bus), d is the demand vector, $\overline{n_{ij}}$ is the maximum number of circuits that can be added to the i- j right-of-way, and Ω is the set of all right-of-ways.

Constraint (2) represents the conservation of power in each node. This constraint models Kirchhoff's Current Law (KCL) in the equivalent DC network. Constraint (3) is an expression of Ohm's Law for the equivalent DC network, so Kirchhoff's Voltage Law (KVL) is implicitly taken into account and these constraints are nonlinear.

2. Dynamic Planning Modeling

In dynamic planning, the planning horizon is divided into several stages, for example in five-year-long stages, and in that context the equipment that should be installed in every planning stage needs to be determined. Considering an annual discount rate I, the present values of the investment costs, for the reference year t0, with an initial year t1, with a horizon of $t_T - t_1$ years and with T stages, are the following [8, 18, 19].

$$c(x) = (1 - I)^{t_1 - t_0} c_1(x) + (1 - I)^{t_2 - t_0} + c_2(x) \ldots + (1 - I)^{t_T - t_0} + c_T(x)$$

(a)

$$c(x) = \delta_{inv}^{1} c_1(x) + \delta_{inv}^{2} c_2(x) + \ldots + \delta_{ii}^{T} \quad (7)$$

$$\delta_{inv}^{T} = (1 - I)^{t_t - t_0}, \qquad t = 1 \quad (8)$$

Where x represents the investment variables (lines to be constructed) and ct(x) represents the investment in the t stage. The DC model for the multistage planning problem assumes the following form [8, 22, 23]:

$$\min v = \sum_{t=1}^{T} \left[\delta_{inv}^{t} \sum_{(i,j)} c_{ij} n_{ij}^{t} \right] \quad (9)$$

s. t. c.

$$S^t f^t + g^t = d^t \quad (10)$$

$$f_{ij}^{t} - \gamma_{ij} \left(n_{ij}^{0} + \sum_{m=1}^{t} n_{ij}^{m} \right) \left(\theta_i^t - \theta_j^t \right) = 0 \quad (11)$$

$$\left| f_{ij}^{t} \right| \leq \left(n_{ij}^{0} + \sum_{m=1}^{t} n_{ij}^{m} \right) \overline{f_{ij}} \quad (12)$$

$$\underline{g}_j^t \leq g_j^t \leq \overline{g}_j^t \quad (13)$$

$$\underline{n}_{ij}^t \leq n_{ij}^t \leq \overline{n}_{ij}^t \quad (14)$$

$$\sum_{t=1}^{T} n_{ij}^{t} \leq \overline{n_{ij}} \quad (15)$$

n_{ij}^t integer

θ_j^t unbounded

$t = 1, 2, \ldots, T.$

The variables are the same from the static planning except t that represents the stages & represents variables of upper limit and represent the lower limits.

3. Genetic Algorithm in Expansion Planning

In this section the basic concepts of the GA as well as the structure of a specialized GA algorithm for dynamic transmission systems planning problem are presented [8, 20].

1. Basic Foundations of Genetic Algorithms:

Genetic algorithms are the most popular form of Evolutionary Algorithms and belong to the class of population-based search strategies. They work in a particular way on a population of strings (chromosomes), in which each string represents a possible candidate solution to the problem being optimized and each bit (or group of bits) represents a value for a decision variable of the problem. The fitness value of each individual determines its probability of appearing or surviving in future generations. Codification is an essential process of GA and binary encoding of the parameters is traditionally employed. Simple GA involves the following steps [8]:

Encoding: Code parameters of the problem as binary strings of fixed length.
Initialization: Randomly generate initial population strings which evolve to the next generation by genetic optimization operators.
Fitness Evaluation: Compute and evaluate each string's fitness which measures the quality of solutions coded by strings.
Selection: Permit highly-fit strings as parents and produce offspring according to their fitness in the next generation.
Crossover: Crossover is the main genetic operator and combines two selected parents by swapping chromosome parts between their strings, starting from a randomly selected crossover point. This leads to new strings inheriting desirable qualities from both chosen parents.

Mutation: Mutation works as a kind of 'life insurance' and flips single bits in a string, which prevents GA from premature convergence by exploiting new regions in the search space.
Termination: The new strings replace the existing ones and optimization process continues until the predetermined termination criterion is satisfied.

4. Security Assessment

The expansion plan obtained from the GA based optimization may contain insecure configurations. To ensure the system reliability and contingency the expansion plan is assessed by a list of credible single line outages, i.e. the "N-1" criteria, using a base case power flow. If the overload happens in any transmission line after removal of any line, best individuals from the rest of the candidate pool are selected to reinforce the network. The security assessment is repeated until no overloading happens in the system and the optimal expansion plan is finalized [20].

The first stage of the procedure for without security analysis attempts to find out the best line to be added, one at a time, until all overloads are removed in the base case and Contemplated single line outage cases. The second stage is used for further refinement of the solution obtained with the first stage. A normalized performance index (16), defined as a ratio of decrease in overloads in all topological cases, after a line addition to the cost of the line, is used to select the best line among the list of candidate lines.

$$NI_{sc} = \frac{OLI^0_{SC} - OLI^l_{SC}}{Cost_l} \quad (16)$$

Where,

NI_{SC}: Normalized security constrained performance index for the addition of l_{th} line,

OLI^0_{SC}: Security constrained overload index before the l_{th} line addition (base case or current topology),

OLI^l_{SC}: Security constrained overload index after the l_{th} line addition,

$Cost_l$: Cost of l_{th} candidate line.

5. Results

The results for DTNEP is obtained with Genetic algorithm for standard test systems i.e. IEEE 24 bus system. The implementation of genetic algorithm is done with the use of MATLAB software. The power flow and security analysis is studied by Power World Simulator (14). The comparison of results is carried out with simple static incremental planning for each year.

1. IEEE 24-bus system:

The data for IEEE 24-bus system is taken from [9]. The maximum number of lines in a corridor is 7. The load increase scenarios for the two years are also given as below.
1st year: base case load/gen (load given in the actual data for STNEP).
2nd year: 1.5*base case load/gen.

A discount rate of 10% is assumed for taking results. The results for DTNEP without security constraints are presented.

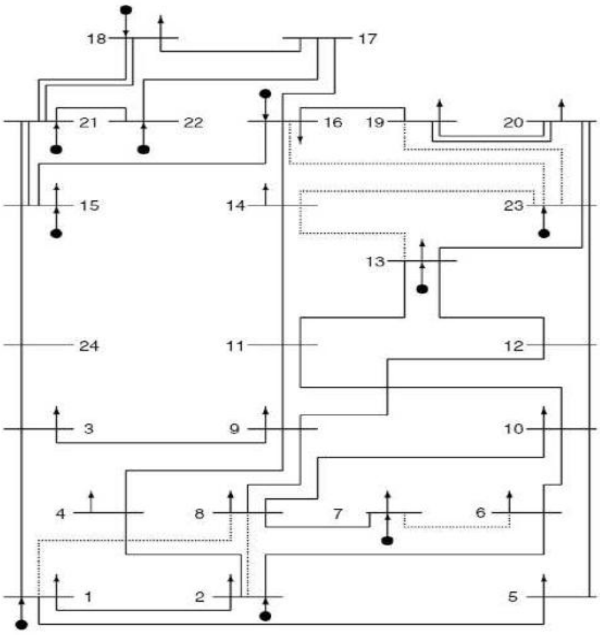

Figure 1: base case of IEEE 24-bus system

1.1 TNEP without security constraints:

In this case TNEPs for two years are obtained as a series of static TNEP for every year. In other words the optimum plan for every year is obtained independently at the beginning of the relevant year.

1st year plan: cost= US\$ 322X10^6, Total Lines=8, Lines: n_{2-6}=1, n_{3-24}=1 , n_{7-8}=2, n_{14-16}=1,n_{15-21}=1,n_{16-17}=1, n_{16-19}=1
2nd year plan: cost= US\$ 598X10^6, Total Lines=16, Lines: n_{21-22}=1,n_{17-18}=1,n_{11-16}=1,n_{2-6}=1,n_{3-24}=1, n_{16-17}=2, n_{9-11}=1, n_{18-21}=1, n_{16-17}=1, n_{16-19}=1 ,n_{2-9}=1,n_{4-9}=1, n_{17-18}=1, n_{7-8}=1, n_{1-2}=1
Cost referred to 1st year: US\$ 920X10^6.

The static TNEP is obtained for last year loading. The optimal expansion plan for this case results in a total investment of US\$ 953X10^6, with the addition of following twenty-two lines, n_{1-2}=1, n_{2-6}=2, n_{3-24}=2, n_{7-8}=3, n_{9-11}=1, n_{9-12}=1, n_{10-11}=1, n_{11-14}=1, n_{14-16}=2, n_{15-21}=1, n_{15-24}=2, n_{16-17}=2, n_{16-19}=1, n_{17-18}=1, n_{21-22}=1.

The expansion planning in a dynamic fashion results in a saving of US\$ 33X10^6 when compared to single stage STNEP. Obviously, these differences will be much higher in more complex and larger systems.

Figure 1 shows the base case of IEEE 24-bus system, Figure 2 and Figure 3 shows the IEEE 24-bus system after 2nd stage of dynamic planning and static planning respectively in which pink dotted lines shows the added lines for the planning.

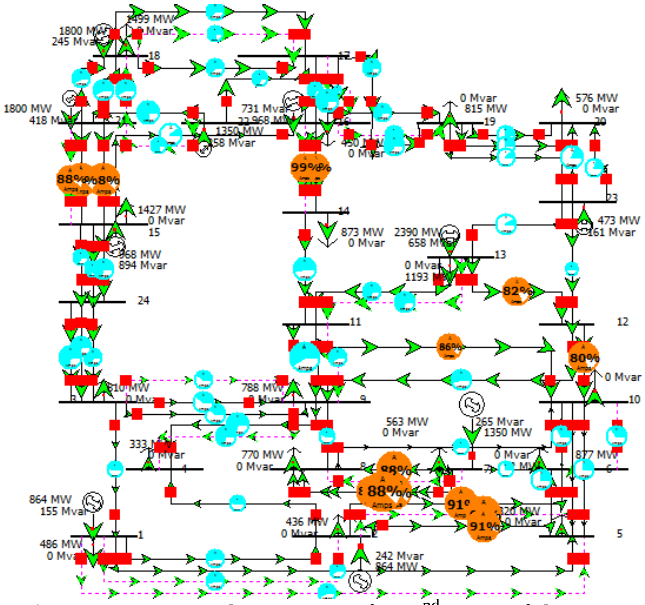

Figure 2: IEEE 24-bus system after 2nd stage of dynamic planning

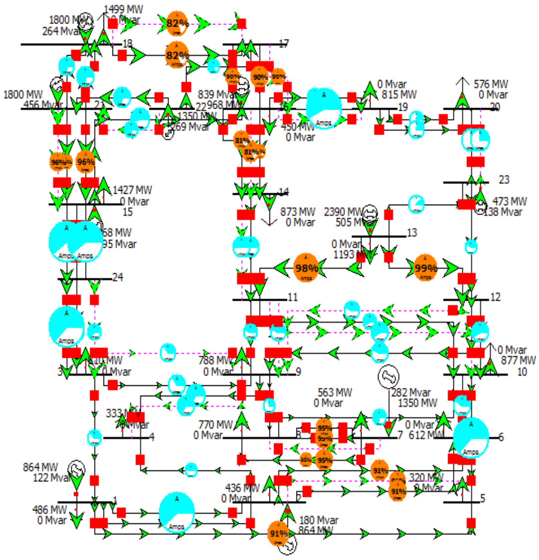

Figure 3: IEEE 24-bus system after static planning

6. Conclusion

The importance of DTNEP over simple static TNEP is demonstrated. The dynamic planning of expansion transmission systems has as its main characteristic that of adapting to the continuous growth of the demand and generation, in contrast with static planning, that considers only the initial and final year's demand and generation. Dynamic planning invests in the proper time and quantity. Besides, dynamic planning takes advantage of economies of scale, because it favors the addition of large-capacity expensive elements necessary in the long term, which are ruled out by static planning, which favors the immediate reinforcements in the transmission system.

7. Future Scope

Transmission network expansion planning with security is the further work of the paper.

References

[1] H. A. Gil and E. L. da Silva, "A reliable approach for solving the transmission network expansion planning problem using genetic algorithm", Electric Power System Research 5845-51, 2001.

[2] M. V. F. Pereira and L. M. V. G. Pinto, "Application of sensitivity analysis of load supplying capacity to interactive transmission expansion planning," IEEE Trans. Power App. Syst., vol. PAS-104, pp. 381–389, Feb. 1985.

[3] R. Romero and A. Monticelli, "A hierarchical decomposition approach for transmission network expansion planning," IEEE Trans. Power Syst., vol. 9, pp. 373–380, Feb. 1994.

[4] R. Romero, R. A. Gallego and A. Monticelli, "Transmission system expansion planning by simulated annealing," IEEE Trans. Power Syst.,vol. 11, pp. 364–369, Feb. 1996.

[5] E. L. Silva, H. A. Gil and J. M. Areiza, "Transmission network expansion planning under an improved genetic algorithm," IEEE Trans. Power Syst., vol. 15, pp. 1168–1175, Aug. 2000.

[6] R. A. Gallego, R. Romero and A. J. Monticelli, "Tabu search algorithm for network synthesis," IEEE Trans. Power Syst., vol. 15, pp. 490–495, May 2000.

[7] R. Romero, C. Rocha, M. Mantovani and J.R.S. Mantovani, "Analysis of heuristic algorithms for the transportation model in static and multistage planning in network expansion systems," IEE Proc. Gener. Transm. Distrib. Vol. 150, No.5, pp. 521-526, 2003.

[8] A. H. Escobar, R. A. Gallego and R. Romero, "Multistage and coordinated planning of the expansion of transmission systems," IEEE Trans. Power Syst., vol. 19, no. 2, pp. 735-744, May 2004.

[9] R. Romero, C. Rocha, J.R.S. Mantovani and I.G.Slanchez, "Constructive heuristic algorithm for the DC model in network expansion planning" IEE Proc. Gener. Transm.Distrib., vol. 152, no.2, pp. 277-282, 2005.

[10] R. Romero, C. Rocha, M. Mantovani and J.R.S. Mantovani," Analysis of heuristic algorithms for the transportation model in static and multistage planning in network expansion systems," IEE Proc.-Gener. Transm. Distrib., Vol. 150, No. 5, September 2003.

[11] E. L. Silva, J. M. A. Ortiz, G. C. Oliveira and S. Binato, "Transmission network expansion planning under a tabu search approach," IEEE Trans. Power Systems, vol.16, no.1, pp. 62-68, Feb. 2001.

[12] R. Romero, R. A. Gallego and A. Monticelli, "Transmission system expansion planning by simulated annealing," IEEE Trans. Power Systems, vol.11, no.1, pp. 364-369, Feb. 1996.

[13] R. A. Gallego, A. Monticelli and R. Romero, "Transmission system expansion planning by an extended genetic algorithm," IEE Proc. Gener. Transm. Distrib., vol. 145, no.3, pp. 329-335, May 1998.

[14] E. L. Silva, H. A. Gil and J. M. Areiza, "Transmission network expansion planning under an improved genetic algorithm," IEEE Trans. Power Systems, vol.15, no.3, pp. 1168-1175, Aug. 2000.

[15] H. A. Gil and E. L. Silva, "A reliable approach for solving the transmission network expansion planning problem using genetic algorithms," Elsevier Science, Electric Power Systems Research, vol. 58, pp.45-51, 2001.

[16] Luis A. Gallego,Marcos J. Rider,Marina Lavorato, and Antonio Paldilha-Feltrin," An Enhanced Genetic Algorithm to Solve the Static and Multistage Transmission Network Expansion Planning," Journal of Electrical and Computer Engineering vol. 2012.

[17] Y. X. Jin, H. Z. Cheng, J. Y. Yan and L. Zhang, "New discrete method for particle swarm optimization and its application in transmission network expansion planning," Elsevier Science, Electric Power Systems Research, vol. 77, pp.227-233, 2007.

[18] I. J. De Silva, M. J. Rider, R. Romero, and C. A. Murari, "Genetic algorithm of chu and beasley for static and multistage transmission expansion planning," in Proceedings of the IEEE Power Engineering Society General Meeting (PES '06), Montreal, Canada, June 2006.

[19] T. Sum-Im, G. A. Taylor, M. R. Irving, and Y. H. Song, "Differential evolution algorithm for static and multistage transmission expansion planning," IET Generation, Transmission and Distribution, vol. 3, no. 4, pp. 365–384, 2009.

[20] Zhao Xu,Zhao Yang Dong,Kit Po Wong, " Multi-objective Transmission Planning," IEEE Trans. Power Systems, 2009.