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Non-deterministic approaches to deal with Uncertainties in Transmission Expansion Planning under Deregulated Environment

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ABSTRACT: The global trend for the deregulation of the power sector has led to significant changes in system planning, management and operation. The optimum approach to transmission expansion planning (TEP) in this environment is an open problem. The objectives, constraints and the approaches should be carefully designed to ensure system reliability as well as to cater the market environment. The paper presents the non-deterministic approaches, adopted in most relevant literature available, to deal with uncertainties in TEP under deregulated environment.

Keywords: Deregulation, transmission expansion planning, random and non-random uncertainties.

I. INTRODUCTION

The transmission expansion planning (TEP) problem consists in finding the optimal expansion of transmission system, which may include the introduction of new transmission lines, induction of higher voltage levels, and new substations, so that the system can operate in an adequate and secured way throughout the specified planning horizon.

The transmission system in the deregulated environment should provide the required atmosphere for competition among market participants. Such an environment increases the reliability and the efficiency of system operation. The vital stakeholders or market participants of the deregulated electricity sector are getting involved in the TEP. These market players have equal concern for investment and profit prospects. The planners have to take into account the preferences of all market players and try to simultaneously satisfy several diverse planning objectives [1]. From the transmission planner's view, planning in the de-regulated environment is the process of balancing multiple conflicting objectives with several constraints. In the new market environment, transmission expansion is no longer coordinated with generation planning. Also some information about generation and distribution companies is trade secrets. The network planner has difficulty in obtaining information about generation and distribution companies [2, 3].

Thus, the objectives of TEP in deregulated power system are many and often conflicting. There are many additional uncertainties which are related to generation capacity, location, timing, load levels, load flow based on market price, cooperation and competition in future electricity trading, future energy and environmental policies. There have been certain new planning methods trying to encounter the challenges especially those related to uncertainties.

In this paper, an updated review of the most relevant publications on TEP considering the objectives, and the uncertainties encountered by a transmission planner in the restructured and deregulated power system is presented.

The paper is organized as follows. Section 2 presents the objectives of transmission expansion in deregulated power system and the market based criteria. Uncertainties in the deregulated environment and the TEP approaches from the uncertainty viewpoint are given in section 3 and 4 respectively. Finally the conclusion is drawn in section 5.

II. OBJECTIVES AND CRITERIA OF TRANSMISSION EXPANSION IN DEREGULATED POWER SYSTEM

A. Objectives of transmission expansion

Under the regulated environment, a utility has the obligation to serve the load demand of all existing and future customers with reliability and at a reasonable rate. Because of regulations, the transmission planners normally have the system data required for TEP such as demand forecasts, existing and planned resources and the required financial return on investment.

Market participants in the deregulated power system are power plant owners, system operators, network owners, power marketers, load serving entities, customers, share-holders of companies and electricity regulators. These new entities are getting involved in the TEP and expansion of the transmission system is seen differently by each. Their objectives are more market-oriented with equal concern for investment and profit prospects. Providing non-discriminatory access, facilitating competition, minimizing the investment and operation cost, mitigating transmission congestion, minimizing the risk, increasing the reliability of the network, increasing the flexibility of operation, and minimizing environmental impacts are the main desires of these stakeholders [4].

Many of today's electricity systems are partially deregulated, i.e., the generation segment are deregulated and competitive whereas the transmission sector has remained regulated. The two major transmission management practices presently adopted are:

(i) System operation and transmission functions carried by a single regulated company,

(ii) Transmission services provided by merchant network investors called merchant transmission.

The objectives of regulated transmission operator and merchant transmission are different and lead the transmission expansion towards different levels. Thus, to a great extent, the optimum transmission capacity expansion depends on the ownership structure or network management.

Many of the research work considering deregulated power system [5,6] the transmission provider is supposed to be a single regulated entity whose main task is to operate and expand the transmission system with the aim of improving competition among market participants and to maximize social welfare. The introduction of merchant transmission may enhance the transmission revenues and could stimulate a competitive market for transmission capacity expansion.

B. Market based criteria

Traits used for transmission planning must reflect planning decisions, their effects, and a real system. Several market based criteria have been presented in [7-8]. Network congestion level is used as the driving signal for transmission expansion in [8- 9]. Apart from congestion cost, other market based criteria such as standard deviation of mean of locational marginal price (LMP), Lerner's index, social welfare percent and congestion cost percent are also used to evaluate the TEP. Reliability and flexibility of network operation can also be proper criteria to evaluate the market performance. The desires of market participants often conflict and cannot always be satisfied simultaneously. Therefore, TEP in a deregulated environment becomes a multi-objective optimization problem (MOOP), which cannot be solved effectively by traditional planning methods.

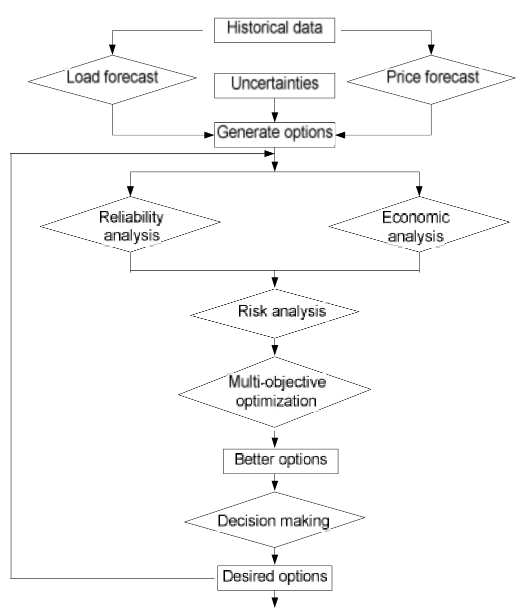

Fig. 1. Framework of TEP in deregulated power system.

A multi-objective frame work that is able to handle these different in-equal objectives with conflicting relation is discussed in [10-12]. The solution to MOOP is not unique and therefore some kind of subjective judgment by the decision maker or planner is also required. A multi-objective formulation considering construction cost, total social cost, maximum adjustment cost, congestion cost, benefit-cost ratio, maximum regret, social welfare maximization, and reliability can be seen in [6, 10- 12].

Thus, the two main observations are:

(i) The objectives of TEP in deregulated power system are different, and often conflicting,

(ii) The uncertainties in the deregulated power system are much more.

A typical framework of TEP in a deregulated power system considering uncertainties, multi-objective optimization, risk analysis and decision making is shown in fig.1.

III. UNCERTAINTIES IN DEREGULATED POWER SYSTEM

A. Uncertainty in Generation

In the new market environment, transmission expansion is usually carried out separately by transmission network service providers and is not coordinated with generation planning. Merchant plant developers and independent power producers (IPP) are constructing most of the new power plants with the main aim of enhancing economic opportunity. The locations, capacities and timing of new power plants, and the closure of old generating units with low profit are decided by the generation companies. These plant owners do not have to provide all their information to the system planners. In fact, some of the information about generation companies are trade secrets, for example, the operational cost and information, bidding strategy and bilateral contracts of generators are kept confidential [2, 13].

Hence the transmission planners no longer have sufficient information regarding the location, capacity, timing, and the availability of new production units. Generation expansion plan can significantly change the load flow pattern of a transmission grid.

B. Uncertainty in Demand

A power system that is designed for a regulated structure shows a specific set of power flow patterns. In a fully deregulated era, electricity prices are more volatile. Consumers, especially bulk consumers are sensitive to this price variance. They can also choose the suppliers of their own choice. Therefore, competitive electricity market causes the power flow patterns to change more frequently and more significantly because of the open access and increased complexity in market transactions. The network planner has difficulty in obtaining information about distribution companies which produces uncertainty in predicting future demand levels [2, 13].

C. Other uncertainties

There are many other uncertainties which are related to cooperation and competition in future electricity trading, future energy and environmental policies. Currently it is not completely clear about the roles and responsibilities that each participant has to play and discharge regarding the TEP. Rate of return on transmission investments are not guaranteed and therefore success on transmission investment is uncertain. The different stakeholders are now competitors and lack the spirit to cooperate with each other and to voluntarily adhere to reliability standards [13, 14].

D. Classification of uncertainties

Uncertainties in TEP can be classified as random and non-random uncertainties. Random uncertainties are deviation of those parameters which do repeat and have a known probability distribution. The statistics of random uncertainties can be obtained from past observations. Non-random uncertainties are parameters which are not repeatable and hence their statistics cannot be derived from past observations.

Random uncertainties in a deregulated power system are because of [4, 9]:

(1) load development,
(2) generation costs and power,
(3) bid of generators and IPPs,
(4) wheeling transactions,
(5) availability of facilities such as generators, lines, etc.

Non-random uncertainty is because of [4, 9]:

(i) Expansion including locations, timing, capacity, availability /closure of generators and or load,
(ii) Installation/ closure of other transmission facilities,
(iii) Replacement of transmission facilities,
(iv) Transmission expansion budget,
(v) Market rules, policies etc.
(vi) Behavior of other participants.
(vii) Deliberate outage of lines.

Vague data are data that cannot be clearly expressed. Vagueness of information is because of inevitable errors in estimation of future forecast. There is vagueness in TEP because of [4, 9]:

(1) importance degrees of stakeholders,
(2) importance degrees of planning criteria,
(3) occurrence degrees of possible future scenarios.

IV. TEP APPROACH FROM THE VIEWPOINT OF UNCERTAINTY

There have been certain TEP methods and approaches trying to encounter the challenges especially those related to uncertainties. From the viewpoint of uncertainty, the TEP approach can be classified as [15]:
(i) deterministic, and
(ii) non-deterministic approaches.
Both the approaches have been used for TEP in regulated and deregulated power system. The deterministic approach considers only the worst case in the system without considering their degree of importance, whereas non-deterministic methods consider various cases by assigning a degree of importance to each of them. The non-deterministic methods used in TEP problem are [15]:
(i) probabilistic methods,
(ii) scenario techniques,
(iii) decision analysis, and
(iv) fuzzy decision making.

A. Probabilistic methods

The probabilistic methods are used when there are random uncertainties. These methods derive the probability distributions of uncertain planning variables from their past observations. Thus, probabilistic information that are based on certain available statistical data for example load development, bid of generators, wheeling transactions, reliability of network components etc. can be obtained in the form of some known probability distribution law and its parameters [15,16].

Probabilistic methods include probabilistic load flow (PLF), probabilistic reliability criteria (PRC), risk assessment methods, and chance constrained programming (CCP). The algorithm for TEP using the PLF and PRC can be obtained from [15]. In the PRC, the reliability indices such as expected energy not served (EENS), expected number of load curtailment (ENLC), expected duration of load curtailment (EDLC), loss of load expectation (LOLE) etc are computed.

A PRC of LOLE to find the optimal expansion plan considering uncertainties related with forced outage of transformers and lines are given in [16-17].

B. Scenario Techniques

It is difficult to model many uncertainties in a strict mathematical manner, and the scenario analysis method provides an alternative way for handling these different kinds of uncertainties.

Scenario techniques are able to take into account non-random uncertainties although they can be used for the planning of any system. The strength of scenario based TEP is in addressing large uncertainties that can have significant impact on final decision making [6, 14, 15]. A scenario is a complete set of specified variables which includes both the uncertainties and the options. Both internal and external scenario analysis approach have been used in TEP. An internal scenario analysis has been used in [6] as it can find a trade-off between risk and cost-benefit analysis. The algorithm employing scenario techniques is as [15]:

1. Define and determine a set of probable scenarios,
2. Allocate a degree of importance to each future.
3. Find a set of possible solutions.
4. Specify a cost function to measure the goodness of each plan.
5. Select the final plan

The final plan is selected using one of the given criterion-

(1) Expected cost criterion
(2) Minimax regret criterion (Risk analysis)
(3) Laplace criterion
(4) Von Neumann-Morgenstern criterion
(5) Hurwicz criterion
(6) Pareto-optimal criterion
(7) Robustness criterion
(8) β-robustness criterion
(9) Fuzzy risk assessment

In the expected cost criterion, a probability or weight is related with each scenario. The weighted average costs of a strategy under different scenario yields an expected cost for each strategy. The advantage is that each scenario is considered and the importance of scenario is reflected through its probability of occurrence. However, this criterion may lead to risky decision as the solution is made without estimation of possible consequences after occurrence of a particular scenario.

Minimax criterion is extremely conservative and tries to find out the best result under worst scenario. The "minimal risk" is also a mini-max criterion which selects a strategy which involves the lowest additional cost under the most adverse scenario [16].

In Laplace criterion, the optimal solution is the one that has the minimum value of the arithmetic mean of costs over the different scenarios.

Expected cost and Laplace criteria are valid for scenarios that are repeatable. Minimax regret and β–robustness criteria are relative and are used where it is required to survive under an unlikely and catastrophic scenario. Von Neumann-Morgenstern and Hurwicz criteria are extremely pessimistic or extremely optimistic. Robustness criterion is very crusty. Although these criteria have deficiency, but are important in selection of final plans especially minimax regret and the expected cost [4]. In [4], the final plan is selected using fuzzy risk assessment method.

C. Risk indices

Risk is the variation of attributes to which a market participant is exposed to because of planning decisions and uncertainties. Regret is a measure of risk and is the difference between the cost of selected solution and the cost of an optimal solution that would have been selected if the future scenarios are known in advance. In risk analysis the best solution is found by minimizing the risk. The common strategies employed to deal with risk include [6]:

- opting for a flexible plan so that changes can be made with the least possible cost.
- selecting plans that are robust.

A flexible TEP focuses on the modeling of uncertainties and on the solving algorithm. Paper [6] proposes maximum adjustment cost as the flexibility criterion and maximum regret as the robustness criterion. Average load curtailment cost can also be used to measure the reliability and flexibility [4].

D. Scenario generation and reduction

Many approaches are there for scenario generation and Monte Carlo Simulation (MCS) is one of them. MCS is based on repeated random sampling and statistical analysis to compute the results. After identifying the probability distribution function (PDF) of input variables, some random samples are generated and output values are calculated in deterministic model. Process is repeated until adequate numbers of output variables are produced [18]. A model based on MCS is proposed in [19] to assess the flexibility of expansion plans and to simulate transmission expansion behavior under different market arrangements. The MCS technique is employed in [8, 12, 20] to simulate the random output of wind power plant, bidding behavior, uncertainties in future load demand, outage rate of generator units and transmission lines etc.

Scenario reduction techniques are applied to reduce the number of scenarios by deleting scenarios with smaller probability or bundling together of similar scenarios. This reduces the computational complexity and time. There must be a trade-off between the accuracy of the solution and the reduced number of scenarios. In [20], MCS and scenario reduction technique are employed to simulate random characteristics of system components i.e. forced outage of generators and transmission lines, and load growth.

E. Decision analysis

Decision analysis along with scenario technique can be used to handle non-random uncertainties. Decision analysis identifies several future scenarios, and then searches an optimal plan under each scenario. These scenarios should consider as many uncertainties as possible that can affect the planning. In decision analysis method the planner tries to get the most flexible plan. It guide to the easiest adaptation to future events. The ability of a plan to adapt to the system quickly and with reasonable cost for any change in the conditions which prevailed at the time it was planned is known as flexibility of a plan. In the decision analysis method, the whole set of scenarios over the planning horizon is described by an event tree which has decision and event nodes [15]. Decisions are taken at decision nodes. The branches that emanate from each decision node give the viable decisions that can be taken at this node and those emanating from each event node show the probable events that may occur. Each of the branches from the decision node is associated with the cost of corresponding decision whereas the branches from the event node give the probability of occurrence.

Decision analysis is used in [21] to minimize the risk of the selected plan whereas in [22] it is employed to determine the best plan which is robust and flexible enough to allow optimal expansion under large uncertainties.

F. Fuzzy decision making

A significant size of valuable information are obtained in linguistic form for example “many”, “small”, “average”, “large” etc. This fuzzy and vague information is very subjective in nature and is usually dealt with expert judgments. Fuzzy decision making is a suitable tool to model imprecision and vague data in TEP problem under deregulated environment. In [4] importance degrees of stakeholder and planning criteria are modeled by fuzzy numbers. The fuzzy decision making approach is [15]:

- Identify set of decision alternatives.
- Identify set of decision criteria.
- Selection of preference ratings for importance weights of the decision criteria and for appropriateness degrees of the decision alternatives against the decision criteria.
- With the help of fuzzy operators, aggregate the importance weights and appropriateness degrees.
- Prioritize the decision alternatives.
- Select the decision alternative with highest priority as the optimal solution.

A network planning based on the combination of probabilistic optimal power flow, scenario technique, and fuzzy decision making is given in [4]. A fuzzy decision making is used in [4, 11] for selecting the final plan. A combination of probabilistic models to represent the reliability of the system components and fuzzy models to incorporate the uncertainty on load evolution can be seen in [22].

CONCLUSION

There are many additional uncertainties in TEP under deregulated environment which are related to generation capacity, location, timing, load levels, load flow based on market price, cooperation and competition in future electricity trading, future energy and environmental policies. Thus, in a deregulated environment, the complexity of TEP problem is mainly caused by the presence of multiple objectives, and large number of uncertainties which the transmission planners have to consider. The optimum approach to transmission planning in this environment is an open problem especially the approaches to deal with increased uncertainties should be carefully designed to ensure system reliability as well as to cater the market requirement. The broad range of uncertainties that crept in TEP because of deregulation, their existing planning tools and methodology is presented in this paper.

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