# Transmission Expansion Planning Considering Security Cost under Market Environment

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***Abstract*-- An important component to be considered in electric power system expansion planning is the security of service that the system is able to provide. In restructured power systems, variables such as agents' profit or Locational Marginal Price (LMP) variances are considered in transmission expansion planning. Finally to have a secure network this plan would be refined for simulated contingencies. This paper proposes a new method for transmission expansion planning in which the Grid Owner (GO) is responsible for expansion while benefiting a fair benefit percentage. The objective function of transmission expansion tries to reduce weighted standard deviation of LMPs and the construction cost as well as the cost of security enhancement. For different scenarios of expansion; at first, the cost of security enhancement is calculated and then it is considered in the objective function of expansion. To investigate the validity of the method, we have applied it to the modified "Garver 6-bus test system for expansion".**

***Index Terms*--Transmission expansion, electricity market, expansion planning, cost of security enhancement, LMP**

## I. Nomenclature

| | |
|---|---|
| ***GO*** | Grid Owner |
| ***CC*** | Investment cost or Construction cost |
| $g_i$ | The generation of generator i |
| $g_{i\max}$, $g_{i\min}$ | Upper and lower bound for the generator i |
| $d_j$ | Demand on bus j [MW] |
| $z_m$ | Power flow in line m |
| $\pi_n^b$ | Customer's bid price [US$/MW] |
| $p_{n,h}^b$ | Customer's energy bid block for the hour h [MW] |
| $\pi_n^s$ | Generator's offer price [US$/MW] |
| $p_{n,h}^s$ | Generator's energy block offer for the hour h [MW] |
| ***LMP*** | Locational Marginal Pricing |
| ***WSDL*** | Weighted Standard Deviation of LMPs |
| ***DWSDL*** | Decrements in the WSDL |
| ***ICk*** | Interruption cost for contingency k [US$/MW] |
| ***IC*** | Interruption cost |
| ***LDuk*** | Load decrease at node u during contingency k [MW] |
| ***LD*** | Load decrease [MW] |
| ***OR*** | Outage rate of a contingency [times/year] |
| ***OD*** | Outage duration of a contingency [h] |
| ***OWLS*** | Optimum weighted load shedding |
| ***SC*** | Security cost or the cost of security enhancement |
| ***Ga*** | Genetic algorithm optimization |
| ***ac*** | Adjusting coefficient for interruption cost |
| ***y*** | Operation period designed during planning [year] |

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## II. Introduction

CONVENTIONALLY power system expansion planning, including transmission expansion planning, is normally carried out by one authority and therefore known as a centralized planning. The task is to determine when and where the new transmission facilities should be installed such that they will operate in an optimal manner, subject to the technical, financial and environmental constraints [1].

Starting from Garver's paper [2] in 1970, a variety of techniques such as branch-and-Bound algorithm, sensitivity analysis, Benders Decomposition, simulated annealing, genetic algorithm (GA), tabu search algorithm and GRASP were used to study the transmission network expansion planning problem. However, the mathematical models presented in the technical literature for the transmission planning problem have been mainly developed for traditional regulated monopoly power system paradigm. These are not strictly suitable for the competitive market environment and new approaches should be investigated [3].

Furthermore, the uncertainty associated with generator sitting and timing will inevitably increase the uncertainty in future power-flow patterns. This brings a new challenge to the transmission planning problem [3].

In vertically integrated systems, the cost of expansion and the security of service as well as expansion benefits for network are taken into account. In restructured cases, researchers have considered other variables as agents' profit [1], [4], [5], or LMP variances [6], [7] through transmission expansion planning under market environment in their studies and finally refined their plan to have an (*N-1*) secure network [8]. In these papers the security of service has not been included in the objective function for expansion planning.

Different investigations have been carried out to obtain security cost of network based on the customers' interruption costs [9], [10], [11]. The articles have considered load reduction costs to save system stable in abnormal situations as the security cost of the system. Considering the security cost during network planning, it is possible to lead the planning of network to a more secure situation.

A new method for transmission expansion planning under market environment considering the cost of security enhancement is discussed in this paper.

In the second section components of transmission expansion planning under market environment are studied. These components are the LMP, construction cost and the cost of security enhancement. In the third part, a new algorithm for obtaining the components is described and finally implementation of the algorithm on the modified "L. L. Garver 6-bus test system" is presented in forth section.

## III. PLANNING COMPONENTS

Transmission line construction is considered to be one of the most expensive and time consuming projects in power systems. This matter intensifies the importance of optimal planning.

The Grid Owner (GO), who is responsible for network planning, looks for agents' benefits and tries to ban market power. The GO should take a measure to reduce price differences among the market to open the access of all participants to the grid.

One of the most important components prohibiting an ideal competitive market is considered to be congestion in transmission lines. This matter could be explored due to the Locational Marginal Pricing (LMP). Congestion would be released by the line upgrading or constructing new lines. Another component considered in network planning methods whether in regulated or deregulated structures, is the Construction Cost (CC). A new comprehensive component, that should also be considered, is the network reaction in contingency situations. Generation supply is considered to be reliable if some special situations exist. In other word, there should be enough reserve available to compensate loss of the largest generator or any other single contingency. However, in some cases, transmission contingencies may be resolved by load shedding to make the network safe and stable. These three components are considered in this section.

### A. Locational Marginal Pricing (LMP)

In an open access market without loss in transmission lines, the cross of demand and supply curves is the only way to extricate the energy price. Congestion and loss in transmission are two major components leading the market to have location dependent operating prices along the network [12].

To get these LMPs among network, ISO runs an OPF program through the grid and tries to maximize the global welfare (all agents' benefit) subject to the network constraints.

$$MaxS_h = \sum[\pi_n^b(p_{n,h}^b) - \pi_n^s(p_{n,h}^s)] \tag{1}$$

S.t.

$$g_{i\min} \le g_i \le g_{i\max}$$

$$\sum_j d_j(t_h) - \sum_i g_i(t_h) = 0$$

$$z_{m\min} \le z_m(t_h) \le z_{m\max}$$

In a day-ahead market, bids and offers for each hour of the next day transaction are submitted to power exchange, and then according to the network constraints, such as power balance, generators and lines' constraints, etc., an OPF problem is extracted. The LMPs will be derived by differentiating the Lagrangian function of the OPF problem for the forecasted demands of P (for obtaining price of active power) and Q (for obtaining price of reactive power) [12].

The LMP variation among the network bans the perfect competition between market agents. Therefore, Weighted Deviation Standard of LMPs (WSDL) in the network is a suitable measure to evaluate the competition level in a market.

Each expansion plan leads the network to have different LMPs and therefore different WSDL. Lower values of WSDL, implies a more effective expansion plan for the market environment.

### B. Construction cost

The construction cost is the sum of investment costs ICp, along the np periods in the horizon, adequately adjusted using a return rate r (2) [13].

$$CC = \sum_{p=0}^{np-1} \frac{IC_p}{(1+r)^p} \tag{2}$$

The estimation cost for planning candidates is determined before the implementation. This cost consists of both the cost of right of lands as well as the cost of construction.

### C. Cost of security enhancement

Network contingencies don't follow a regular structure. However, they can be categorized and be retorted by prepared responses. A Network usually operates while it is (*N-1*) secure. This means that the network can overcome a single contingency and over pass this harm situation safely. Therefore, during planning period, it is necessary to consider the security of service and find the most reliable plan.

Generation reserve (for small networks equal to the largest generator) will be provided through ancillary service markets and agents having the ability of providing these services, participate in the competition. These extra costs for generation reliability will be recovered through added costs to customers' bills.

Transmission contingencies should be resolved by load shedding to make the network safe and stable. Different types of load result in different load shedding costs, for instance, the cost of an interruption in the supply of an industrial customer is much higher than a residential one. Therefore, for the load shedding, the Optimal Weighted Load Shedding (OWLS) should be carried out to keep the network stable with the minimum necessary cost.

Transmission line outages split to permanent outages and transient outages. Permanent outages are those which require component repair in order to restore the component to service [14]. For a permanent outage, both the Outage Rate (OR) and the Outage Duration (OD) are necessary to be observed. Transient outages are not permanent, including both automatic and manual reclosing. For a transient outage, the outage rate is important to be considered and the duration of outage is usually short.

Line outage probability calculation is the reliability subject and is related to the operation condition, equipment maintenance and facility planning. The operation conditions are factors such as line length, weather condition, wind speed, voltage level and geographic location [14].

Analysis requires a great deal of historical data on the failures in order to obtain meaningful failure rates for the failable elements represented [14].

Another important research that should be carried out through network is the observation of customers' Interruption Cost (IC). Customers can be divided to residential, commercial and industrial. Subtle observation among customers, like what is done in [15] and [16], could clarify these interruption costs. IC is defined by the effect that contingencies may have on operating conditions, leading to the possible need for interrupting part of the system demand. IC relation with the interruption duration is not linear. For simplicity the average IC per hour of interruption ($/MWh) is considered for each type of customers.

To obtain the cost of security enhancement or the Security Cost (SC) for a contingency event, sum of its effects on loads should be considered.

$$SC_k = OR \times OD \times \sum_u ICu \times LDuk \tag{3}$$

SCk is the cost of security enhancement for the line k in a year. It means the SCk is equal to the cost of all necessary load sheddings during the contingency on the line k. OR and OD are the outage rate (1/year) and outage duration (hour) of line k. LDuk is the necessary Load Decrease (LD) for the user u during the contingency k. To obtain optimum LDs during each contingency, the OWLSs are computed through the Genetic Algorithm (GA) optimization. This optimization is used to attain minimum necessary cost for considering the generators' limits, preventing the line overloads and voltage instabilities.

$$\textit{for contingency } k:$$

$$Min\ \ SC_k = OR \times OD \times \sum_{u=1}^{n} IC_u \times LD_u \tag{4}$$

S.t.

$$V_{\min} \le V_l \le V_{\max} \qquad l = 1 \ldots m$$

$$g_{i\min} \le g_i \le g_{i\max}$$

$$z_{m\min} \le z_m \le z_{m\max}$$

$$g_{i\min} \le g_i \le g_{i\max}$$

Each plan leads the network to a unique level of security. Therefore, the cost of security enhancement during contingencies is different for each planning measure. This difference is an adequate measure to rank expansion candidates. The security cost will be achieved by (5).

$$\textit{for each new line candidate}:$$

$$SC = \left(\sum_{k=1}^{n}\left(\sum_{u=1}^{m} IC_u \times OWLS_u\right) \times OR_k \times OD_k\right) \times y \times ac$$
$$= \left(\sum SC_k\right) \times y \times ac \tag{5}$$

The cost of security enhancement for contingency k is the sum of necessary OWLSs' costs multiplied by OR and OD. For the expansion plan i, sum of all SCs multiplied by operating period (year) identifies the cost of security enhancement for the expansion i. For simplicity a permanent IC is specified for each type of users (industrial, commercial or residential). However, in practice, IC depends on more factors such as backup systems and specially outage time (from no load to full load time). Usually lines outages for repair don't happen during the full load periods. Therefore, *ac* is a coefficient less than one to refine assumed IC.

## IV. Final Objective Function of Planning

There are three factors dealing with the expansion planning under market environment; the LMP, the construction cost and the security cost.

There may be different aspects to consider these three factors together. In this paper, the modification of what is used in [6] has been considered.

The objective function is the decrement in the weighted standard deviation of mean LMP (DWSDL) divided by Construction Cost (CC) plus the cost of security enhancement (6).

$$OF = \frac{DWSDL}{CC + SC} \tag{6}$$

This would be calculated for each expansion candidate to extricate the optimum candidate. The different point is the attachment of SC to the CC for refining the objective function to the cost of security enhancement too. To obtain the objective function components for a given network, the trend shown in the flowchart in "Fig. 1," is used.

## V. Case Study

The modified "Garver 6-bus test system" [2] is used to illustrate the described method. The one line diagram of this network is shown in "Fig. 2," Predicted information of generators, lines and loading condition for the operation period is given in Tables I and II.

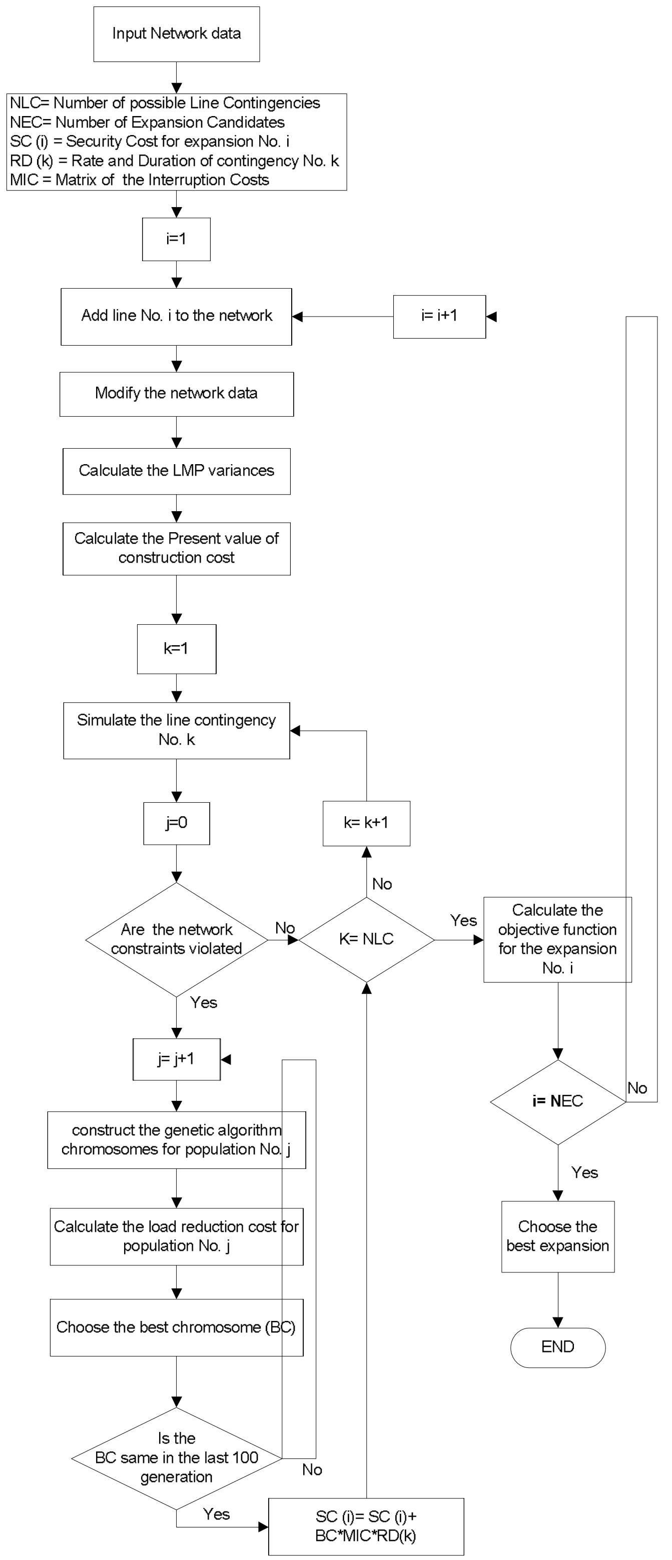


Fig. 1. General structure of the proposed method for obtaining objective function components.

The market structure of the system consists of three generating units and five loads. Two of the loads (D2 and D4) are industrial customers and their loads' interruption leads to high losses. Their demand is assumed to be performed through long-term contracts. However, for simplicity we assume that they should pay according to the nodal prices. Agents' average offers and bids are shown in Table I.

Table II shows the line information of the system. The first two columns provide the nodes of origin and destination of the lines, the third and fourth columns show the electric parameters of the lines and the fifth column shows the transmission lines capacities. The construction costs for all lines are shown in the sixth column. Status of a line (already built or not) is shown in the seventh column, zero value defines the possibility of building new line.

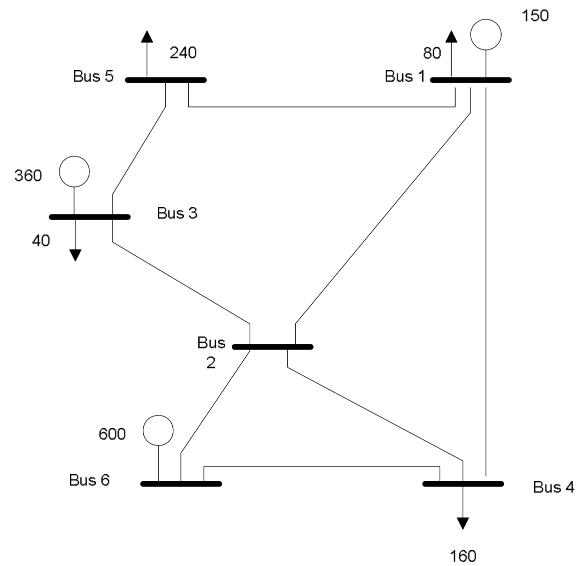


Fig. 2. Schematic of modified 6-bus test system.

For a real network the contingency rates should be performed through reliability analyses like what is done in [17]. Reliability analysis are not given for the L. L. Garver test system, hence, outage rates and outage duration shown in Table II are assumed according to the data given in [17] for IEEE 30-bus test system.

TABLE I
GENERATORS AND LOAD INFORMATION

| | Generator | | | Load | | | |
|---|---|---|---|---|---|---|---|
| | | MWh offer | Offer price [$/MWh] | | MWh bid | Bid price [$/MWh] | IC [$/MWh] |
| 1 | G1 | 150 | 10 | D1 | 80 | 30,28,26,20 | 280 |
| 2 | - | - | - | D2 | 240 | - | 4800 |
| 3 | G2 | 360 | 15,19,20 | D3 | 40 | 28,26,24,22 | 280 |
| 4 | - | - | - | D4 | 160 | - | 4800 |
| 5 | - | - | - | D5 | 240 | 34,30,26,24,18 | 280 |
| 6 | G3 | 600 | 8,12,15,17,19,21 | - | - | - | 280 |

Interruption costs were considered 4800(US$/MW) for industrial customers and 280(US$/MW) for residential users for an hour of interruption. These values are based on the data given in [9], [15] and [16].

TABLE II
LINE INFORMATION

| f | t | R (p.u) | X (p.u.) | limit | CC (M$) | already built | OR (1/yr) | OD (h) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 0.1 | 0.4 | 100 | 40 | 1 | 0.2 | 15 |
| 1 | 3 | 0.09 | 0.38 | 100 | 38 | 0 | 0.2 | 15 |
| 1 | 4 | 0.15 | 0.60 | 80 | 60 | 1 | 0.2 | 15 |
| 1 | 5 | 0.05 | 0.20 | 100 | 20 | 1 | 0.2 | 15 |
| 1 | 6 | 0.17 | 0.68 | 070 | 68 | 0 | 0.2 | 15 |
| 2 | 3 | 0.05 | 0.20 | 100 | 20 | 1 | 0.2 | 15 |
| 2 | 4 | 0.1 | 0.40 | 100 | 40 | 1 | 0.2 | 15 |
| 2 | 5 | 0.08 | 0.31 | 100 | 31 | 0 | 0.2 | 15 |
| 2 | 6 | 0.08 | 0.30 | 200 | 30 | 1 | 0.2 | 15 |
| 2 | 6 | 0.08 | 0.30 | 200 | 30 | 0 | 0.2 | 15 |
| 3 | 4 | 0.15 | 0.59 | 82 | 59 | 0 | 0.2 | 15 |
| 3 | 5 | 0.05 | 0.20 | 150 | 20 | 1 | 0.2 | 15 |
| 3 | 5 | 0.05 | 0.20 | 150 | 20 | 0 | 0.2 | 15 |
| 3 | 6 | 0.12 | 0.48 | 100 | 48 | 0 | 0.2 | 15 |
| 4 | 5 | 0.16 | 0.63 | 075 | 63 | 0 | 0.2 | 15 |
| 4 | 6 | 0.08 | 0.30 | 200 | 30 | 1 | 0.2 | 15 |
| 4 | 6 | 0.08 | 0.30 | 200 | 30 | 0 | 0.2 | 15 |
| 5 | 6 | 0.15 | 0.61 | 78 | 61 | 0 | 0.2 | 15 |

Expansion candidates are those are zero in seventh column in Table II and study results of the method are shown in Table III. Decrement in the Weighted Standard Deviation of LMPs (DWSDL) among the market, comparing with the condition that no expansion occurs, is shown in the fourth column.

Weights are the amount of power traded at a specific node (sum of production and consumption). The DWSDLs, for some of the candidates, are negative which imply that implementing these expansions the competition level decreases among the market.

SC is performed due to the given data and (5) for 25 years of operation and adjusting coefficient (ac) of 0.5. If no expansion measure takes place, the cost of security enhancement will be 28.5 million dollars. The cost of security enhancement for each candidate is shown in Table III.

TABLE III
IMPLEMENTATION RESULTS

| candidate | f | t | DWSDL | SC (M$) | CC (M$) | Objective |
|---|---|---|---|---|---|---|
| 1 | 1 | 3 | -223.76 | 28.01 | 38 | - |
| 2 | 1 | 6 | 219.83 | 21.53 | 68 | 0.3520 |
| 3 | 2 | 5 | 131.513 | 18.66 | 31 | 1.1652 |
| 4 | 2 | 6 | 283.197 | 10.75 | 30 | 1.8430 |
| 5 | 3 | 4 | -144.87 | 15.11 | 59 | - |
| 6 | 3 | 5 | -227.49 | 21.08 | 20 | - |
| 7 | 3 | 6 | 316.67 | 28.59 | 48 | 0.4201 |
| 8 | 4 | 5 | 38.95 | 16.64 | 63 | 0.2133 |
| 9 | 4 | 6 | 80.82 | 5.37 | 30 | - |
| 10 | 5 | 6 | 269.166 | 26.02 | 61 | 0.5056 |

Objective function shows the triumph of 4th candidate among other expansion candidates. It means that construction of a new line between buses 2 and 6, refines the competition level in the market more than other candidates according to the CC and SC for each planning.

An important point to be considered is the amount of SC obtained for each plan. It is interesting that these costs are really close to the construction costs. Therefore, this matter intensifies the necessity of their consideration during planning periods.

## VI. SUMMARY AND CONCLUSION

A new strategy for transmission expansion planning under market environment is discussed in this paper. In this method, further to other effective components of the expansion planning under market environment, the cost of security enhancement has also been considered. The security cost has been obtained using the value of lost load during network contingencies.

The costs for different planning measures are different. Therefore, by considering them during network planning, it is possible to obtain a more stable and economical network. The attained results of applying the method to the test system confirm the importance of the added term to the objective function.

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