APPLICATION OF METAHEURISTICS IN TRANSMISSION NETWORK EXPANSION PLANNING-AN OVERVIEW

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ABSTRACT

Within the electric power literature the transmission expansion planning problem (TEP) refers to the problem of how to upgrade an electric power network to meet future demands. As this problem is a complex, non-linear, and non-convex optimization problem, researchers have traditionally focused on approximate models of power flows. This research paper deals with various planning tools for TEP based on solution methods, the treatment of the planning horizon, and the consideration of the new competitive schemes in the power sector. Metaheuristics are by far the most popular and define mechanisms for developing an evolution in the search space of the sets of solutions in order to come close to the ideal solution with elements which will survive in successive generations of populations.

KEYWORDS: *transmission expansion planning (TEP), metaheuristics, heuristics, ant colony algorithm (ACO), particle swarm optimization (PSO).*

I. INTRODUCTION

Transmission system is one of the major parts of the electric power industry. It does not only provide a linkage between generation and distribution, but also a non discriminative and reliable environment to suppliers and demanders. The purpose of a power transmission network is to transfer power from generation plants to load centers securely, efficiently, reliably and economically. Since any practical transmission system is ever expanding, so TEP involves to indentify where to add new circuits to meet the increased demand by transferring the power from old to new network.

In the last few years, research in the area of synthesis transmission planning models experienced an expansion. Many papers and reports about new models have been published in the technical literature due mostly to the improvement of the computer power availability, new optimization algorithms, and the greater uncertainty level introduced by the power sector deregulation. Several publications skillfully describe the general planning problem, Transmission system planners tend to use many methods to address the expansion problem. Planners utilize automatic expansion models to determine an optimum expansion system by minimizing the mathematical objective function subject to a number of constraints [1-6].

To find an optimal solution of TEP over a planning horizon, extensive parameters are required; for instance topology of the base year, candidate circuits, electricity demand and generation forecast, investment constraints, etc. This would consequently impose more complexity to solving TEP problem. Given the above information, in–depth knowledge on problem formulation and computation techniques for TEP is crucial and therefore, this paper aims essentially at presenting fundamental information of these issues.

The paper is organized as follows. Section II deals with publications that propose to classify the transmission planning problem (static and dynamic) and various models used for TEP problem. Section III reviews the techniques to solve TEP problem. Later on, in section IV some of the features of the available tools for development of transmission planning models are discussed. Finally, conclusion is drawn in section V.

II. CLASSIFICATION OF TEP PROBLEM

Based on planning horizon, transmission expansion planning can be traditionally classified into two categories, namely static (single-stage) and dynamic (multi-stage) planning. In static planning, only a single time period is considered as a planning horizon. In contrast, dynamic planning considers the planning horizon by separating the period of study into multiple stages [1].

For static planning, the planner searches for an appropriate number of new circuits that should be added into each branch of the transmission system and in this case, the planner is not interested in scheduling when the new lines should be constructed and the total expansion investment is carried out at the beginning of the planning horizon [6]. Many research works regarding the static TEP are presented in [5, 8, 9, 10] that are solved using a variety of the optimization techniques.

In contrast, time-phased or various stages are considered in dynamic planning while an optimal expansion schedule or strategy is considered for the entire planning period. Thus, multi-stage transmission expansion planning is a larger-scale and more complex problem as it deals with not only the optimal quantity, placement and type of transmission expansion investments but also the most suitable times to carry out such investments. Therefore, the dynamic transmission expansion planning inevitably considers a great number of variables and constraints that consequently require enormous computational effort to achieve an optimal solution, especially for large-scale real-world transmission systems. Many research works regarding the dynamic TEP [6, 11, 12, 13] are presented some of the dynamic models that have been developed.

III. SURVEY OF VARIOUS TECHNIQUES TO SOLVE TEP PROBLEM

Over past few decades, many optimization techniques have been proposed to solve the transmission expansion planning problem in regulated power systems. These techniques can be generally classified into mathematical, heuristic and meta-heuristic optimization techniques. A review of these methods is discussed in this section:

1. Mathematical Optimization techniques

Mathematical optimization methods search for an optimal expansion plan by using a calculation procedure that solves a mathematical formulation of the planning problem. In the problem formulation, the transmission expansion planning is converted into an optimization problem with an objective function subject to a set of constraints. So far, there have been a number of applications of mathematical optimization methods to solve the transmission expansion planning problem, for instance, linear programming [10], nonlinear programming [12] and, dynamic programming [13], branch and bound [9], mixed-integer programming [14] and Benders decomposition [15].

In 1970, Garver proposed a linear programming method to solve the transmission expansion planning problem [10]. This original method was applied to long-term planning of electrical power systems and produced a feasible transmission network with near-minimum circuit miles using as input any existing network plus a load forecast and generation schedule. Two main steps of the method, in which the planning problem was formulated as load flow estimation and new circuit selection could be searched based on the system overloads, were presented in [10].

In 1984, an interactive method was proposed and applied in order to optimize the transmission expansion planning by Ekwue and Cory [11]. The method was based upon a single-stage optimization procedure using sensitivity analysis and the adjoint network approach to transmit power from a new generating station to a loaded AC power system.

Discrete dynamic optimizing (DDO) was proposed to solve the transmission planning problem by Dusonchet and El-Abiad [13]. The basic idea of this method was to combine deterministic search procedure of dynamic programming with discrete optimizing a probabilistic search coupled with a heuristic stopping criterion.

In 2003, Alguacil et al. [14] proposed a mixed-integer linear programming approach to solve the static transmission expansion planning that includes line losses consideration. The proposed mixed-integer linear formulation offers accurate optimal solution.

Haffner et al. [9] presented a new specialized branch and bound algorithm to solve the transmission network expansion planning problem. Optimality was obtained at a cost, however: that was the use of a transportation model for representing the transmission network. The expansion problem then became an integer linear programming (ILP) which was solved by the proposed branch and bound method.

A new Benders decomposition approach was applied to solve the real-world power transmission network design problems by Binato et al. [15]. This approach was characterized by using a mixed linear (0-1) disjunctive model, which ensures the optimality of the solution found by using additional constraints, iteratively evaluated, besides the traditional Benders cuts.

2. Heuristic and Meta-heuristic techniques

Among the soft computing components, instead of EA (which can represent only one part of the search and optimization methods used), heuristic algorithms and even metaheuristics should be considered.

The term heuristics comes from the Greek word “heuriskein”, the meaning of which is related to the concept of finding something and is linked to Archimedes’ famous and supposed exclamation. On this basis, a large number of heuristic procedures have been developed to solve specific optimization problems with great success, and the best of these have been extracted and used in other problems or in more extensive contexts. This has contributed to the scientific development of this field of research and to the extension of the application of its results. As a result, metaheuristics have emerged, a term which appeared for the first time in an article by Fred Glover in 1986.

The term metaheuristics derives from the combination of the word heuristics with the prefix meta (meaning beyond or of a higher level), and although there is no formal definition for the term metaheuristics, the following two proposals give a clear representation of the general notion of the term:

a) I. H. Osman and G. Laporte [18]: "An iterative generation process which guides a subordinate heuristic by combining intelligently different concepts for exploring and exploiting the search space".

b) S. Voss et al. [19]: "is an iterative master process that guides and modifies the operations of subordinate heuristics to efficiently produce high quality solutions".

It is therefore clear that metaheuristics are more broad-brush than heuristics. In the sections which follow, we will focus on the concept of metaheuristics, and will start by pointing out that in the terms that we have defined, certain metaheuristics will always be better than others in terms of their performance when it comes to solving problems.

There are so many and such a variety of metaheuristics available that it is practically impossible to agree on one universally-accepted way of classifying them. Nevertheless, the hierarchy on which there is the most consensus considers three (or four) foremost groups:

1) metaheuristics for evolutionary procedures based on sets of solutions which evolve according to natural evolution principles.

2) metaheuristics for relaxation methods, problem-solving methods using adaptations of the original model which are easier to resolve.

3) metaheuristics for neighborhood searches, which explore the solution space and exploit neighbourhood structures associated to these solutions.

4) other types of intermediate metaheuristics between the ones mentioned above or derived in some way from them, but which we will not consider because of their great variability (and to avoid dispersion).

In addition to mathematical optimization methods, heuristic and meta-heuristic methods become the current alternative to solve the transmission expansion planning problem. There have been many applications of heuristic and meta-heuristic optimization methods to solve transmission expansion planning problem, for example heuristic algorithms [5, 19], tabu search [20], simulated annealing [21], genetic algorithms [6, 22, 23, 24], artificial neural networks [25], particle swarm [31] and hybrid artificial intelligent techniques [25]. The detail of these methods is as discussed below.

Constructive heuristic algorithm (CHA) is the most-widely used heuristic algorithms in transmission expansion planning. A constructive heuristic algorithm is an iterative process that searches a good quality solution in a step-by-step process. Romero et al. [3] presented and analysed heuristic algorithms for the transportation model in static and multistage transmission expansion planning. A constructive heuristic algorithm for the transportation model (TM) of Garvers work [10] was extensively analysed and excellent results were obtained in [3].

Tabu search (TS) is an iterative improvement procedure that starts from some initial feasible solution and attempts to determine a better solution in the manner of a „greatest descent neighbourhood" search algorithm [2]. The basic components of the TS are the moves, tabu list and aspiration level (criterion). Simulated annealing (SA) approach based on thermodynamics was originally inspired by the formulation of crystals in solids during cooling [2]. Simulated annealing technique has been successfully applied to a number of engineering optimization problems including power system optimization problems. Romero et al. [21] proposed a simulated annealing approach for solving the long-term transmission system expansion planning problem.

Expert system is a knowledge-based or rule-based system, which uses the knowledge and interface procedure to solve problems. The state of the field of expert systems and knowledge engineering in transmission planning was reviewed by Galiana et al. [16].

Genetic algorithm (GA) is a global search approach based on mechanics of natural selection and genetics. GA is different from conventional optimization techniques as it uses the concept of population genetics to guide the optimization search. GA searches from population to population instead of point-to-point search. In 1998, Gallego et al. [17] presented an extended genetic algorithm for solving the optimal transmission network expansion planning problem. Two main improvements of GA, which are an initial population obtained by conventional optimization based methods and the mutation approach inspired in the simulated annealing technique, was introduced in [17].

Ant colony search (ACS) system was initially introduced by Dorigo in 1992 [18]. ACS technique was originally inspired by the behaviour of real ant colonies and it was applied to solve function or combinatorial optimization problems. Gomez et al. [19] presented ant colony system algorithm for the planning of primary distribution circuits. The planning problem of electrical power distribution networks, stated as a mixed nonlinear integer optimization problem, was solved using the ant colony system algorithm.

Particle swarm optimization (PSO), using an analogy of swarm behaviour of natural creatures, was started in the early of the 1990s. Kennedy and Eberhart developed PSO based on the analogy of swarms of birds and fish schooling [20], which achieved efficient search by remembrance and feedback mechanisms. By imitating the behaviours of biome, PSO is highly fit for parallel calculation and good performance for optimization problems. A new discrete method for particle swarm optimization was applied for transmission network expansion planning (TNEP) in [21].

Al-Saba and El-Amin [20] proposed the application of artificial intelligent (AI) tools, such as genetic algorithm, tabu search and artificial neural networks (ANNs) with linear and quadratic programming models, to solve transmission expansion problem. An intelligent tool started from a random state and it proceeded to allocate the calculated cost recursively until the stage of the negotiation point was reached.

IV. TOOLS FOR DEVELOPING PLANNING MODELS

The main options available nowadays to develop transmission planning models (optimization) are [22], [23]:

A. General Purpose Programming Languages

In this case, the planning model is developed using a general purpose programming language (like Fortran, C, etc.) and commonly the algorithm calls an optimization dynamic library (*.dll). Using this option makes sense when the execution time is critical, the model must run very often (multiple scenarios), when made-to-measure interfaces are needed or when the model has to be integrated to another application. That is usually the case of planning models for real world power systems.

Some of the generic features required for development of real world transmission planning models are:

- Highly optimized code, efficient mathematics, and robustness that allow maximal speed of execution;
- Easy interaction with optimization packages and other external tools;
- Availability of comprehensive diagnostic messages.

As programmers who are equally comfortable working with several computer languages and with no intention of depreciating the features of C or any other language for numerical calculations, the authors want to clarify why Fortran is still a good option for high performance scientific and engineering applications.

In addition to Fortran and C, there are other powerful and free languages that could also be considered: functional programming languages as Haskell [24]; concurrent programming languages as Erlang (www.erlang. org); and constraint programming languages as Mozart [25].

B. Languages or Environments for Numerical/Symbolic Calculations

This option includes spreadsheets (e.g., Excel [26]), or environments for technical computing (e.g., MATLAB [27], Scilab [28], etc.), or symbolic computation (e.g., MAPLE [29], Mathematica [30], Fermat [31], etc.).

The environments for numerical or symbolic computation, for instance MATLAB, were not specially designed to solve optimization problems, but make easy to deal with matrices or vectors. All of these alternatives can be used for prototype quick development since they have great graphic visualization features but it is very hard to use them to solve very large optimization problems as transmission planning for real world power systems.

V. RESULT

Although metaheuristics are different in the sense that some of them are population-based (EC, ACO), and others are trajectory methods (SA, TS, ILS, VNS, GRASP,PSO), and although they are based on different philosophies, the mechanisms to efficiently explore a search space are all based on intensifi cation and diversification. Nevertheless, it is possible to identify .sub-tasks. in the search process where some metaheuristics perform better than others. This has to be examined more closely in the future in order to be able to produce hybrid metaheuristics performing considerably better than their pure parents . In fact we can and this phenomenon in many facts of life, not just in the world of algorithms. Mixing and hybridizing is often better than purity.

VI. CONCLUSION AND FUTURE SCOPE

In this paper, we have presented a classified list of major publication on transmission expansion planning (synthesis models). This list is by no means complete.We have also presented and compared nowadays most important metaheuristic methods for TEP. In Section III we have outlined the basic metaheuristics as they are described in the literature and proposed a conceptual comparison of the different metaheuristics based on the way they implement the two main concepts for guiding the search process: Intensification and diversification. This comparison is founded on the *I&D frame*, where algorithmic components can be characterized by the criteria they depend upon (objective function, guiding functions and randomization) and their effect on the search process.

Transmission planning researchers have worked and set their interest mostly on static planning models. The dynamic and pseudodynamic planning models are still in an undeveloped status and they have some limitations for their application to real power systems.

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ACKNOWLEDGEMENT

Authors are very much thankful to all the informants, doctors and the people who have been directly or indirectly involved in writing this paper.

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