Electrical Power System Transmission Planning-A Survey

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Abstract- The three main stages of an Electrical Power system are Generation, Transmission and Distribution. Over the years all these three sectors have made tremendous growth in the Electrical Power industry. Transmission system is one of the major parts of the electric power industry as it connects Generation side to Distribution side which can highly affect the total cost of electrical energy. The purpose of a power transmission network is to move power from generation plants to load centres safely, proficiently, reliably and economically .Since any practical transmission system is ever expanding, Transmission Expansion Planning involves to identify where to add new circuits to meet the increased demand by transferring the power from old network to new network. Transmission expansion planning is a challenging problem due to the fact that Power systems are large, widely spread and complex. There are several techniques proposed to solve this large scale Transmission Expansion Planning optimization problem. This paper describes the various optimization techniques to solve the Transmission Expansion Planning.

Keywords – Transmission Expansion Planning, Mathematical Optimization, Heuristic and Meta heuristics.

I. INTRODUCTION

Electrical Transmission Network is wide spread, large sized and complex hence planning such a network becomes large scale combinatorial problem. The complex decision making process is to decide where ,when and what new reinforcements should be built in the power system network in order to minimize the total system cost which is the sum of investment and operational cost is a crucial step in the expansion of Electrical Transmission System. Hence Transmission Expansion Planning (TEP) becomes an optimization problem in minimizing the objective function which is the total system cost subject to a set of equality and inequality constraints. These constraints constitute a set of economic, technical and reliability limitations. Apart from minimizing the total system cost, TEP also should ensure electrical power system are able to meet the forecasted demand without any interruptions.

Considering the planning horizon, TEP can be classified as static (single-stage) or dynamic (multi-stage) planning.

Static transmission planning aims giving answers to 'what' transmission facilities should be added and 'where' should they be installed considering the minimum cost for a single year on the planning horizon[1]. But in dynamic planning in addition to 'what' and 'where', 'when' the transmission facilities should be added also come in to picture[2].In static planning, the planning is done for a single year in a planning horizon , whereas in dynamic planning multiple years are considered. The static planning is of first interest and has been addressed with mathematical and heuristic techniques. Considering the fact that dynamic planning has to take in to account the timing considerations, it becomes more complex than static planning [3, 4]. Hence dynamic planning requires more computational effort to get the optimal solution. Heuristic algorithms are usually used to solve dynamic planning problems.

TEP problem is generally modelled in two ways; ac power flow model and dc power flow model [5, 6].The steady-state model of a power transmission network is done most accurately with a set of nonlinear power flow equations. This represents AC power flow model. In AC power flow model, TEP is modelled as a mixed-integer nonlinear programming problem which are difficult to solve using mathematical optimization techniques or heuristic approach [7, 8, 9]. The DC power flow is a purely linear equation and is most commonly used for solving TEP. In DC power flow model, TEP problem is modelled as a mixed-integer linear programming problems. The following assumptions are made to make the power flow equation linear:

i) Ignoring the reactive power balance equations
ii) All the voltage magnitudes are equal to 1 p.u.
iii) Ignoring the resistance of the branch, hence ignoring line losses.
iv) Ignoring all ground branches.

II. TRANSMISSION EXPANSION PLANNING APPROACHES

The three main techniques to solve TEP are (i) mathematical optimization models and (ii) heuristics (iii) meta-heuristics.

2.1 Mathematical Optimization Methods-

The mathematical optimization methods are also called classical or traditional optimization techniques. The most commonly proposed traditional optimization techniques to solve TEP problem are linear programming [10], non-linear programming [11], dynamic programming [12, 13], mixed integer programming [14], Quadratic Programming [36,37],Branch and bound [15, 16] and Benders decomposition [17, 18]. The critical issue with traditional optimization models is that they usually require a large computational effort. Hence it is difficult to find optimum solution for medium and large power systems. Due to this drawback, TEP problems are more approached using heuristic or meta-heuristic techniques [19].

2.11 Linear Programming

One of the first traditional optimization methods for solving the transmission network expansion is the linear programming (LP) technique, in which both the constraints and the objective function are linear. Several advantages of the LP technique are (i) can handle a large number of variables and constraints (ii) has good converging properties and (iii) high computational efficiency. Disadvantages of LP techniques are (i) as size of the problem increases number of iterations also increases and (ii) inefficient in finding the system losses [20, 21]. In 1970, Garver proposed a linear programming method to solve the transmission expansion planning problem [22]. The new method presented uses two model, dc power flow model and a transportation model for solving two networks: one consisting of the actual installed facilities and the other consisting of artificial elements(Overload network).

2.12 Non-linear programming

If any of the functions among the objectives or the constraints is nonlinear, the problem is called a nonlinear programming (NLP) problem. The advantages of NLP methods are (i) high accuracy (ii) global convergence. The disadvantage is the reliability issues when dealing with large complex networks [23, 27]. Quasi-Newton and Newton method [24, 25] are the examples of NLP method which has good convergence properties. In 1984, Ekwue and Cory proposed an interactive method to solve TEP using sensitivity analysis and the adjoint network approach[26]. The nonlinear programming technique of gradient projection followed by a round-off procedure was used for this optimization method.

2.13 Dynamic Programming

Dynamic Programming (DP) is based on the principle of optimality states. The disadvantage is that it suffers from the dimensionality issues [28]. In 1973, Dusonchet and El-Abiad proposed Discrete dynamic optimizing (DDO) to solve TEP problem [29]. The most crucial point of this proposed method was to integrate deterministic search procedure of dynamic programming with discrete optimizing. The proposed method has the advantages of solving large size and complex problems as well as it has also the advantage of applying neighbourhood concept in solution process.

2.14 Mixed-Integer Programming

For many optimization problems some of the independent variables can take only integer values (e.g. ON status =1, and OFF status =0, transformer tap ratio, phase shifter angle) and such problem are called integer programming [23]. When some of the variables are continuous, the problem is called Mixed Integer Programming (MIP). Mainly two approaches i.e. 'branch and bound', and 'cutting plane methods', have been used to solve integer problems [31-34]. The advantages of this method are (i) reduction in number of iterations required (ii) less computation time and memory space. However difficulty of mixed integer programming depends upon the structure of problem and the number of discrete variables involved. In 2003, Alguacil et al. proposed a mixed-integer linear programming approach to solve the static transmission expansion planning that includes line losses consideration [30]. The proposed technique was tested to Graver's 6-bus system, the IEEE reliability test system and a realistic Brazilian system which produced accurate optimal solution. A bi-level transmission expansion planning model with mixed integer programming (MIP) market clearing problem has been proposed by Hossein Haghihat and Bo Zeng. [35]. A customized reformulation-and decomposition scheme was developed to solve this bi-level MIP program. A multi stage transmission expansion planning problem modelled like a mixed binary linear programming problem solved using a heuristic to reduce the combinatorial search space is presented in [90]. A novel methodology to find a solution to the transmission expansion planning problem under generation expansion in uncertainty in a min–max regret approach is presented in [92].The proposed model is a five level mixed integer LP based model consisting of the optimal network investment plan, generation expansion, transmission expansion ,system outages, and optimal post-contingency controls. A cutting plane algorithm is used to solve this five level model.

2.15 Quadratic Programming
Quadratic programming (QP) is a distinguished form of nonlinear programming. The objective function of QP optimization model is quadratic, and the constraint are in linear form. Quadratic programming has higher accuracy than LP – based approaches [36]. The problem of transmission networks expansion has been solved by considering the cost of losses as well as the cost of investment in the objective function has been proposed by M.M El-Metwally and Z.M. Al-Hamouz [37]. The problem is solved using an exact quadratic programming technique. This new formulation has been applied to a 6- bus system and shows a better result.

2.16 Branch and Bound
Haffner et al. proposed a new specialized branch and bound algorithm to obtain cost minimization with the use of a transportation model for representing the transmission network [38]. A new method for transmission line expansion planning using the branch and bound method is presented by Hong-Shan et al [39].The planning computed by this method is very productive in solving the mixed optimization problem, and the relaxations of sub-problems were achieved by interior point method. The planning algorithm presented was applied to IEEE39 bus testing system. Branch and Bound make use of selective/partial lists, which can lead to memory issues for large problems. Also it has also high execution times. A mixed-integer optimization approach for transmission system planning with an AC network model making use of the conic programming relaxation solved using branch and cut algorithm is presented in [49].The model is applied to Garver system, IEEE 24-bus system and 46-bus South Brazilian system to show the performance of the proposed model.

2.17 Benders Decomposition
Benders proposed Benders decomposition in 1962[40]. In this method, the variables of the original problem are divided into two subsets, i.e. (i) first-set variables whose values are determined by the master problem and (ii) second set variables whose values are obtained by solving the slave problem. Binato et al. proposed a new Benders decomposition approach to solve the real-world power transmission network expansion problems [41]. The two subsets here are defined a Gomory cuts and Benders Cuts. Here a mixed linear disjunctive model is used to obtain the optimal solution. The Benders decomposition approach to solve a multiyear transmission expansion planning considering the transmission congestion and the impact of generation investment is presented in [86].The proposed approach is applied to a hypothetical system and Turkish power system to solve the effectiveness of the model.

2.18 Decomposition Method
M. V. F. Pereira et al. proposed a decomposition approach model for automated Generation/transmission expansion to be used in long term system planning studies [42]. Here the transmission network can be represented either by a transportation model or by a linearized power flow model. The solution technique is based on Benders decomposition, network-flow models, and linear programming models where capacity expansion problem is decomposed into investment and operation sub problems. R. Romero et al. proposed a hierarchical decomposition based on Benders approach for optimal transmission expansion planning in finding a global optimal solution for transmission planning problems [43]. This method results in reduced number of iterations and make use of three models: transportation models, hybrid models, and dc models. A novel integrated optimization of generation and Transmission expansion planning using decomposition method is proposed to deal with both generation and transmission expansion problem [44] is proposed by Hyounngtae Kim et al. on linearized AC power flow model taking in to account the constraints of reactive power is proposed. The proposed method has been successfully applied to Garver's six bus system results in improved accuracy and computation time.
2.2. *Heuristic and Meta-heuristic Methods–*

In addition to mathematical optimization methods, heuristic and meta-heuristic methods have become the current alternative to solve the transmission expansion planning problem. These heuristic and meta-heuristic techniques are efficient algorithms to optimize the transmission planning problem [45].

2.21 Heuristic models

The term "heuristic" (to invent, to create) is used to describe all those techniques that, instead of using a classical optimization approach, go step-by-step generating, evaluating, and selecting expansion options, with or without the user's help[45].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. A constructive heuristic algorithm for the transportation model was extensively analyzed and excellent results were obtained in [46]. Isabela M. Mendonca et al. proposed a constructive heuristic algorithm based on an indice for static expansion planning of electrical power system represented by a dc power flow model [47]. Here the expansion decisions are represented by a hyperbolic tangent function. The solution to a transmission planning network represented by AC model is presented in [48]. A constructive heuristic algorithm for obtaining better solution is presented for solving this complex mixed integer nonlinear programming problem. The model is applied to Garver system, IEEE 24-bus system and 46-bus South Brazilian system to show the performance of the proposed model. A heuristic method known as Greedy Randomized Adaptive Search Procedure to solve the transmission network expansion problem is presented in [83].The proposed method has two phases namely construction phase and local search to obtain optimal solution is also presented.

2.22 Tabu Search

Tabu search (TS) is an iterative improvement system that begins from some initial achievable solution and attempts to decide a better solution in the way of a greatest descent neighborhood search algorithm [28]. The basic components of the TS are the moves, tabu list and aspiration level (criterion).Edson Luiz da Silva et al. proposed Tabu search method for long-term transmission network expansion planning problems [52]. Fushuan et al. [50] proposed a method is to solve the single stage optimal planning problem for a transmission network with the problem formulated as a 0 -1 integer programming problem .The proposed method has the advantage of high efficiency and ease of implementation by the tuning of many parameters in the solution process. A third generation TS algorithm known as parallel Tabu Search algorithm for solving the static transmission network expansion problem is proposed by Ramon A Gallego et al.[51]. The proposed algorithm includes many advanced features such as elite configurations, intelligent initialization, strategic oscillations, neighborhood reduction, and path relinking and also includes hybrid features taken from Genetic Algorithm and Simulated Annealing. Optimal solution were obtained for small and medium size cases and near optimal solution were obtained for large cases.

2.23 Simulated Annealing

Simulated annealing (SA) approach based on thermodynamics was originally inspired by the formulation of crystals in solids during cooling [28]. R. Romero et al. proposed a simulated annealing approach to the long term transmission expansion planning problem and has been found to be a highly suitable method for solving hard combinatorial optimization methods [53]. A parallel simulated annealing optimization technique for solving long term transmission planning problem has been proposed by Gallego et al. [54]. The fundamental cause for proposing parallel simulated annealing is to improve the computational time and quality of solution hence increases the chance of obtaining global optimal solution. This paper also determines the state under which the proposed algorithm is most efficient.

2.24 Expert Systems

Expert system is a knowledge-based or rule-based system, which uses the knowledge and interface procedure to solve problems [28]. Galiana et al. [55] reviewed Expert system in transmission planning in 1992.The review included aim, constraints, methodologies and the applications of expert systems in TEP. R.C.G Tieve et al. proposed a cooperative expert system for electrical power system transmission planning problem in 1998[56]. This paper proposes a planning computational environment with critical features that the planner must take in to consideration. An expert system approach to short-term expansion planning (STEP) is explained in [57] which includes rules for short term transmission planning. The rules can be categorized as ampacity management, MW and MVAR rules for alleviating transmission line congestion, voltage control at load buses.

2.25 Genetic Algorithms

Genetic algorithm (GA) is a global search approach that searches from population to population instead of point to point searches [28]. An extended genetic algorithm for solving the optimal transmission network expansion planning problem is presented by Gallego et al. in 1998[58]. The application of an improved genetic algorithm was also proposed to solve the transmission network expansion planning problem by Silva et al. [59]. Ruben Romero et al. proposed genetic algorithm to solve the static and multistage transmission expansion planning problem. The proposed GA results better performance than the other Meta heuristics to solve the static and multistage TEP problem. A multi-objective meta-heuristics method is proposed for transmission network expansion planning with controlled Non dominated sorting Genetic algorithm is presented in [60].The proposed method was successfully applied to the IEEE 24-bus system and proved its effectiveness. A cost effective solution to static transmission planning problem in the deregulated power system environment including losses using Genetic Algorithm is presented in[62].The proposed method is applied to Garver's six bus system to check its effectiveness in optimized cost . Dike et al. presented transmission system expansion planning using genetic algorithm [63]. The number of transmission lines to be added as well as the corresponding network adequacy also obtained. The model was also tested on IEEE 30 – bus network satisfying economic and technical constraints. An enhanced genetic algorithm to solve the long-term transmission expansion planning problem with the features including, generation of an initial population using fast, efficient heuristic algorithms, better implementation of the local improvement phase and efficient solution of linear programming problems is presented in [64].A comparative analysis is also made between traditional and proposed genetic algorithm. A genetic algorithm is presented to solve the problem of dynamic transmission network expansion planning in [95].

2.26 Ant Colony System Algorithm

Ant colony search (ACS) system was initially introduced by Dorigo in 1992[65]. ACS technique was originally inspired by the behavior of real ant colonies and it was applied to solve function or combinatorial optimization problems. An improved coding method with improved search efficiency by introducing individual ant velocity thus creating new pheromone release functions is presented in [66]. A multiobjective Algorithm considering three objectives such as minimizing cost, minimizing operational cost and minimizing power loss is presented in [67].The augmented G-constraint Method using lexicographic optimization for objective function is presented to obtain the best optimal solution. The proposed model has been applied to Garver's six bus test system and furthermore to a north-eastern part of the Iranian national 400-kV transmission network. A utilization of ant colony optimization to unravel the static transmission expansion problem based on DC power flow model considering security limitation is introduced in [68]. The principal objective is to confine the investment cost of transmission lines that should be added to a present system in order to supply the estimated load as economically as possible subject to physical and economic constraints. The proposed system is applied to Garver 6 buses system and the 46 buses of South Brazilian system and proved to have excellent characteristics in terms of convergence and computational efficiency. A novel heuristic model based on Ant Colony Optimization for the multi-year TNEP is presented in [69]. For validating the model, 25 years plans were calculated in the Garver's 6-bus system and in the IEEE 118-bus system.

2.27 Particle Swarm Optimization

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 [70]. A new discrete method for particle swarm optimization was applied for transmission network expansion planning in [71]. Numerical outcomes exhibited that the proposed discrete method was feasible and efficient for small test systems. Electrical power system TEP represented by DC power flow model using a two stage methodology comprising constructive heuristic algorithm and particle swarm optimization is presented in [72]. The proposed methodology was applied to the Garver framework and to two genuine comparable frameworks for the South and Southeast of Brazil, where the productivity of the proposed framework can be checked. A novel solution methodology dependent on Chaotic Particle swarm approach for optimal planning of high-voltage transmission network investments to limit capital costs required for new system components while meeting forced operating constraints is proposed in [73].A new method named Improved Discrete Particle Swarm Optimization is employed for the solution of TEP problem in the presence of loss and uncertainty in load demand is proposed in [74].The proposed approach is applied to the real transmission network of Azerbaijan Regional Electrical Company located in northwest of Iran. Comparison of the outcomes got from the proposed technique with those of Discrete Particle Swarm Optimization (DPSO) approach checks the viability and accuracy of the strategy in STNEP issue.

2.3 Multi Objective and Hybrid Techniques-

Al-Saba and El-Amin [75] 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. The effectiveness of these AI methods in dealing with small-scale and large-scale systems was tested through their applications to the Graver six-bus system, the IEEE24 bus network and the Saudi Arabian network. A hybrid search technique based on Backward Search (BS), Forward Search (FS) and Hybrid Search (HS) Techniques for obtaining efficient Transmission Expansion Planning is presented in [76]. The proposed technique uses DC load flow analysis and is tested in a Garver test system .A new hybrid GA with linear modeling is proposed in [77].The proposed GA strategy has an adaptable structure and the viability of the technique is tested on Garver 6-bus, IEEE 24-bus, and South Brazilian test problems. It is seen that recently proposed hybrid GA shows a quick convergence on the test issue. A contemporary transmission expansion planning methodology to reduce total system operating cost and line construction/investment cost using Mixed-Integer Nonlinear Multi-Objective Optimization is proposed in [78]. The power system is represented by AC power flow model. The proposed model is applied to an IEEE 30-bus system and an IEEE 118-bus system. A multi objective transmission expansion planning methodology considering three objectives as investment cost, reliability and congestion cost is presented in [79].The proposed system uses a hybrid optimization techniques comprising genetic based NSGA II algorithm and fuzzy decision making analysis. The proposed system is applied on the IEEE 24-bus test system and real life system of north eastern part of Iranian national 400-kV transmission grid. A multi-objective transmission planning methodology comprising two objectives as cost of power purchase and network expansion and the revenue of power delivery using particle swarm optimization is proposed in [80].The proposed multi-objective planning approach has been verified by the 77-bus system linked with 38-bus distribution network junctions. A novel dynamic transmission expansion planning problem using information gap decision theory and augmented ε-constraint method is presented in [81]. A multiobjective methodology for transmission expansion planning utilizing AC power flow model considering three objectives are introduced in [82].The objectives are to limit the investment cost , minimize the operation cost and also to minimize the power losses. The augmented G-constraint method was used so as to solve the proposed model and has been applied to Garver's six bus test system and also to a real system of north-eastern part of the Iranian national 400-kV transmission grid. A bi-level evolutionary optimization is proposed for coordinated TEP in [93] incorporating a hybrid method consisting of Roulette wheel optimization and Genetic Algorithm. A novel method for real time system's Transmission Expansion Planning for deregulated power systems by introducing a new cost function which includes cost of new transmission lines, cost due to project delay, cost due to inflation, cost due to right of way and congestion cost[94]. The objective function is optimized for 6-bus Roy Billinton Test System using Genetic Algorithm and Bacterial Foraging Optimization Algorithm.

2.4 Other Techniques

A Meta heuristic algorithm using Hopfield Neural Network for TEP of large interconnected system is proposed in [84].The objective function considers the investment cost in generation and transmission and system operational cost. The proposed method is tested on both the Garver's 5 bus system and the IEEE 14 bus system to demonstrate its advantages. Mario et al. illustrates sensitivity analysis method for long term transmission expansion planning [85]. A comprehensive Fuzzy Evaluation for power transmission network planning based on entropy Weight method is presented in [87].The proposed method is applied to The IEEE Garver-6 bus system to show the effectiveness and feasibility for the practical application. A stochastic TEP incorporating Reliability solved using Shuffled Frog Leaping Algorithm metaheuristic technique is presented in [88].The objective function is to minimize the investment cost and reliability cost. A comprehensive in a two-stage robust optimization model with two different types of uncertainty sets comprising Ramping Requirements and construction periods to solve TEP is proposed in [89]. An extension of reduced disjunctive model considering N-1 criterion for multi stage security constrained transmission expansion planning is presented in [91]. *A* self-adaptive differential evolution algorithm applied straightforwardly to the DC power flow based so as to effectively illuminate transmission network expansion planning problem is introduced in [96]. A self-versatile differential development calculation applied straightforwardly to the DC power stream based model so as to effectively illuminate transmission arrange extension arranging (TNEP) issue is introduced in [96].The proposed method is applied on IEEE 25-bus system giving the most attractive feature as good computational performance. A single-stage generation and transmission expansion planning based on game theory is proposed in [97]. Cournot model is used to simulate the expansion strategies of generation and transmission enterprises. The equilibrium is obtained by using the Mixed Complementarity Problem approach. In addition, the proposed model is applied to a three-bus system, which verifies the feasibility of this model. A novel power transmission expansion planning using Chaos Optimal Algorithm is introduced to solve TEP. The algorithm considers the transmission surplus capacity and load factor of the transmission Line [98] is presented. A well-being method and cost-optimization method to solve the transmission expansion planning problem. Is presented in [99] and applied to a IEEE-RTS 24 bus system to test its reliability.

III.CONCLUSION

Review of a classified list of mostly used techniques for Transmission Expansion Planning is presented. Review of Hybrid as well as multi objective methods for TEP is also presented. In addition to the above some of the supplementary techniques that are proposed to solve transmission expansion planning is also presented. New planning methodologies should be researched in dynamic power flow model for obtaining optimal solution as most of the current methodologies deals with static transmission planning taking limited uncertainties.

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