

# Novel binary PSO algorithm based optimization of transmission expansion planning considering power losses

**Astuty\* and T Haryono**

Electrical and Information Technology Departement  
Universitas Gadjah Mada, Yogyakarta

\*Corresponding author: astuty.stl13@mail.ugm.ac.id

**Abstract.** Transmission expansion planning (TEP) is one of the issue that have to be faced caused by addition of large scale power generation into the existing power system. Optimization need to be conducted to get optimal solution technically and economically. Several mathematic methods have been applied to provide optimal allocation of new transmission line such us genetic algorithm, particle swarm optimization and tabu search. This paper proposed novel binary particle swarm optimization (NBPSO) to determine which transmission line should be added to the existing power system. There are two scenerios in this simulation. First, considering transmission power losses and the second is regardless transmission power losses. NBPSO method successfully obtain optimal solution in short computation time. Compare to the first scenario, the number of new line in second scenario which regardless power losses is less but produces high power losses that cause the cost becoming extremely expensive.

## 1. Introduction

The additional of high scale power generating capacity increases over the year to fulfill the electricity demand. Most of generating plants are located far from the load center. Transmission network is an important infrastructure that must be considered in generation expansion planning. To avoid line overloading, net transmission capacity (NTC) has to meet reliability criteria while delivering electric power to the load. The construction of transmission line which needs a high budged becoming an issue in transmission expansion [1]. Transmission expansion planning (TEP) aims to minimize the line construction which directly relates to investment cost. It determines which line must be added to existing power system by considering technical, economic and reliability aspect.

There are a lot of mathematical methods that have been used to do TEP optimization. Genetic algorithm has been used in several researches in binary and decimal codification model [2]. Discrete PSO with decimal codification also has been applied in STEP optimization. The precision and convergence speed of discrete PSO are better and faster than genetic algorithm. In addition to discrete PSO, traditional PSO with real number for continuous model also have been used to find the optimum transmission line considering line loading [4]. The other methods such as discrete evolutionary particle swarm optimization, simulated annealing algorithm, tabu search, and hybrid algorithm successfully provide optimum solution [5]-[8]. Ordinal optimization and mixed integer linear programming also have been applied to solve TEP problem [9]-[11].

Most of previous researches conducted TEP study to obtain optimal cost of transmission line investment regardless power losses in power system. In this research, the optimization of TEP considers investment cost, power losses and line loading transmission. Novel binary PSO algorithm is applied to solve TEP problem in this research.



## 2. Literature Review

### 2.1. Transmission Expansion Planning

In 1970, Garver proposed a research about transmission expansion planning. The research was conducted by using linear programming method. Ever since, study of TEP have been done by many researchers. Heuristic method is a developing method to solve such problem.

Based on stage of process, TEP is classified into two types, which are:

- Static transmission expansion planning (STEP)
- Dynamic transmission expansion planning (DTEP)

STEP determines which line should be added and how many lines should be added in electric power system in a certain period. DTEP determines when the lines should be added in addition to determine the location and the number of line should be added.

### 2.2. Particle Swarm Optimization

In 1995, Eberhart and Kennedy introduced particle swarm optimization as a population based search algorithm based on the simulation of social behavior of birds, bees or a school of fish [3]. The original PSO was developed for continuous values spaces. But in 1997, discrete PSO was introduced for discrete optimization problem.

TEP problem consist of discrete time parameter. Binary particle PSO (BPSO) and Discrete PSO (DPSO) are two methods in PSO technique that can be used to solve TEP problem. BPSO is applied in this paper to determine which line should be added in power system. In addition to TEP problem, BPSO has been applied in power generation scheduling.

In BPSO, each particle represents its position in binary values which are 0 or 1. Each particle's value can then be changed from one to zero or vice versa. In BPSO, the velocity of particle defined as probability that a particle might change its state to one. Then, a novel BPSO is introduced to improve the weakness in original BPSO. In novel BPSO, the velocity of a particle is its probability to change its state from its previous state to complement value, rather than the probability of change to one.

### 2.3. Novel Binary Particle Swarm Optimization

The  $P_{lbest}$  and  $P_{gbest}$  of the swarm is updated as in continuous or binary version. The mayor difference between NBPSO and original PSO is the interpretation of velocity. Here, as in continuous version of PSO, velocity of the particle is the rate at which the particle changes its bit's value. Two vectors for each particle are introduced as  $\vec{V}_i^0$  and  $\vec{V}_i^1$ .  $\vec{V}_i^0$  is the probability of that bits of the particle change to zero while  $\vec{V}_i^1$  is the probability of that bits of the particle to change to one. Since in update equation of these velocities, the inertia term is used, these velocities are not complement. So the probability of change in  $j$ -th bit of  $i$ -th particle is simply defined as follows:

$$V_{ij}^c = \begin{cases} V_{ij}^1, & \text{if } x_{ij} = 0 \\ V_{ij}^0, & \text{if } x_{ij} = 1 \end{cases} \quad (1)$$

In this way, the velocity of particle is simply calculated. Also the update  $\vec{V}_i^0$  and  $\vec{V}_i^1$  is as follows: consider the best position visited so far for a particle is  $P_{lbest}$  and the global best position for the particle is  $P_{gbest}$ . Also consider that the  $j$ -th of  $i$ -th best particle is one. So to guide the bit  $j$ -th of  $i$ -th particle to its best position, the velocity of change to 1 ( $\vec{V}_i^1$ ) for that particle increases and the velocity of change to zero ( $\vec{V}_i^0$ ) is decreases. Using this concept following rules can be extracted:

$$\text{if } P_{lbest}^j = 1 \text{ then } d_{ij,1}^1 = c_1 r_1 \text{ and } d_{ij,1}^0 = -c_1 r_1$$

$$\text{if } P_{lbest}^j = 0 \text{ then } d_{ij,1}^0 = c_1 r_1 \text{ and } d_{ij,1}^1 = -c_1 r_1$$

$$\text{if } P_{lbest}^j = 1 \text{ then } d_{ij,1}^1 = c_1 r_1 \text{ and } d_{ij,1}^0 = -c_1 r_1$$

$$\text{if } P_{gbest}^j = 1 \text{ then } d_{ij,2}^1 = c_2 r_2 \text{ and } d_{ij,2}^0 = -c_2 r_2$$

$$\text{if } P_{gbest}^j = 0 \text{ then } d_{ij,2}^0 = c_2 r_2 \text{ and } d_{ij,2}^1 = -c_2 r_2$$

Where  $d_{ij,1}^1, d_{ij,1}^0$  are two temporary values, while  $r_1$  and  $r_2$  are two random variables in the range of (0,1) which are updated each iteration. Also  $c_1$  and  $c_2$  are two fixed variables which are determined by user, then:

$$\begin{aligned} V_{ij}^1 &= wV_{ij}^1 + d_{ij,1}^1 + d_{ij,2}^1 \\ V_{ij}^0 &= wV_{ij}^0 + d_{ij,1}^0 + d_{ij,2}^0 \end{aligned} \quad (2)$$

In fact, this algorithm if the  $j$ -th bit in the global best variable is zero or if the  $i$ -th bit in the corresponding personal best variable is zero, the velocity ( $V_{ij}^0$ ) increases. And the probability of changing to one also decreases with the same rate. In addition, if the  $j$ -th bit in global best variable is one,  $V_{ij}^1$  increases and  $V_{ij}^0$  decreases. After updating velocity of particles,  $\vec{V}_i^1$  and  $\vec{V}_i^0$ , the velocity of change is obtained as in (1).

In NBPSO, A normalization process is done by using sigmoid function as:

$$v_{ij}(t) = \text{sig}(v_{ij}(t)) = \frac{1}{1 + e^{-v_{ij}(t)}}$$

and the next particles state is computed as follows:

$$x_{ij}(t+1) = \begin{cases} \bar{x}_{ij}(t) & , \text{if } r_{ij} < V_{ij} \\ \bar{x}_{ij}(t) & , \text{if } r_{ij} < V_{ij} \end{cases} \quad (3)$$

That is, if  $x_{ij} = 0$  then  $\bar{x}_{ij} = 1$  and if  $x_{ij} = 1$  then  $\bar{x}_{ij} = 0$ . Meanwhile  $r_{ij}$  is a uniform random number between 0 and 1.

### 3. Problem Formulation

The optimization in this paper will be conducted by applying NBPSO algorithm considering power losses in transmission line to get the optimal solution.

#### 3.1. Objective function

The objective function in this TEP is to get the optimal total cost of the investment of line construction and the cost of power losses in the network [2]. The objective function of conventional TEP can be written as follows:

$$C_T = \sum_{i=1}^{NB} \sum_{j=1}^{NB} CL_{ij} n_{ij}$$

To minimize power losses in line ( $P_{loss\ i}$ ), TEP can be written as follows:

$$C_T = \sum_{i=1}^{NB} \sum_{j=1}^{NB} CL_{ij} n_{ij} + 8760 \times C_{MWh} \times \sum_{t=1}^{NYE} P_{loss\ t} \quad (4)$$

$$P_{loss\ t} = (LGC)^{t-1} \times P_{loss}$$

Where  $NB$  shows the number of bus.  $C_{MWh}$  represents cost per MWh in \$US.  $CL_{ij}$  for construction cost of line transmission in \$US.  $LGC$  is load growth coefficient.  $NB$  and  $NYE$  are number of branch and life time prediction of line expansion (year). While  $i$  and  $j$  represent branch to and from.

### 3.2. Constraints

Optimization in TEP has several constraint to be fulfilled.

$$P(V, \theta, n) - P_G + P_D = 0$$

$$Q(V, \theta, n) - Q_G + Q_D = 0$$

$$P_g^{min} \leq P_g \leq P_g^{max}$$

$$V^{min} \leq V \leq V^{max}$$

$$(n_{ij} + n_{ij}^0)S^{from} \leq (n_{ij} + n_{ij}^0)S^{max}$$

$$(n_{ij} + n_{ij}^0)S^{to} \leq (n_{ij} + n_{ij}^0)S^{max}$$

$$0 \leq n_{ij} \leq n_{ij}^{max}$$

$$Line_{loading} \leq LL_{max}$$

Variable  $P_G$  is real power generated by electric generator, while  $P_D$  represents the real power in the load side.  $V, \theta, n$  are magnitude of voltage, angle, and bus respectively.  $S$  is apparent power, the superscript from and to refer to apparent power from bus or to bus, while superscript min and max represent the upper and lower boundary. A constraint that has to be considered is line loading in transmission must be less or equals to maximum line loading ( $LL_{max}$ ).

### 3.3. Fitness function

The result of fitness function marks how optimal the solution we get. in this function, the total cost is added by penalty function. Penalty function itself is a function accumulating all of constraints violation [2].

$$fitness = \frac{1}{C_T + penalty\ function} \quad (5)$$

while penalty function ( $pf$ ) is written as follows

$$pf = \alpha \sum_{i=1}^{NB} f(P_{gi}) + \beta \sum_{i=1}^{NB} f(V_i) + \gamma \sum_{j=1}^{\Omega} f(line\ loading)$$

$\alpha, \beta$  and  $\gamma$  are penalty coefficient. The penalty is set up as follow,

$$f(x) = \begin{cases} 0 & \text{if } x_{min} \leq x \leq x_{max} \\ x - x_{max} & \text{if } x > x_{max} \\ x_{min} - x & \text{if } x < x_{min} \end{cases}$$

## 4. Proposed Methodology

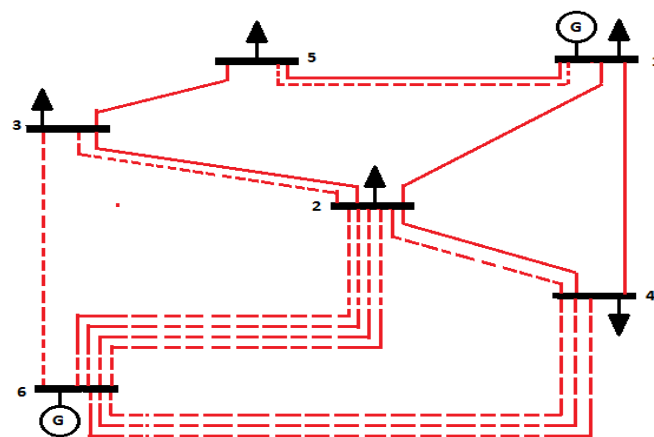
### 4.1. IEEE Garver's 6-Bus System

The NBPSO algorithm will be applied to Garver's system [2]. The system consists of five busses. To fulfill the additional demand, new power generation will be added to the existing power system.

**Table 1.** Garver's Bus Data

Bus Number	Max. generation (MW)	Generation (MW)	Demand (MW)
1	160	100	80
2	-	-	240
3	370	260	150
4	-	-	180
5	-	-	240
6	610	550	0

The single line diagram of Garver 6-bus system is shown in figure 1. There are 6 existing lines and 11 planning transmission network which marked by dashed line. New power plant will be placed in bus 6.

**Figure 1.** Garver's 6-Bus

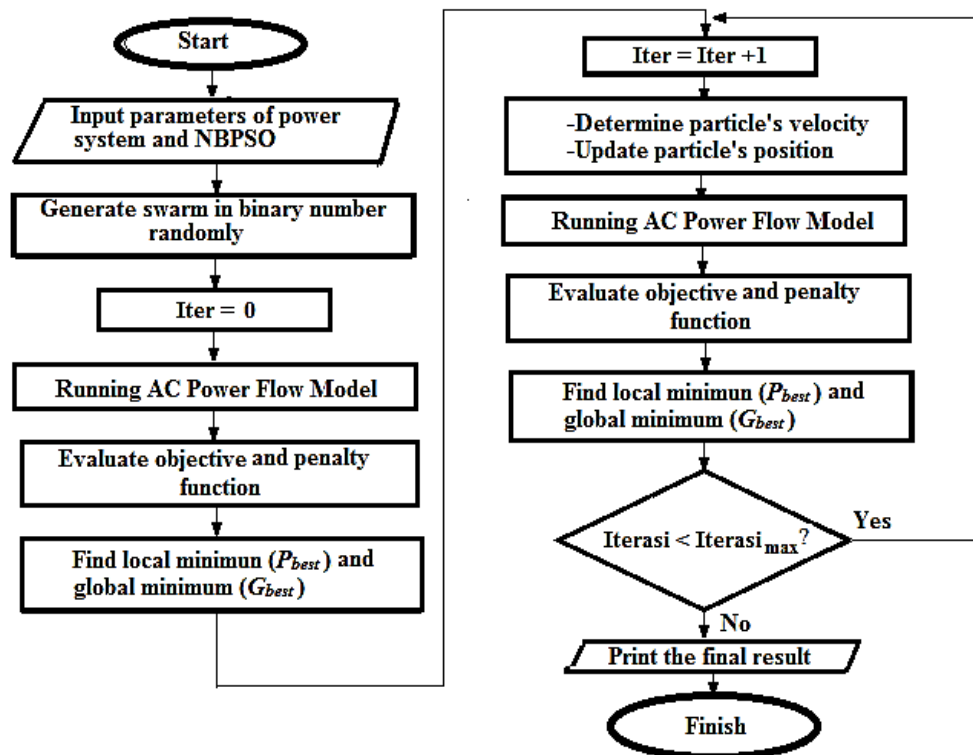
The additional of new power generation in bus 6 will influence the performance of transmission line in carrying power to the load. To support generation expansion, transmission line should also be planned to expand. Table 2 shows the number of new transmission lines that planned to be added.

**Table 2.** Garver's line data

Line	Resistance (p.u)	Reactance (p.u)	Capacity (MVA)	Length (km)
1 – 2	0.0070	0.0248	750	200
1 – 4	0.0105	0.0372	750	300
1 – 5	0.0035	0.0124	750	100
2 – 3	0.0035	0.0124	750	100
2 – 4	0.0035	0.0124	750	200
3 – 5	0.0035	0.0124	750	100

#### 4.2. Simulation

Simulation will be conducted to find the line being loaded more than 50% of the MVA rating.  $LL_{max}$  in this simulation is 750 MV. The test will also run within two scenario. First, consider power losses in TEP optimization. Second scenario is optimizing TEP without considering power losses in the network. Table 3 shows parameters that use in NBPSO algorithm.



**Figure 2.** Flowchart of TEP Using NBPSO

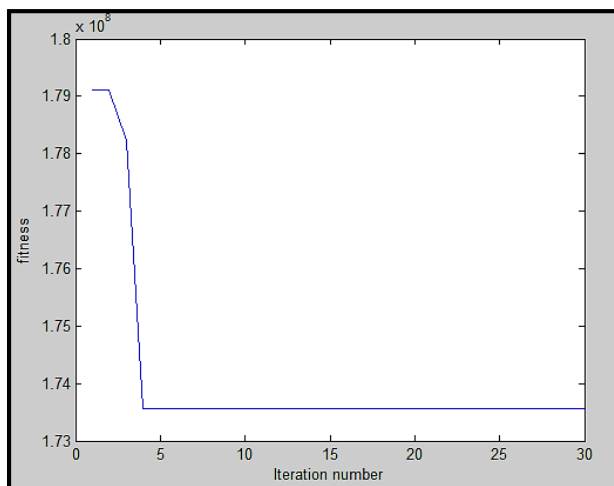
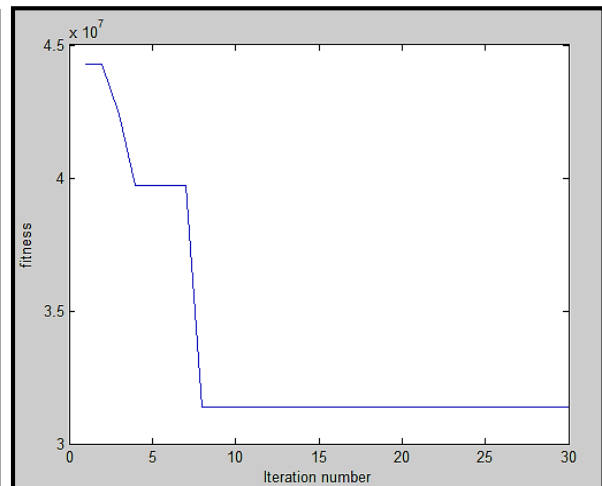
Figure 2 shows the flowchart of this research. The algorithm of TEP optimization by using NBPSO is initialized by generating swarm in binary value randomly. Binary value represents the status of the line whether active or not. Evaluate the performance of each particle by running power flow. Fitness function is calculated by applied equation (5). Next step is finding the initial local best  $P_{best}$  and global best  $G_{best}$ . Changing the velocity of the particle  $\vec{V}_i^1$  and  $\vec{V}_i^0$  according to (2) to determine the velocity of the particle,  $\vec{V}_i^c$  as in (1). After that generate the random variable  $r_{ij}$  in the range (0,1). Updating the position to a new position according to the equation (3). Running power flow to update the new  $P_{best}$  and global best  $G_{best}$  and repeat until maximal iteration is afforded

Table 3. NBPSO's Parameter Control and Object Solution

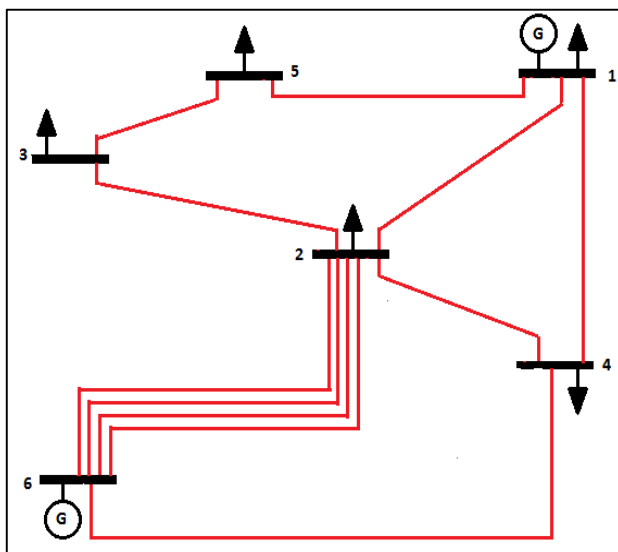
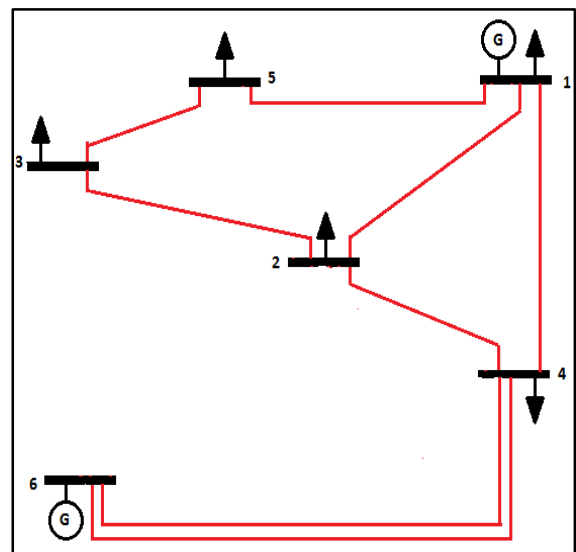
Parameter	Value
Number of population	30
Number of iteration	100
$C_1, C_2$	2
$v_{max}$	4
NYE	20
$C_{MWh}$	36.1
LGC	1.08

## 5. Result and Discussion

The simulation was run using 2 scenarios. First scenario is optimizing TEP considering power losses in the network and the other was optimizing TEP regardless power losses. The convergence curve obtained from test is shown if Figure 3 and Figure 4.

**Figure 3.** Convergence Curve of Scenario 1**Figure 4.** Convergence Curve of Scenario 2

The test was conducted in ten times for each scenario. Figure 3 shows the convergence is reached before fifth iteration in 6 seconds. The convergence time of scenario 2 is longer than scenario 1. the fitness value of scenario 2 is changing up to eighth iteration.

**Figure 5.** Garver's 6 Bus for scenario 1**Figure 6.** Garver's 6 Bus for scenario 2

The configuration for the scenario 1 is shown by Figure 5. By considering power losses in the network, there are four new transmission lines from bus 2 to bus 6 and one transmission line from bus 4 to bus 6. The optimization regardless power losses only require 2 lines from bus 4 to bus 6 as depicted in Figure 6.

**Table 4.** Cost of investment and losses

Type of cost	Amount of cost (US\$)	
	Scenario 1	Scenario 2
Transmission	81.202.000	31.366.000
Losses	92.355.000	341.610.000

Compared to scenario 1, scenario 2 that does not consider power losses in the network only requires two new lines to support power delivery. Although it needs less additional line, the losses of

power in transmission produce the cost of loss becoming extremely expensive. Based on Table 4, the investment cost for scenario 1 is more expensive, but its operational cost is lower than scenario 2.

## 6. Conclusion

This paper shows that novel binary particle swarm optimization method successfully finds optimal solution for transmission expansion problem. NBPSO's method has less time consume and stable convergence characteristic. The solution obtained by proposed method provide expectation for effective implementation to further research.

## References

- [1] H. Shayeghi, M. Mahdavi, and A. Bagheri 2010 Discrete PSO algorithm based optimization of transmission lines loading in TNEP problem *Energy Conversion and mangement* 2010, p. 112-121.
- [2] Ikrima Alfi 2014 Transmission expansion planning using genetic algorithm considering transmission loading *Gadjah Mada University Repository* 292091
- [3] Mojtaba Ahmedieh Khanesar, Mohammad Teshnehlab, and Mahdi Aliyari Shoorehdeli 2007 A novel Binary Particle Swarm Optimization *Proceeding of the 15<sup>th</sup> Mediterranean Conference on Control & Automation T* **33001** July 27-29, 2007, Athens. Greece
- [4] D. Khavita, and K. Shanti Swarup 2010 Transmission Expansion Planning Using LP-Based Particle Swarm Optimization *IEEE*
- [5] Manuel Costeira da Rocha, João Tomè Saraiva 2011 Multiyear Transmission Expansion Planning using Discrete Evolutionary Particle Swarm Optimization *8<sup>th</sup> International Conference on the European Energy Market (EEM)*, 2011. Zagreb, Croatia.
- [6] A. S. D. Braga, J. T. Saraiva 2005 A Multiyear Dynamic Approach for Transmission Expansion Planning and Long-Term Marginal Cost Computation *IEEE Trans. On Power System* **20** 1631-1639
- [7] M. V. Pereira, L. M. V. G. Pinto, S. H. Cunha, G. C. Oliviera 2001 A Decomposition Approach to Automated Generation/Transmission Expansion Planning *IEEE Trans. On Power System* **16** 247-253, May 2001.
- [8] Mohammad Sadegh Sepasian, Hossein Seifi, Asghar Akbari Foroud, and A. R. Hatami 2009 A Multiyear Security Constrained Hybrid Generation-Transmission Expansion Planning Algorithm Including Fuel Supply Cost *IEEE Transaction on Power System* **24**
- [9] Min Xie, Jin Zhong, and Felix F Wu 2007 Multiyear Transmission Expansion Planning Using Ordinal Optimization **22** 1420-1428.
- [10] Jamshid Aghaei, Nima Amjady, Amir Baharvandi, and Mohammad Amin Akbari 2014 Generation and Transmission Expansion Planning: MILP-Based Probabilistic Model *IEEE Transaction On Power System* **29** 1592-1601.
- [11] H M D R H Samarakoon, R M Shrestha 2001 A Mixed Integer Linear Programming Model For Transmission Expansion Planning With Generation Location Selection **23** 285-293