viruses and bacteria. The identification of antigens is the mission of a type of white blood cells known as lymphocytes. The two types of lymphocytes are B cells and T cells. The mentioned algorithms in the artificial immune system can be divided into three groups:

1- Algorithms which are made based on the colony selection of B cells.
2- Algorithms which are made based on reverse selection of T cells.
3- Algorithms which are made based on immune system theory.

For solving a problem using the artificial immune system, three questions must be answered. First, how the problem data are exhibited or either define the shape space, second the measurement criterion of affinity and third choosing an artificial immune algorithm for solving the problem. These procedures can be casually assumed identical to the stages of chromosome exhibition, defining the evaluation function and selection of evolutionary algorithms. For implementing an artificial immune algorithm the following stages are needed:

1. Define the objective function of the problem and determine the algorithm parameters.
2. Chose an antigen randomly and expose it to all of the antibodies.
3. Select the antibodies with the highest affinity.
4. Carry out the reverse mutation action for each generated twin regarding possibility and then calculate the affinity of the new answer.
5. Expose the new community inhabitants i.e. twins to the antigens.
6. Exchange the antibodies with the least affinity with the best twins.

In (Chena et al., 2006) the refined immune algorithm was used for execution of generation expansion planning within a deregulated electric market. The RIA algorithm is a combination of IA and TS algorithm. Regarding the variety of loads (peak load, average load, base load) and the competition of IPPs, the generation expansion planning model has been applied under operational limitations, reliability limitation and the C02 limitations. The tabu list is used for increasing the performance of system through using the innovative rules in the search process. The results are compared with GA revealing that the refined immune algorithm is superior in two aspects in comparison with the genetic algorithm; utilizing tabu list for prevention of invalid searches especially in applied programs with several limitations, and the automatic adjustment of cross-operation frequency and rise particularly in sensitive applied programs.

**Theory of Fuzzy Series/ Fuzzy Logic**

The Fuzzy Logic was offered by Professor Zadeh, the university professor of computer science at the Berkley University in California. The Fuzzy Logic is multi-valuable conceptually, allowing in-between definitions like two values such as “right/wrong”, “yes/no”, or “up/down” etc. concepts like “very”, “relatively”, “approximately” and etc. these form the basis of usual human thought and reasoning and can be transformed into mathematics to be understandable by the computer.

Generally three points should be known in the fuzzy logic: first, a definition or model for variables, second; how the variables are connected (that is if we have a number of inputs) and third how to reach a conclusion.

The most significant surveys which have been reported on the application of the fuzzy series theory in GEP are as follows:

In (ABASS and Massoud, 2007) a fuzzy approach was used for solving the problem of generation expansion planning within a multi-objective environment. In this paper the concept of “member functions” are used for defining a fuzzy decision-making model in order to obtain the optimal solution. In the suggested model one fuzzy version is formulated by fuzzifying all functions. The devised method is basically carried out using member functions for each objective function. In the suggested method there is the possibility of compromise among the three objectives. A rational numeral test has been performed to show the efficiency of the suggested method. It has been claimed that the suggested method reduces the costs up to 4.93% in overall.

In (Torabi and Madadi, 2010) a new multi-objective programming fuzzy model of multi-objective mixed integer number has been offered for solving this problem. Hereafter, through the help of a numerical example, and by application of functional strategies in transforming an initial fuzzy model into a definite model, it is shown that the fuzzy model not only creates flexibility in the model, but it also brings about more reliable results compared with the results of a certain model.
CONCLUSION

This paper reviewed the metaheuristic techniques applied for solving the problem of generation expansion planning, applications, description of algorithms and how they operate. All of the mentioned algorithms- including PSO, NSGA-II, and ANN- for solving the large-scale GEP problem are very powerful.

REFERENCES


