# THE MULTIOBJECTIVE FRAMEWORK FOR MARKET BASED TRANSMISSION EXPANSION PLANNING USING WIND ENERGY

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## ABSTRACT

*Transmission network plays important role in electricity market by providing nondiscriminatory competitive environment for all market participants. The main goal of deregulation is to maximize the social welfare while maintaining power system reliability.Transmission network expansion planning (TNEP) methodology is developed with some objectives such as investment cost, absorption of private investment and reliability of the system for interconnecting wind generation to the power system. The decision making process are used to obtain the final optimal plan. It clearly shows the consumer requirements and reliability of the transmission lines.The above multi-objective problem is solved by using Particle Swam Optimization algorithm to obtain the Probabilistic optimal power flow (POPF).The Algorithm is implemented in IEEE 30 bus system to evaluate the feasibility and usefulness of the developed planning strategy.*

***Keywords:Transmission System, Deregulation, Wind Generation, IEEE 30 Bus System, Etc.,***

## I. INTRODUCTION

Transmission system plays a vital for providing a non-partial inexpensive environment for all market participants[1].The transmission expansion planning (TNEP) provides a reasonable competitation within the market both for system load and generation growth. The multiobjective are considered in TNEP deregulated power system (DPS) rather than the single objective of investment cost minimization [2]-[4].The minimization of investment cost will lower the tariffs of transmission service area for the market participants[2]. Deregulation in TNEP motivate the private investors in transmission project and increase their active participation in transmission projects [3]. In addition, successful trade requires a desirable level of reliability which should be in transmission project [4]. In other power system the transmission service pricing, tariffs and investment risk causes inactive participation of private investors in transmission project. In united states the main drawback for construction of new transmission project is lack of economic incentives in recovering the investment cost[5].In addition, favorable wind profiles in distant areas from the load centers need the construction of new transmission lines which are less utilized due to the discontinuous nature of wind power [6]. Therefore,The TNEP strategy in a restructured power market with renewable energy generation should address the private investors' needs and provide economic incentives to encourage their investment in the transmission network.

The reliability criteria limits the transfer capability of a transmission system which are established by the North American Electric Reliability Council (NERC), Regional Reliability Council, or local jurisdiction (state or ISO).

These reliability criteria are determined by the stability limits, thermal limits, voltage collapse,and resource deficiency of the transmission lines [8]. The secure and efficient operation of the transmission network is of significant importance to provide a desirable level of reliability and avoid congestion in a DPS. Towards this end, the TNEP strategy should provide transparent transmission prices while maintaining system reliability to support a competitive and non-discriminatory environment for the market participants and avoid the market power in a deregulated structure. The bottlenecks regarding the transmission expansion are alleviated by two types of projects: reliability project and market economic projects [10]. The reliability projects are regulatory requirements to satisfy the reliability criteria where an accepted transmission rate is allocated to the investment regaining. Thus,TNEP in a restructured power system should provide a proper plan to consider the uncertainties of the wind power system and maximize private investments absorption. Reference [11]-[14] shows TNEP problem without considering uncertinity in wind generation.The stochastic models of reference [15], the reliability Criteria is not incorporated into the modeling. Reference [16] did not consider the risk involved in transmission investments and provide a probabilistic TNEP framework for the power systems with high wind penetration. A game-theory based TNEP was proposed in [18] without incorporating the financial factors to manage the risk.Multi-objective optimization framework to consider different criteria including investment cost, congestion cost and reliability for TNEP in deregulated power systems was proposed in references [2], [16],and [17].However,The financial aspects of transmission lines are not addressed in the above references, which are the determining factors for the private investment.

This is essential in restructured power systems where the lack of economic incentives and events for the transmission sector discourage private investment.Therefore, an appropriate plan is required to determine the market economic projects and also mitigate the monopoly power over the transmission network.This paper develops a multi-stage multi-objective TNEP framework to provide the economic incentives and maximize the absorption of private investment for market participants. The PSO optimization algorithm is used to obtain a set of Pareto optimal solutions.The best final plan is then selected using a decision-making method. Section II explains the modeling methods including the wind,load and transmission financial modeling. Section III proposes PSO algorithm to solve the multi-objective problem of TNEP. An efficient decision-makingmethod is explained in Section III to select the best optimal solution based on the planner's preferences. Case studies and their simulation results are given in Section IV. Section V presents conclusions.

## II. MODELLING

### 2.1 Wind and Load Modelling

The uncertainties associated with wind speed and load demand is modelled by using Probability density functions (PDFs) [18].The behavior of wind speed is stochastically characterized using the Weibull distribution:

$$f_{wd}(v) = \left(\frac{\alpha}{\beta}\right)\left(\frac{v}{\beta}\right)^{\alpha-1} e^{-\left(\frac{v}{\beta}\right)^{\alpha}}, \quad 0 \le \upsilon \le \infty \;.....(1)$$

Where α, β, υ and $f_{wd}$ are the shaping, scaling coefficients, wind speed and PDF of wind speed, respectively. The power-speed curve is used to calculate the wind power.

$$P_W = \begin{cases} 0 & \\ \frac{v-v_i}{v_r-v_i} P_{Wr} & v \le v_i \;,\; v \ge v_o \quad \ldots (2) \\ P_{Wr} & v_i \le v \le v_r \\ & v_r \le v \le v_r \end{cases}$$

Where $v_i$ , $v_r$, $v_o$, $P_{Wr}$ and $P_W$ are the cut-in, rated, cut-out wind speeds, rated, and output wind powers, respectively. The variation of load demand is modeled by the Gaussian distribution as

$$f_{ld}(l) = \frac{1}{\sqrt{2\pi\sigma^2}} exp[-\frac{(1-\mu)^2}{2\sigma^2}] \quad \text{.... (3)}$$

where $l$, $\mu$ , $\sigma$, $f_{ld}$ are the load, mean value, standard deviation, and PDF of the load, respectively.

## 2.2 Transmission Financial Modeling

### 2.2.1 Transmission Pricing

The proper transmission pricing mechanism is required to calculate the cost of transmission services based on the amount of use of transmission resources. A well-prepared and fair pricing method creates economic signals and incentives for the essential support and expansion of the transmission network. The traditional methods for the recovery of transmission costs are Postage-stamp rate and contract path method. The postage-stamp rate method charges transmission users based on an average fixed cost where the use of transmission facilities by each user is not considered. The contract path method restricts the transaction to a definite path which may differ from the actual path taken in reality. The MW-mile method recovers the transmission costs based on the actual use of the transmission network calculated by DC power flow [19]. The unused transmission capacity method is an improved version of MW-mile method to charge the users based on the percentage utilization of the transmission facility.

The cost equation for this method is given by

$$TC_t = \sum_{k=1}^{k} \frac{c_k L_k |f_{k,t}|}{|\overleftarrow{f}_k|} \quad \text{..... (4)}$$

Where $TC_t$ is the cost of transmission service and $f_{k,t}$ is the flow of line k for transaction t. $c_k$ , $L_k$ and $\overleftarrow{f}_k$ are the cost per MW per unit length, length, and maximum capacity for line k, respectively.

### 2.2.2 Rate of Return and Investment Risk Evalution

The most important determining factors for the investment in transmission projects are Rate of return and risk. The risk level increased due to Power system uncertainties and make transmission investment less attractive to the private investors. Modern portfolio theory (MPT) provides a mathematical model to select an economic range based on risk-return trade-offs and efficient modification [20]. Here, the return rate of an investment is taken as random variable whose mean value indicates the expected success.The highest rate of return with a desirable level of risk is given by an economic portfolio. The return rate of an investment is calculated by solving the following equation for i:

$$\sum_{n=1}^{N} \frac{A_n}{(1+i)^n} = I_C - P_S \quad \text{……..(5)}$$

Where $I_C$ is the investment cost, $P_S$ is the present worth of the salvage value, $A_n$ is the annual revenue, and i is the return rate of the investment.

## III. METHODOLOGY

### 3.1 Objective Functions

#### 3.1.1 Investment Cost Minimization

The transmission investment cost minimization in a deregulated environment decreases the cost of transmission services for market participants. The transmission investment cost *IC* is minimized using

$$Min\ IC = Min \sum_{(i,j)\in\Omega} c_{ij}\, n_{ij} \quad ……(6)$$

Where *IC* is the total investment cost of a candidate plan, $c_{ij}$ is the cost of an added line and $n_{ij}$ is the number of added lines to the corridor i -j, and $\Omega$ is the set of all corridors.

#### 3.1.2 Private Investment Maximization

Insufficient transmission capacity mitigates monopoly power over the transmission network. An appropriate transmission expansion strategy is required to maximize private investment and eliminate monopolies in a deregulated environment. Based on the revised unused transmission capacity method,the periodic revenue for transmission line is calculated by

$$A_n^l = \alpha.TC_l \quad ……(7)$$

Where $A_n^l$ is the periodic revenue, $\alpha$ is the annual return, and $TC_l$ is the total cost of transmission service for the transmission Line l. $A_n^l$ and (5) are then utilized to calculate (i) the rate of return for each new transmission investment.We maximize private investment for the $PI^{AL}$ determined attractive lines:

$$Max\ PI^{AL} = Max \sum_{l=1}^{L} PI_l^{AL} \quad ......(8)$$

Where $PI^{AL}$ and $PI_l^{AL}$ are the absorbed private investment for the attractive lines and lth attractive line, respectively, L is the set of attractive lines determined by constraint.

#### 3.1.3 Reliability Maximization

A probabilistic reliability analysis is required to include both capability and security criteria for the expansion planning of transmission systems with wind generation. The probabilistic analytical state enumeration method is used to calculate the reliability index . This method uses the interrupted load and probability for every contingency to calculate the reliability index of a transmission network. Expected energy not supplied (EENS) is utilized as an energy index to represent the reliability level of transmission network.The reliability index of a transmission network can be calculated using

$$EENS_T = \sum_{i\in\varphi}\sum_{j\epsilon\theta} IL_i^j.P_j \quad ….. (11)$$

where $EENS_T$ is the expected energy not supplied for the transmission network, $IL_i^j$ is the interrupted load at bus i due to the contingency j, $P_j$ is the occurrence probability of contingency j , $\Theta$ represents the load buses, and $\Phi$ is the set of contingencies. The following linear programming sub problem which minimizes the total interrupted load is solved to calculate the interrupted load for each contingency:

$$obj\ .fun = min \sum_{j\in\theta, i\epsilon\varphi} IL_i^j \quad …(12)$$

This objective function is subject to the following physical constraints of the network:

$$\sum_{i=1}^{nb} pg_i = \sum_{i=1}^{nb} pd_i$$
$$f_{jk} = B_{jk}(n_{jk} + n_{jk}^{ex})(\theta_j - \theta_k)$$
$$\left| f_{jk} \right| \le (n_{jk} + n_{jk}^{ex})\, \bar{f}_{jk}$$
$$\underline{P}_{gi} \le P_{gi} \le \overline{P_{gi}}$$
$$\underline{P}_{di} \le P_{di} \le \overline{P}_{di}$$
$$0 \le n_{jk} \le \bar{n}_{jk}$$
$$IL_i^j = \overline{P}_{di} - P_{di} \quad \text{.......(13)}$$

$f_{jk}$, $B_{jk}$, $\bar{f}_{jk}$ =power flow , susceptance and power flow limit of the line in bus k. $\theta_j$ , $\theta_k$ =voltage phases at bus j and k. $n_{jk}^{ex}$ , $n_{jk}$ , $\bar{n}_{jk}$ =no.of existing lines, no.of new trans lines. $pg_i$ , $\underline{P}_{gi}$ , $\overline{P_{gi}}$ =output power, lower and upper generating limits for i th bus. $pd_i$ , $\underline{P}_{di}$ , $\overline{P}_{di}$ =supplied load, lower load limit and load demand for i th bus.

## IV. PARTICLE SWAM OPTIMISATION

PSO is an evolutionary computation technique developed by Eberhart and Kennedy in 1995, which was inspired by the social behavior of bird gathering and fish schooling. It utilizes a population of particles that fly through the problem hyperspace with given velocities. At each iteration, the velocities of the individual particles are stochastically adjusted according to the historical best position for the particle itself and the neighborhood best position. Both the particle best and the neighborhood best are derived according to a user defined fitness function. The movement of each particle naturally evolves to an optimal or near-optimal solution.

The word "swarm" comes from the irregular movements of the particles in the problem space, now more similar to a swarm of mosquitoes rather than a flock of birds or a school of fish. PSO is a computational intelligence-based technique that is not largely affected by the size and nonlinearity of the problem, and can converge to the optimal solution in many problems where most analytical methods fail to converge. It can, therefore, be effectively applied to different optimization problems in power systems.PSO is based on two fundamental disciplines: social science and computer science. In addition, PSO uses the swarm intelligence concept, which is the property of a system, whereby the collective behaviors of unsophisticated agents that are interacting locally with their environment to create coherent global functional patterns.

## V. DECISION MAKING METHOD

After obtaining the Pareto-optimal solution, the Decision making method is used to choose one best compromised solution according to the planner preference for different applications. Here a linear membership function $u_i$ is defined for each of the objective functions $F$ :

$$u_i = \begin{cases} \frac{F_i^{max} - F_i}{F_i^{max} - F_i^{min}} & F_i^{max} > F_i > F_i^{min} \\ 1 & F_i \le F_i^{min} \\ 0 & F_i \ge F_i^{max} \end{cases} \quad \text{.....(14)}$$

In the above definition, $F_i^{max}$ and $F_i^{min}$ is the value of
the maximum and minimum in the objective functions,
respectively. For every solution *k* , the membership function can be normalized as follows:

$$u^k = \frac{\sum_{i=1}^{0} u^k i}{\sum_{k=1}^{s}\sum_{i=1}^{0} u^k i} \quad .......(15)$$

The solution with the maximum membership $u^k$ can be seen as the best compromised solution.

## VI. RESULT AND DISCUSSION

The proposed technique has been developed in order to make it suitable for solving nonlinear constraints optimization problem. A computation process will check the feasibility in all stage of the search process. The proposed MBO technique was tested on IEEE a 30-bus 6-generator test system. The wind power plant is connected to the 2,3,8,10,13 bus of 30 bus system the test system is shown below Fig 1.In addition 3 new lines are also added to the 30 bus system.

**Table 6.1 Newly Added Lines**

| From | To | R | X |
|---|---|---|---|
| 5 | 10 | 0.21 | 0.55 |
| 8 | 9 | 0.35 | 0.28 |
| 9 | 12 | 0.45 | 0.15 |

**Table 6.2 Generation Bid Coefficients**

| unit | G1 | G2 | G3 | G4 | G5 | G6 |
|---|---|---|---|---|---|---|
| Pmin | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Pmax | 0.50 | 0.60 | 1.00 | 1.20 | 1.00 | 0.60 |
| Cost a | 10 | 10 | 20 | 10 | 20 | 10 |
| b | 200 | 150 | 180 | 100 | 180 | 150 |
| c | 100 | 120 | 40 | 60 | 40 | 100 |

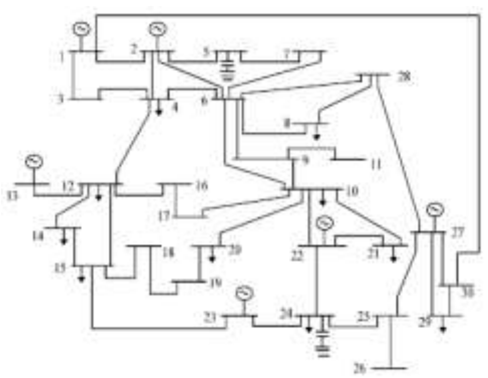

**Fig.1 Test System**

The increase of investment cost of the transmission line increases the traiff of the market participants.The minimization investment cost reduces the tariff of market participation.In the base case the investment cost is 3M$ as shown in fig 2 but in proposed case by using PSO algorithm the investment cost is reduced to 2M$ as shown in Fig 3.

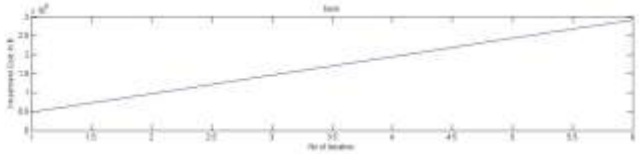

**Fig 2 Investment Cost for Base Case**

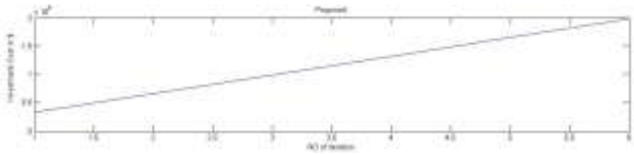

**Fig 3 Investment Cost for Proposed Case**

Private investment increases the economy for installation of transmission lines in power system.In base case the private investment are not stable as shown in fig 4 but in proposed case the private investment increases upto 47M$ as shown in fig 5.

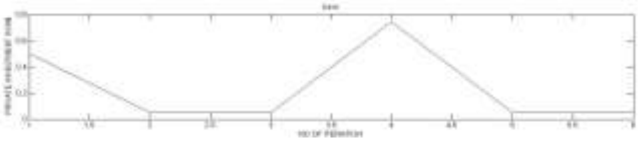

**Fig 4 Private Investment for Base Case**

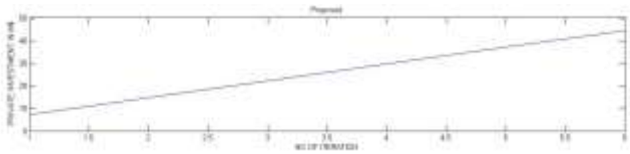

**Fig 5 Private Investment for Proposed Case**

The important one in transmission line is to improve the reliability of the system.In the base case reliability is improved after 5 iteration shown in Fig 6 but in proposed case the reliability is improved in first iteration itself and also provide maximum reliability compared tobase case shown in Fig 7.

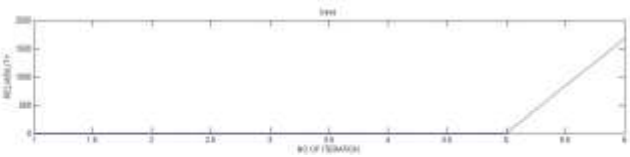

**Fig 6 Reliability for Base Case**

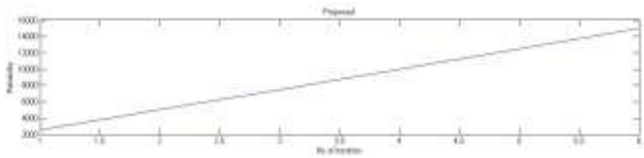

**Fig 7 Reliability for Proposed Case**

## VII. CONCLUSION

This paper provide a framework for transmission network expansion planning in deregulated power systems with wind generation.The proposed method provide a multistage multi-objective model to satisfy reliability requirements and provide economic incentives for private investors. A PSO algorithm was used to determine trade-offs between reliability measures, absorption of private investments and installation costs for different solutions.The decision-making process was to determine the final optimal plan based on the planner's decision. The final plans clearly show two groups of trade and reliability transmission lines. The proposed strategy provides visions for both private investors and transmission network operators.Simulation results for the IEEE 30-bus system demonstrate the feasibility and practicality of the developed planning algorithm.

## VIII. BIOGRAPHY

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