TRANSMISSION EXPANSION PLANNING IN RESTRUCTURED POWER SYSTEM: AN OVERVIEW

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Abstract- *Transmission expansion planning is experiencing significant change with the introduction of deregulation. It now involves a complex balancing of technical issues with the economical ones. The growing role of market forces dictates that transmission planning should be carefully redesigned to ensure compliance of new objectives and constraints in the market environment. Various conflicting issues need to be considered to fulfill new challenges. This paper organizes and classifies the existing transmission expansion planning strategies in both regulated and restructured environment, considering various economic and engineering issues and challenges by reviewing recent theoretical and practical developments in transmission investment and planning methodology.*

Keywords-componen: *Deregulation, regulated environment, transmission expansion planning, transmission investment, electricity market.*

1. Introduction

Power system planning is a complex process that requires a significant amount of work, involving major stages such as system reliability assessment, forecasting of demand and fuel prices, and security assessment. The reform in transmission network involves a number of complexities, and many new issues have surfaced, such as transmission costing and pricing, payment allocation, power wheeling and congestion management, available power transfer capabilities, the natural monopoly status of transmission networks and transmission rights, etc. Among them, the transmission expansion planning (TEP) poses particularly a difficult question in the newly deregulated environment. The role of the transmission system has expanded beyond the historical role of connecting generation with load and enhancing reliability. In the new environment inadequate transmission capacity would result in transmission bottlenecks enabling generators in certain locations to exercise market power in a local market. In its new role, the transmission system can enhance competition and mitigate market power.

In traditional power system planning, generation planning is core while transmission planning is based on it. The idea is to determine when and where transmission facilities should be installed so that they operate in an optimal manner subject to a list of technical, financial and environmental constraints. The change in load demand is fulfilled by appropriate dispatch by generator. The expansion planning is performed solely by the system operator with the objective of minimizing the capital required for a certain scheme while fulfilling the obligation of energy supply with reliability requirements. It is basically least cost planning approach. Most of the research has been done to reduce the computational time or to increase convergence towards its optimal solution.

Market deregulation has introduced several new challenges for transmission planners including conflicting planning objectives and increasing uncertainties. Traditionally, the whole power system was operated by a single system operator and planners had unlimited right to access the information about all aspects of the system. After deregulation, transmission expansion planning no longer remains dominated by system operator. Since transmission and other ancillary services are now commodities, expansion planning should now include their market impacts in the decision-making process. Also the data such as demand forecasts, existing generators, fuel prices, existing and planned resources and the financial return on investment, earlier available with planners and operators, out of which some data kept confidential in new environment, which increases uncertainties about bidding strategy and hence the future price patterns. This introduces significant uncertainty about future power flow patterns [1]. Here participant make own decision independently and strategically to maximize their profit. On the other hand customers, who are sensitive to electricity price, adjust their consumption. In general there are two types of uncertainties handled by TEP. They are *Random* and *nonrandom* uncertainties.

Random uncertainties are deviation of those parameters which are repeatable and have known probability distribution. For example: Load, Generation costs, Power and bid of independent power producer, and availability of generators, lines etc. Nonrandom uncertainties are those parameters which are not repeatable and hence their statistical formulation is not possible from the past observation. For example: generator expansion, facility, Transmission expansion cost and rules etc.

Major uncertain sources in restructured environment include [2-5, 13].

- Load forecasting uncertainty
- Availability of generator, transmission lines and other facilities.
- Transmission expansion cost.
- Expected unreserved energy cost.
- Market rules and government policies etc.

Due to increased uncertainties transmission planner are facing greater risk in restructured environment. This paper presents a review of the main issues and solution approaches for transmission planning in a restructured power system.

2. Transmission expansion planning in restructured environment

In Traditional power system, the utilities are mostly vertically integrated and owned by the government. Since the utility has control over all generators, when a constrained operation becomes compulsory, re-dispatch can be scheduled through least cost optimization by using optimal power flow. Here profit can be optimized through cost minimization. Fig.1 shows Traditional TEP procedure while Fig.2 shows TEP procedure in deregulated environment. Conventional approach Transmission expansion planning decomposes the problem into three main steps:

a) Generate alternative candidate transmission expansion plans using simplified model of problem.

b) Financial Analysis

c) Technical Impact analysis to ensure the selected plan feasibility.

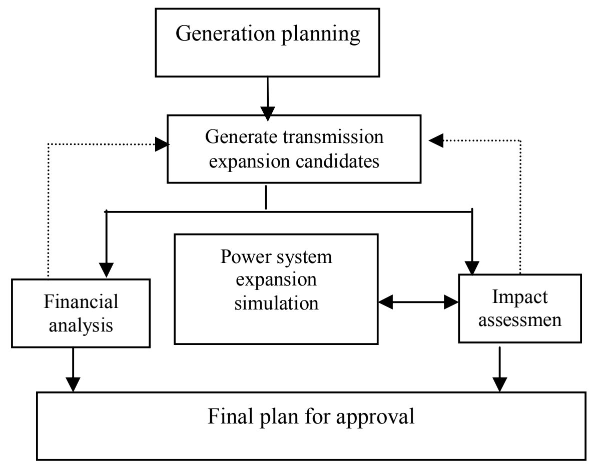

Fig.1.Traditional Transmission expansion planning procedure [13].

Transmission Expansion planning in deregulated market can be classified mainly into two categories, which are *Transmission investment* and *transmission planning*. Transmission investment can be managed by monopoly management and market driven transmission investment. Transmission planning can be managed by analytical tools while should have the ability to perform economical as well as technical assessment. [9].

Transmission expansion planning in restructured environment is much complex task. The possibilities of generation planning and demand side management as alternate for transmission expansion must be considered when applicant for transmission expansion is generated. The process of alternate applicant generation for transmission expansion must be flexible and robust. Future revenue for transmission investment depends upon the operating condition of existing system. The financial analysis is done considering (a) traditional basis focusing on reliability, engineering feasibility and environmental impact and (b) Economic assessment of impact of new system on society.

TEP follows the following objectives in deregulated power system. [10-12]

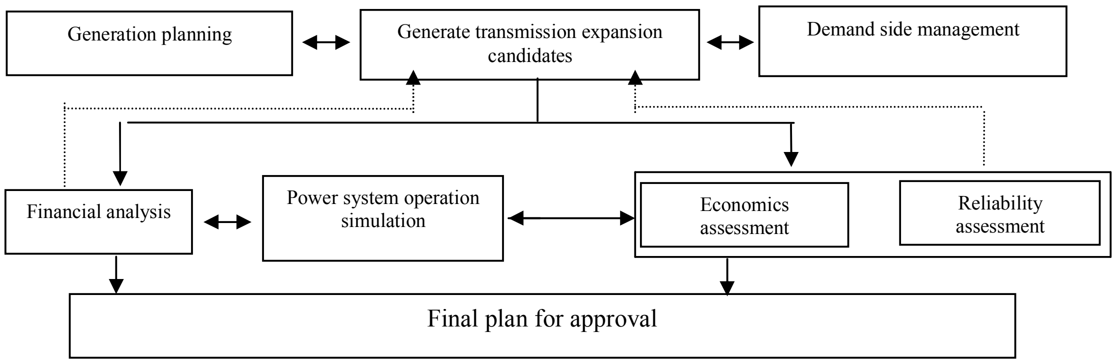

Fig.2. Transmission Expansion planning procedure in Restructured Environment [13]

- Encouraging and facilitating competition among electric market participants.
- Providing nondiscriminatory access to cheap generation for all customers.
- Mitigating transmission congestion.
- Minimizing investment
- Minimizing risk associated with investments
- Providing a robust transmission network against all uncertainty.
- Minimizing environmental impact.

The objective of transmission expansion planning in deregulated environment is different from traditional power system. Transmission network owners or investors are more interested in maximizing their own profit rather than social welfare. Due to the above mentioned conflicting objectives, the TEP problem becomes a multi-objective optimization problem which cannot be solved by traditional planning methods.

3.Transmission Expansion planning algorithm

In deregulated market, market based approach is very popular. Market based planning approach is sum of financial and Engineering issues that considers economic as well as physical laws of generation , load and transmission.

A transmission planning approach to achieve balanced expansion planning in both economic and system reliability is proposed by H. Chao et al [15]. Reliability criteria and economic impact on power system are analyzed by Monte Carlo simulation and finally Transmission network Expansion is achieved based on reliability, indicated by expected energy which is not served and loss of expectation. Economic impact is indicated by expected local marginal price.

In open market environment it is difficult to measure the importance of different stakeholders and different planning objectives, which introduces another type of uncertainty. Fuzzy decision making can be employed to handle this issue. Market based Planning approaches were proposed by M.O. Buygi *et al* [16-17]. Probabilistic tool is used for modeling random uncertainties in transmission expansion planning. The final expansion plan is selected according to shake holder desire [17].

Apart from market based approaches optimization approach such as genetic Algorithm, expert system, fuzzy set theory petro-based solution technique have been proposed to solve Transmission expansion plan [18].

H.B. Sun and D.C. Yu [19] proposed multiple objective fuzzy optimization models. A multiple objective optimization model, which is converted into a single objective one, is solved. This proposed model provides solution considering almost all constraints for TEP.

A static transmission expansion methodology is presented using a multi-objective optimization framework by Pouria Maghouli *et al* [20]. The genetic based NSGA II algorithm is used here followed by a fuzzy decision making analysis to obtain the final optimal solution.

G.B. Shrestha and P.A.J. Fonseka [21-22] proposed a frame work for transmission planning in deregulated environment. A level of congestion in network is utilized as driving signal for need of transmission network expansion and a comparison between the congestion cost and investment cost is used for determination of optimal expansion plan.

Multi-year transmission expansion planning considering transmission congestion cost and impact of investment cost is proposed by O. Bulent Tor, A. N. Guven and M. Shahidehpour [23] to evaluate sensitivity of optimal TEP to congestion level and financial constraints. Here Benders decomposition is utilized to decompose the TEP in two sub problem ie security and optimal operation. Operation cost due to congestion is used to evaluate competitiveness in electricity market.

R. Fang and A. David [24] propose a congestion management model which is appropriate for power pool. PSO (particle swarm optimizer) is introduced to solve the complex nonlinear model. J. Silva, I. Raider M.J. Romero, R. Garcia and A.V. Murari [26] presented mathematical model to solve the transmission network expansion planning problem with security constraints using (n-1) security criterion. Genetic algorithm designed to solve the reliable expansion planning in an efficient way. Also a variety of emerging problem in competitive environment is described in [27-32].

Mathematical optimization model such as Benders decomposition and branch &bound algorithm are generally used for transmission expansion planning in deregulated environment.

Bender decomposition technique was utilized to solve the expansion scheduling investment and power pool operation problem to upgrade the capacity of transmission lines. [18, 21-22, 24, 33].The level of congestion in transmission network is used as an indicator for need of additional transmission lines.

A branch and bound method was proposed to solve optimal transmission expansion plan using fuzzy se theory that uses maximum power flow with minimum cut approach to power system by J. Choi *et al* [34].Branch and bound method considering probabilistic reliability criteria is again proposed by J. Choi *et al* [35]. Here integer programming approach is used to locate optimal strategy using probabilistic branch and bound method to power system.

In restructured power system game theory is also applied as a transmission expansion planning approach P.A Ruiz and J. Contreras [36], J. Contreras and F.F .Wu [37], D.A. Lusan *et al* [38] presented game theory approach to solve transmission expansion planning problem in restructured environment.

H. Singh, H. Hao and A. Paralexopoulos [39] provide the cost evaluation techniques considering transmission congestion cost. They examine two approaches for dealing with these costs with the help of Game-theoretic evaluation technique. The first approach is based on a nodal pricing framework and forms the basis of the so-called pool model and second approach is based on cost allocation procedures proposed for the so-called bilateral model.

A multi instrument system is developed to assign player to conform coalition and cost allocation for electric value engineering.

4. Solution approach for TEP in competitive environment

A feasible transmission expansion plan should be able to meet future transmission capacity requirements, secure and fast return on investment, boost the economy and to ensure the level of reliability and quality expected by customer. Hence new analytical tools should be able to select an optimal plan which efficiently evaluates alternatives and uncertainties based on economics and reliability issue. The tool should have the following functions [10].

- Scenario analysis.
- Project Identification and screening.
- Generation of candidate transmission lines based on generation and demand side management.
- Economic evaluation.
- Reliability evaluation.

A. Scenario Analysis:

Scenario analysis becomes a universally adopted method to handle uncertainty to reduce risk in different market condition [1-6, 10-12, 40]. The uncertainty in transmission planning mainly arises from generation expansion and load growth. The range of transmission capacity requirement within each scenario can be identified using probabilistic or fuzzy modeling. Scenarios of load growth in different buses and scenarios of new generation plant location, capacity and timing have to be considered. The number of possible generation scenarios may be large, since generation planning is made by independent power generation companies and each plan may differ based on type of fuel used, its location and timing of plant operation.

As a result possible combination of scenarios is very large and it is not possible to analyze all of them. Therefore it is easy if we classify generation scenario into a group with identical transmission requirements and selecting a delegate scenario from each group for analysis.

Generally the candidate power plant sites are known to public due to availability of energy resources, but the timing and its potential capacity is not known. Therefore to model this probability or fuzzy set theory is used.

On the other hand, an exact load growth forecasting is essential otherwise there is a risk in planning. The planning based on lower load forecasting affects the system reliability, while the planning based on higher load forecasting affects the economics of operation [41, 42]. The existing method of load forecasting can be employed for the new environment but some emerging factor must be taken into account.

B. Selection of candidate transmission lines:

The purpose of Transmission expansion is to relieve current congestion and potential transmission blockage.

Formulation of initial candidate pool for expansion is based on information about the given system, such as generation and transmission capacity, estimated tariff for the new circuit and corresponding forecasted system demand etc. to ensure its fulfillment with practical engineering and management considerations based on following major limits.

- Network redundancy
- Financial limits
- Environmental factors
- Estimated construction time of lines and time perspective of the planning.

The pool is first formulated based on redundant transmission lines as required for system reliability. By examining the investment requirement and construction period of the individual lines, a number of candidates can be dropped at this stage. By considering environmental factors, a further reduction in pool size can be made to avoid excessive workload.

C. Economic and reliability evaluation:

Economic and reliability evaluation is very crucial in transmission expansion planning [6], with the objective of minimizing financial risk and to ensure optimum benefit from the investment plan.

Economic analysis of transmission expansion planning is the measures of economic benefit that can be produced by transmission upgrades.

The economic benefit by transmission expansion is responsible for the improvement in market competition and mitigates the misuse of market power.

The economic benefits of transmission expansion in deregulation system have been evaluated in references [43, 44].

Kurt Jornsten [45] proposed optimization model for zonal pricing in deregulated power system considering maximum social benefit.

The optimal spot pricing method considering power system operating cost, and they are based on short-term marginal cost proposed by F. Schweppe *et al* [46]. This methodology has been adopted by many countries.

Economic benefit method for allocation of transmission expansion cost considering active power, losses and network constraints is proposed by R. Reta *et al* [47].

The meaning of reliability in the deregulated environment is based on customer impact, not on the reliability of equipment or other part of the power system [48-52]. But the reliability of supply will be equally important in deregulated power system also since the performance parameter is widely utilized in managing profit of transmission network by the investor.

Reliability can also be evaluated in an economic manner. Customer damage Functions is one of the method to evaluate reliability of the system [49].

Mechanism of 'provider insurance' is introduced by E.H. Allen and D. Ilic [51]. Generator who provides the insurance of reliable power supply through its reserve, should always collect the payment (the premium), and be rewarded with the spot market price for its called reserve. The consumer, who buys insurance, pays premium and obtains a reliable power supply (the claim). Such market mechanism will result in the maximum social welfare.

D. Solution Models:

Several methods and models using classical mathematical optimization methods as well as modern heuristic based methods have been applied for solving the complex and uncertain problem of TEP. The classical methods are time consuming and unsuitable for solving the non-linear non convex TEP problem. On the other hand the heuristic methods are simpler and have many advantages.

The transmission planning tool must be able to deal in different types of uncertainty and must adjust in dynamic change in power system. The object oriented approach is quite suitable since it offers the advantage of concern flexibility, expandability maintainability and data integrity. The object oriented software model for determining the dynamic planning in deregulated power system is proposed by Edmund Handschin *et al* [53] and object oriented on line network analysis method is proposed by M. Folley and A. Bose [54].

Also a verity of heuristic model is presented. But the above model does not able to satisfy the practical constraint of power market [55]-[59]. Therefore, transmission expansion planning problem is a issue of judgment making [60]

5. Conclusion

Restructuring of the power system has received much attention around the world in the last two decades. Transmission expansion planning becomes more difficult in the restructured power system because of economic and system reliability both since system operation and many other issues are internally related. In this paper TEP in both regulated and restructured environment has been classified and discussed. The recent development in economic and technical aspect of transmission investment and planning has been reviewed. TEP aims to strike a proper balance between conflicting objective like cost, reliability and security etc. Therefore there is a need to develop a comprehensive tool which will work in the uncertain real word environment. For such analysis probabilistic or fuzzy set theory balanced approaches can prove very effective.

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