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A Literature Study on Transmission Expansion Planning Problems

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Abstract— In general, the objective of transmission expansion planning (TEP) problem is the assurance of adequate future load supply via optimally expanding and also reinforcing the facilities of transmission as well. More non linear and linear programming has been already used for solving the TEP problem. This paper comes out with a deep analysis on the TEP problem. Some 15 papers are processed under reviewing various TEP models. Finally, the result of analysis is subjected in the upcoming sections under various forms like diagrammatic representation and tabulation that reviews the work in terms of proposed models and performance measures.

Keywords—TEP; Linear Programming; Non-linear Programming; Algorithmic Analysis; Performance Measures

I. INTRODUCTION

In general, TEP is one of the main functions of Transmission Network (TN) planners that facilitating the electricity [21] trade from reduced investment. Frequently, the planners have worked with restricted budget, and each feasible Right of Way (ROW) has the restricted corridors count. With the response over the improving concerns on climate change, more countries have get on the mission on reducing the emission of greenhouse gas by the growing share of renewable energy (RE) with their total energy matrix [3]. Establishment of additional transmission corridors might go forward for the beginning of novel RE modalities in the electricity grid. More research work on TEP has considered the static characteristics of planning horizon. Many models give a comparative study of different arithmetical approach of TEP. Some of the methods are congestion-driven TEP, bi-level model, which are mainly modeled for reducing the cost of network investment. The flat locational marginal price (LMP) model in TEP assures the fair as well as the viable electricity pricing. Subsequently, models are there that considers the congestion of transmission line along with the effect of cost of generation investment.

Further, the consideration of security is the main aspect, and the method like flexible TEP approach, which was on the basis of Differential Evolution Algorithm is mainly meant for reducing the cost along with reliability as well as security. Recently, the Renewable energy sources (RES)'s installation ability is maximizing rapidly, hence the respective transmission corridors require to create under the delivery of renewable generation with high RES. Unlike the conventional generation, the renewable energy generation has the uncertainity characteristics that bring the barriers on system operation. In order to allow the RES's huge-scale integration, the transmission network requires to get updated, and the interregional connected. This turns into very complex on carrying TEP on various regions co-coordinately, for the reason that the planner may have the knowledge of only some regions, so the candidate lines are very difficult to be chosen.

Many models are there that addresses the TEP uncertainties. The models like stochastic coordination of generation based TEP model, Monte–Carlo (MC) simulations are mainly utilized for capturing the uncertainties of component of system, as well as errors of load forecast. Then, the TEP is evaluated as the renovated programming issue (Mixed Integer Linear). A robust optimization [22] model is concerned with assessing various uncertainty levels and conservation. However, the limitations in terms of optimization problem solving are not yet rectified, and some advanced model is required for solving those drawbacks.

This paper makes a keen review on TEP problem under certain methodologies and performance measures. The rest of the paper is arranged as follows: Section II explains the literature work. Section III explains the analytical result of various TEP models from the reviewed papers and explains the research gaps and challenges. Section IV concludes the paper.

II. LITERATURE REVIEW

A. Related Works

In 2017, Nima et al. [1] have presented a new approach namely two-stage adaptive robust transmission expansion planning (AR-TEP) problem, which has considered the future load demand's uncertainty and the production of future wind power. They have utilized a Linear decision rules (LDRs) for reformulating the AR-TEP approach as the tractable mixed-integer linear programming issue, and that could be directly resolved via off-the-shelf optimization packages. The developed LDR-based AR-TEP approach was represented by Garver 6-bus system, IEEE 24-bus system, and a 236-bus system on various conditions. Finally, the results have shown the superiority of proposed model over other methods in terms of budget uncertainty.

In 2018, Yao et al. [2] have presented an extension of minimized disjunctive approach for considering N-1 criterion in TEP (multi-stage). The extension was done through the linearizing nonlinear terms that provoked by N-1 contingency conditions. Then, the proposed approach was compared to the conventional models; the extensive RDM has minimized the count of binary variables along with the conditions. Finally, the arithmetic outcomes from used 3 test systems have indicated that the developed model could consistently enhance the performance in terms of solving the TEP problem.

In 2018, Li et al. [3] have presented a chance-constrained TEP model, which considers the renewable generation uncertainty along with load. Based on the idea of density-based clustering approaches, the authors have presented a new scenario generation model for characterizing the uncertainty sources in representative scenarios form. Subsequently, the chance conditions that forced on the sampling situation were included into the TEP approach for avoiding the investment of uneconomical transmission. Further, they have developed an enhanced Benders decomposition (BD) algorithm with dedicated Benders cuts for solving the issue of chance-constrained TEP. Finally, some arithmetical evaluations were given for evaluating the validity of developed TEP model The outcomes on test systems have demonstrated that the developed BD algorithm was computationally more effective to solve the liberated issue.

In 2017, Subir et al. [4] have proposed a `2-stage' deterministic algorithm to do effective TEP with renewable energy (RE) resources on the statement presents in conventional generators. They have considered the Zero-RE penetration as the `reference scenario', along with the objective of cost-minimization as the conditions of planning criterion (Phase 1). In the developed model, phase 2 is needed to be resolved if and only if the performance of network degrades in association with the reference scenario. Here, the authors have included the congestion cost as the sub-objective. At last, the developed algorithm has guaranteed the network enhancement. The planning horizon was subdivided into little blocks for facilitating the investment of delay. The developed approach was developed on IEEE 24-bus system, and it has produced the least cost plan with effective performance.

In 2018, Zhi et al. [5] have proposed a method that comprises of 5 phases for selecting the candidate corridors. This could grant the optimal candidate set for the planners (system planners). Here, in the 1st two phases, the authors have used the conventional corridors for eliminating the congestion along with satisfying the N-k security criteria. Afterward, in the3rd phase, they have identified the candidate buses for specifying the possibility of novel, feasible corridors. At the 4th phase, they have applied the difference of local marginal price for choosing the new corridors. Finally, at 5th phase, the remaining feasible corridors were checked through a linear relaxation approach for enhancing the candidate set performance and also for minimizing the needed computation time. Finally, the model was implemented on IEEE 24-bus system as well as revised IEEE RTS-96-bus system and has proven the superiority of proposed work.

In 2017, Jing et al. [6] have developed a Risk-aware framework for ensuring the secure, economical as well as reliable operations of power systems. Rather than utilizing the deterministic security aspect, the authors have proposed an insecurity Risk Cost (RC) for granting the network planners along problem insight, options regarding the problem along with the future applications in taking decisions. Particularly, the proposed RC could quantify the security of the system, concerning the probability aspect along with contingencies severity. Similarly, they have modeled the DR's economic value and has included them into included optimal operation solutions. Further, the authors have developed an algorithm, iterative solution that was on the basis of Benders decomposition for enhancing the computational efficacy. Finally, the developed approach was arithmetically modeled on Garver's 6-bus, IEEE 24-bus RTS, as well as 2383-bus polish systems, and has proven the superiority of proposed work over other methods.

In 2018, lei et al. [7] have developed a new incremental reliability assessment approach (IRAA) for the problem of TEP. Then, the fundamental idea was for developing an evaluation approach of incremental reliability, and hence the model attains great computational efficacy. Initially, they have categorized the contingencies into 3 scenarios as per the states of the supplemented components of planning approaches. Subsequently, they have analyzed the incremental reliability indices. It turns that the contingencies of single scenario could only affect the mentioned indices and, hence the residual contingencies could be eradicated. On the basis of this phenomenon, the authors have developed an IRAA for TEP, and that could enhance the performance of different conventional reliability assessment approaches. Finally, they have implemented in IEEE RTS 24-bus and 300-bus system and has demonstrated that the developed model was more superior with respect to accuracy as well as efficiency.

In 2018, Ziaee et al. [8] have combined 2 planning issues or issues into a single planning issue or problem and has arithmetically reviewed the advantages of their combination. Particularly, they have combined the optimal TEP problem and the optimal position of thyristor controlled series compensators (TCSCs). The developed math program (single period) for the joined problem has reduced the cost of investment under new lines as well as TCSCs and also has the estimated generation costs, and load shed with the consideration of multiple operation situations. The model has relied on the DC power flow approximation and has tied the greatest flow limit of every line to their length. They have developed the operational scenarios with the consideration of load as well as wind power generation of a distinctive period via a developed approach for scenario minimization. They have used the general linearization approach and disjunctive approach for linearizing the polynomial conditions in the issue. The final outcomes have reviewed the betterment of proposed work under solving the optimization issue by means of cost benefits as well as wind penetration.

In 2018, Mohammad and rose [9] have developed a framework that was more capable in utilizing both progressive hedging as well as Benders decomposition algorithms for decomposing and parallelizing a huge-scale problem (either in vertically or horizontally). They have developed a scenario bundling approach for creating the bundles via three steps, i.e., classification, clustering, as well as grouping that aims in increasing the similarity among bundles. The respective bundling approach could enhance both the result quality (minimizing the optimality gap) along with the performance (minimizing the computational time) of developed framework. To formulate the ability of developed approach, the approach was applied in a minimized ERCOT system with 3179 buses, 4458 branches, and 10 scenarios. The outcomes from the case study have shown that the developed model could solve huge scale issue tractable, and also has granted high-quality results.

In 2018, Xuan and Antonio [10] have solved the TEP problem on both long as well as uncertainty (short-term). Here, the Long-term uncertainty has pertained for changing across years, while short-term uncertainty has pertained on changing within a year. They have evaluated the problem of expansion as the adaptive robust optimization issue that grants the support over long-term uncertainty. The problem was solved via the decomposition algorithm implementation, which has focused on the effective subproblem solution. The developed algorithm has proven its superiority over other concepts on identifying the robust expansion plans and their computational efficacy.

In 2018, Luis and Ana [11] have proposed an adaptive optimization model to model TEP. In fact, the problem was evaluated on the central planner, For instance, the transmission system operator, which aims at the determination of generation as well as the plans of TED, which could reduces the costs like expansion cost and cost of operation. The central planner has generated the facilities of transmission and has promoted the creation of the most appropriate generating units between private profit-oriented investors. Via the confidence bounds, the future peak uncertainties and the future generation (fuel) were modeled. Meanwhile, they have modeled the demand variability uncertainties and the stochastic units production by a count of operating constraints. The implementation of developed work was carried out in the IEEE 118-bus system, which has shown the efficiency of developed model.

In 2017, Jahromi *et al.* [12] have utilized the systematic approach, which was on the basis of multi-state Markov approach for representing the V2G's presence uncertainty. In order to examine the effect of PEVs, they have developed a probabilistic TEP with the existence of V2Gs (P_TEPV2G). In the developed approach, the basic function has included the whole line cost as well as Risk costs (RCs). Further, the optimal location as well as and PEV capacity were concerned as the decision variables. Since P_TEPV2G was a difficult and non-linear optimization issue, the authors have utilized an Improved cuckoo search algorithm (ICS) for resolving the issue. Finally, the simulation work on IEEE 24 bus system has proven that the proposed model could minimize the RC.

In 2017, jing and Rashid [13] have introduced a non-linear economic design to the responsive, which was on the basis of demand's price flexibility and the benefit function of customers. Further, they have also developed a probabilistic multi-objective TEP approach that has concerned the DRPs. Also, they have implemented a probabilistic analysis approach for handling the loads uncertainty, DRPs as well as DG in TEP problems. A differential evolution program was used for solving the TEP because of problems' non-convex formulations. Here, the developed TEP approach could identify the optimal trade-off among investment of transmission as well as demand response expenses. They have demonstrated the planning approach on IEEE 118-bus system and has proven the betterment of proposed work.

In 2017, Jing et al. [14] have proposed a stochastic TEP model for assessing the effects of wind power penetration and the inclusion of demand response. They have introduced a risk conditions and has investigated the impacts on solutions of TEP. Further, for minimizing the complexity and the problem size, they have adopted a decomposition-based model. As per the arithmetic outcomes on Garver's six-bus and the altered IEEE 30-bus systems, the TEP solutions were subjected to the deviations of wind power and cannot be defined in straightforward. Thus, the risk-analysis has been taking place for guiding the investment of transmission with maximum flexibility. The inclusion of wind power uncertainty has raised the whole cost along with the estimated energy not supplied, and it was mitigated via the developed TEP approach.

In 2017, Shengjun and Venkata [15] have investigated a static DC TEP using a new multi-group particle swarm optimization (MGPSO) algorithm. This was for ameliorating the performance on accuracy and efficiency for the TEP solution from the algorithm design aspect. In fact, the MGPSO was on the basis of discrete PSO model with various demandable improvement including Sobol sequence initialization approach, the strategy of multi-group co-evolution, and the approach of mutation. They have extracted the linear equation system to the solution of linear programming subproblem within the MGPSO model. Subsequently, they have addressed with effective LU decomposition model. They have implemented the Case studies and have proven the superiority of proposed work.

III. REVIEW UNDER VARIOUS TEP MODELS

B. *Algorithmic Analysis*

The algorithms that used in the reviewed works is diagrammatically illustrated in Fig 1. The diagram reviews various methods or algorithms proposed by the authors. The methods aimed to solve the TEP problem with the consideration of main factors like Total cost, Computational Time and so on. Some adaptive models and also the optimization concepts have been developed in different papers. The used methods are as follows: Two-Stage AR-TEP is used in [1] for solving the TEP problem. The disjunctive mode, Extended Reduced Disjunctive Model (RDM) is used in [2]. Improved benders decomposition algorithm [3] is the effective methods proposed by the authors of [3]. In [4], the authors have proposed an Two-stage' deterministic algorithm. Selection algorithm and Risk-averse TEP framework are proposed in [5] and [6] of the reviewed papers. In [7], an assessment approach was proposed namely, incremental reliability assessment approach (IRAA). A single period math program is used in [8]. In [9], the authors have proposed a scalable and configurable decomposition framework for solving TEP problem. Three-level robust optimization model is used in [10]. Adaptive Robust Optimization (ARO) has been proposed in [11].The models like Multi-state Markov model, non-linear economic design, stochastic TEP model and multi-group particle swarm optimisation (MGPSO) algorithm are the models used in [12] [13] [14] and [15], respectively.

Fig. 1: Algorithmic Analysis of Reviewed Works

C. *Performance Measure Analysis*

From the analysis, it is proven that the performance of proposed models has been analyzed in terms of certain performance measures. Some of the common measures used in the reviewed papers are Investment cost, Total cost, Operation cost, CPU time, Transmission line, Expected Energy Not Supplied (EENS), Demand Response time and other measures. Here, 26.66% contributions have used the investment cost measure. Among all the methods, 46.66% of contribution has measured the total cost of the models. Moreover, the operation cost is one of the measures, which is used by 20% of contributions. Almost all the contributions have measured the CPU time, i.e., 66.66% of contributions have measured the CPU time. Only 20% of contributions have used the transmission line measure for analyzing the performance of their proposed works. EENS has been measured by 13.33% of contribution. Then some other measures like Master problem measure, Simulation time, Total line cost, Wind generation cost, Risk cost, Wind generation cost and so on has also been used by some contributions

TABLE I. PERFORMANCE MEASURE ON REVIEWED WORKS

Citation	Investment cost	Total Cost	Operation cost	CPU Time	Transmission Line	EENS	Demand Response cost	Others
[1]	✓	✓	✓	✓				✓
[2]				✓				✓
[3]		✓		✓				✓
[4]	✓			✓	✓			✓
[5]				✓	✓			✓
[6]		✓				✓		✓
[7]				✓		✓		✓
[8]	✓			✓				✓
[9]				✓				✓
[10]	✓	✓						✓
[11]		✓						✓
[12]		✓		✓	✓			✓
[13]			✓					✓
[14]		✓	✓				✓	✓
[15]				✓				

*D. **Maximum Attainment Measures***

Table II summarizes the maximum attained measure. Here, the best performance value of CPU time is 0.25 s. The least total cost that attained from all the contributions is 152. The less investment cost among all the contributions is 8.28. Then, the least production cost of all contribution is 0.7753, and it is clear from [13]. From [15], the least average time is attained as 2.845. The DRC of [14] is 78.25, which is the maximum attained measure. The NB of [2] is 135 and NC is 11551. The least generation cost among [4] and [10] is 375.26. In [9], the optimally gap measure is used, and the maximum attained value is 0.24%. Among [14] and [6], the best EENS value is 0.0112.

TABLE II. MAXIMUM VALUE OF VARIOUS PERFORMANCE MEASURES

Measure	Best performance value	Citation
CPU Time	0.25 s	[1] [2] [3] [4] [5] [7] [8] [9]
Total cost	152	[1] [3] [6] [10] [11] [12] [14]
Investment cost	8.28	[1] [4] [8] [10]
Production cost	0.7753	[13]
Average time	2.845	[15]
DRC	78.25	[14]
NB	135	[2]
NC	11551	[2]
Generation cost	375.26	[4] [10]
Optimally gap	0.24%	[9]
EENS	0.0112	[14] [6]

E. ***Number of used Transmission lines***

This survey has also reviewed the used number of Transmission lines at each contribution. Fig 2 represents the contributions on number of lines. Here, it is reviewed that the 70% of contributions have used 5-10 lines, 10% of contributions have used 10-30 transmission lines, 10% of contributions have used 30-50 transmission lines, and 10% of contributions have used 100-200 transmission lines.

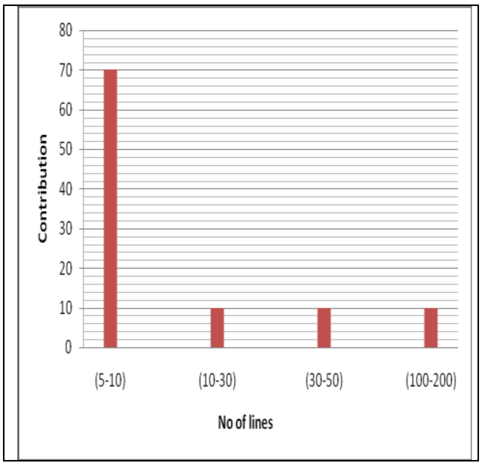

Fig. 2: Algorithmic Analysis on Reviewed Works

IV. RESEARCH GAPS AND CHALLENGES

Though the TEP problem is undertaken in some means of linear and nonlinear modality, the problem solving can be extended in a multiple direction. Most of the shorter-term uncertainties are feasible to utilize the statistical approaches for approximating probabilities that are associated to every scenario; however, some expert knowledge should be used on assigning those probabilities on evolution, related cost, future generation and so on. Some possible robust stochastic optimization evaluation should be carried out for assigning each scenario under uncertainty. The work can be expanded to the adaptive robust optimization for modeling uncertainties of TEP for finding an expansion plan, which convinces the worst case scenario. Moreover, this dissertation work can be focussed toward the robust optimization concept for integrating the uncertainties range that required being concerned for the worst case scenarios. However, one of the drawbacks behind this TEP is the identification of appropriate attributes to process the bundling.

The multi-stage TEP is not up to the mark and some effective research work should be done in future to satisfy the same. Along with this, the feasibility maintenance in long-term uncertainties face is also a most crucial characteristic of the solutions for far future decisions. Evaluation of long-term TEP studies must be revised in the future developing TEP model. In some cases, the models are not so flexible in all real time cases, and hence the need for modified planning is more crucial. Most importantly, solving all the mentioned drawbacks with some advanced stochastic models in real-world environment is a needy aspect.

V. CONCLUSION

This paper has reviewed 15 papers under various TEP problem-solving models. The review results have analyzed the various proposed methodologies, along with the analysis under performance analysis and maximum attained measures. The analysis has been under diagrammatic representation and tabulation that reviews the work in terms of proposed models and performance measures. After this, the analyzed challenges and the way to the future move were also described clearly.

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