A DISCRETE IMPERIALIST COMPETITION ALGORITHM FOR TRANSMISSION EXPANSION PLANNING

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Abstract

This paper describes the application of a Discrete Imperialist Competition Algorithm (DICA) to deal with the solution of the Transmission Network Expansion Planning (TNEP) problem. Imperialist Competition Algorithms have demonstrated the ability to deal with non-convex, nonlinear, integer-mixed optimization problems, like the TNEP problem, better than a number of mathematical methodologies.

Some special features with heuristic search have been added to the basic Imperialist Competition Algorithm to improve its performance in solving the TNEP problem for 6-bus Garver, IEEE 24-bus and a real-life large-scale transmission system.

Results obtained reveal that ICA represents a promising approach for dealing with such a problem.

INTRODUCTION

Transmission expansion planning has always been a rather complicated task especially for large-scale real-world transmission networks.

First of all, electricity demand changes across both area and time. The change in demand is met by the appropriate dispatching of generation resources. As an electric power system must obey physical laws, the effect of any change in one part of network (e.g. changing the load at a node, raising the output of a generator, switching on/off a transmission line or a transformer) will spread instantaneously to other parts of the interconnected network, hence altering the loading conditions on all transmission lines.

The ensuing consequences may be more marked on some transmission lines than others, depending on electrical characteristics of the lines and interconnection. The electric transmission expansion planning problem involves determining the least investment cost of the power system expansion and operation through the timely addition of electric transmission facilities in order to guarantee that the constraints of the transmission system are satisfied over the defined planning horizon. The transmission system planner is entrusted with ensuring the above-stated goals are best met whilst utilizing all the available resources. Therefore the purpose of transmission system planning is to determine the timing and type of new transmission facilities. The facilities are required in order to provide adequate transmission capacity to cope with future additional generation and power flow requirements. The transmission plans may require the introduction of higher voltage levels, the installation of new transmission elements and new substations. Transmission system planners tend to use many techniques to solve the transmission expansion planning problem. Planners utilize automatic expansion models to determine an optimum expansion system by minimizing the mathematical objective function subject to a number of constraints.

In general, transmission expansion planning can be categorized as static or dynamic according to the treatment of the study period [1]. In static planning; the planner considers only one planning horizon and determines the number of suitable circuits that should be installed to each branch of the transmission network system. Investment is carried out at the beginning of the planning horizon time. In dynamic or multistage planning, the planner considers not only the optimal number and Location of added lines and type of investments but also the most appropriate times to carry out such expansion investments. Therefore the continuing growth of the demand and generation is always assimilated by the system in an optimized way. The planning horizon is divided into various stages and the transmission lines must be installed at each stage of the planning horizon. Many optimization methods have been applied when solving the transmission expansion planning problem. The techniques range from expert engineering judgments to powerful mathematical programming methods. The engineering judgments depend upon human expertise and knowledge of the system. The most applied approaches in the transmission expansion planning problem can be classified into three groups that are mathematical optimization methods (linear programming [2], nonlinear programming [3], integer and mixed integer programming [4] and branch and bound [5], etc.), heuristic methods (mostly constructive heuristics [6]) and meta-heuristic methods (genetic algorithms [7-8], taboo search [9], simulated annealing [10], particle swarm [11], evolutionary algorithms [12], etc). Over the past decade, algorithms inspired by the observation of natural phenomena when solving complex combinatorial problems have been gaining increasing interest because they have been shown to have good performance and efficiency when solving optimization problems. Such algorithms have successfully applied to many power system problems, for example power system scheduling, power system planning and power system control. In this research, an Imperialist Competition Algorithm (ICA) [13-15] will be proposed and developed to solve static transmission expansion planning problems by direct application to the DC power flow based model.

dc model

A dc-based power flow model is applied to solve TNP problems.

Mathematically the problem can be formulated as follows:

$$\min v = \sum_{(i,j)\in\Omega} c_{ij} . n_{ij} \tag{1}$$

$$g = B\theta + d \tag{2}$$

$$f_{ij} = \gamma_{ij}\left(n_{ij}^{o} + n_{ij}\right)\times\left(\theta_i - \theta_j\right) \tag{3}$$

$$\left|f_{ij}\right| = \left(n_{ij}^{o} + n_{ij}\right).f_{ij}^{\max} \tag{4}$$

$$g_i^{\min} \le g_i \le g_i^{\max} \tag{5}$$

$$0 \le n_{ij} \le n_{ij}^{\max} \tag{6}$$

where :

v : Transmission investment cost

Ω : set of all condidate barnches for expansion

c_{ij} : cost a candidate circuit for addition to the branch i-j

n_{ij} : number of circuit added to the barnch i - j

n_{ij}^{0} : number of circuit in original base system

$n_{ij}^{\max}$: maximum number of circuit added to the branch i-j

g : real power generation vector

g_i : real power generation at node i

$g_i^{\min}$: lower real power generation limits at node i

$g_i^{\max}$: upper real power generation limits at node i

B : susceptance matrix

θ : bus voltage phase angle vector

d : real load demand vector

f_{ij} : total branch power flow in branch i - j

$f_{ij}^{\max}$: maximum branch power flow in branch i-j

γ_{ij} : susceptance of branch i - j

Constraint (2) represented the conservation of power at each node; constraint (3) represented the real power flow equation in dc network, constraint (4) is applied to TEP in order to limit the power flow for each path, constraint (5) represented power generation limits and constraint (6) defines the maximum number of circuit that can be installed in a specified location.

INTRODUCTION OF IMPERIALIST COMPETITIVE Algorithm

Imperialist Competitive Algorithm (ICA) [13] is a new evolutionary algorithm in the Evolutionary Computation field based on the human's socio-political evolution. The algorithm starts with an initial random population called countries. Some of the best countries in the population selected to be the imperialists and the rest form the colonies of these imperialists. In an N dimensional optimization problem, a country is an $1 \times n$ array. This array defined as below

$$Country = [p_1, p_2, ..., p_n] \tag{7}$$

The cost of a country is found by evaluating the cost function f at the variables $(p_1, p_2, ..., p_n)$. Then

$$c_i = F(Country_i) = F(p_{i1}, p_{i2}, ..., p_{in}) \tag{8}$$

The algorithm starts with N initial countries and the N_{imp} best of them (countries with minimum cost) chosen as the imperialists. The remaining countries are colonies that each belong to an empire. The initial colonies belong to imperialists in convenience with their powers. To distribute the colonies among imperialists proportionally, the normalized cost of an imperialist is defined as follow

$$C_n = \max\{c_i\} - c_n \tag{9}$$

Where, c_n is the cost of nth imperialist and C_n is its normalized cost. Each imperialist that has more cost value, will have less normalized cost value. Having the normalized cost, the power of each imperialist is calculated as below and based on that the colonies distributed among the imperialist countries.

$$p_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \tag{10}$$

On the other hand, the normalized power of an imperialist is assessed by its colonies. Then, the initial number of colonies of an empire will be $NC_n = rand\{p_n \times N_{col}\}$ where, NC_n is initial number of colonies of nth empire and N_{col} is the number of all colonies.

To distribute the colonies among imperialist, NC_n of the colonies is selected randomly and assigned to their imperialist. The imperialist countries absorb the colonies towards themselves using the absorption policy. The absorption policy shown in Fig.1 makes the main core of this algorithm and causes the countries move towards to their minimum optima. The imperialists absorb these colonies towards themselves with respect to their power that described in (11). The total power of each imperialist is determined by the power of its both parts, the empire power plus percents of its average colonies power.

$$\begin{aligned} TC_n &= \cos t(imperialis\, t_n) \\ &+ \xi \times mean\{\cos t(colonies\ of\ empire_n)\} \end{aligned} \tag{11}$$

Where TC_n is total cost of the nth empire and ξ is a positive number which is considered to be less than one.

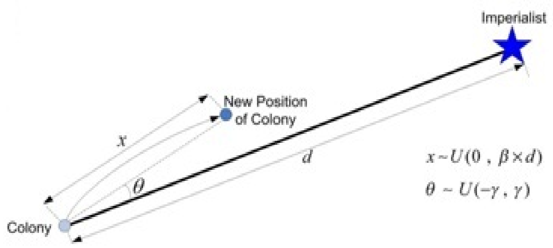

Fig. 1. Moving colonies toward their relevant imperialist

ξ is a positive number which is considered to be less than one.

$$x \sim U\left(0, \beta \times d\right) \tag{12}$$

In the absorption policy, the colony moves towards the imperialist by x unit. The direction of movement is the vector from colony to imperialist, as shown in Fig.1, in this figure, the distance between the imperialist and colony shown by d and x is a random variable with uniform distribution. Where β is greater than 1 and is near to 2. So, a proper choice can be $\beta = 2$. In our implementation γ is 45 (deg) respectively.

$$\theta \sim U\left(-\gamma, \gamma\right) \tag{13}$$

In ICA algorithm, to search different points around the imperialist, a random amount of deviation is added to the direction of colony movement towards the imperialist. In Fig. 1, this deflection angle is shown as θ, which is chosen randomly and with a uniform distribution. As shown in Fig.2 While moving toward the imperialist countries, a colony may reach to a better position, so the colony position changes according to position of the imperialist.

In each iteration we select some of the weakest colonies and replace them with new ones, randomly. The replacement rate is named as the revolution rate.

In this algorithm, the imperialistic competition has an important role. During the imperialistic competition, the weak empires will lose their power and their colonies. To model this competition, firstly we calculate the probability of possessing all the colonies by each empire considering the total cost of empire.

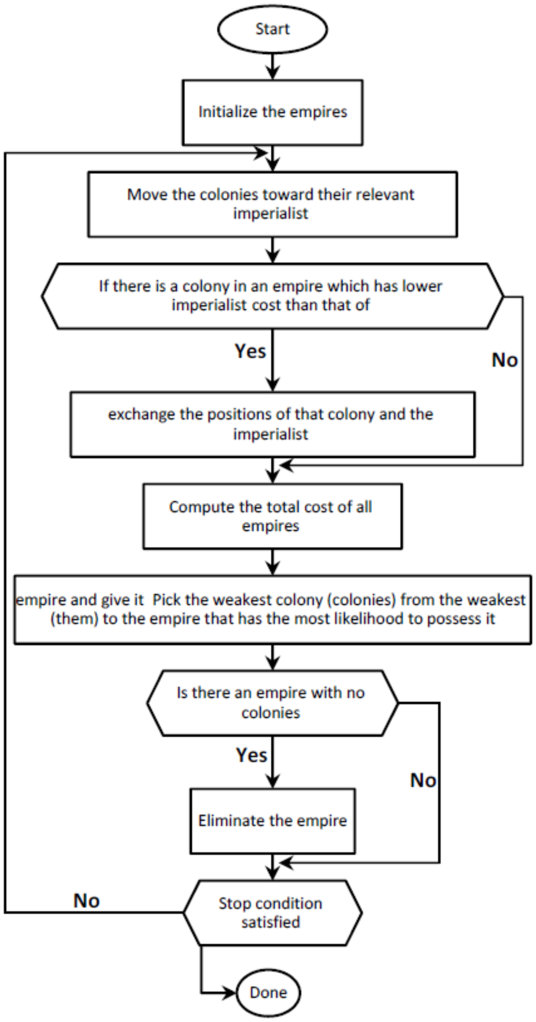

Fig. 3. Flowchart of the proposed algorithm

$$NTC_n = \max\left\{TC_i\right\} - TC_n \tag{14}$$

Where, TC_n is the total cost of nth empire and NTC_n is the normalized total cost of nth empire. Having the normalized total cost, the possession probability of each empire is calculated as below

$$p_{p_n} = \left| \frac{NTC_n}{\sum_{i=1}^{N_{imp}} NTC_i} \right| \tag{15}$$

After a while all the empires except the most powerful one will collapse and all the colonies will be under the control of this unique empire. Fig.3 shows the flowchart of this algorithm.

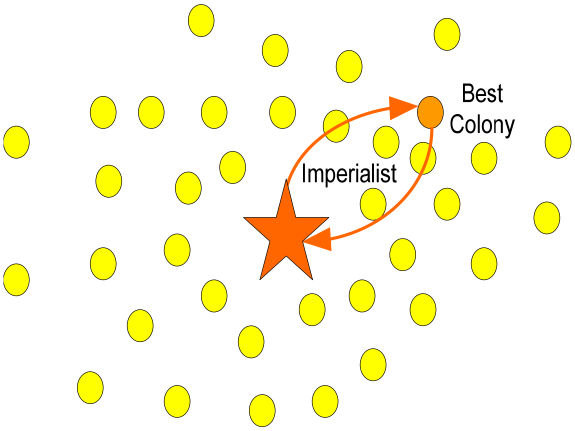

Fig. 2. Exchanging the positions of a colony and the imperialist

Solution technique

Generation initial countries

ICA method depends on initial value so for select the initial countries the below procedure was followed:

1) K=0;

2) $n_{ij} = n_{ij}^{\max}, \quad \forall (i,j) \in \Omega$;

3) Randomly select a line and remove that from circuit;

4) Solve a DC power flow if an over flow occur go to 5 else go to step 3;

5) Save this solution and K=K+1;

6) If K= {number of countries}, stop, if not go to 2.

This procedure generates better initial values (whit lower possible investment cost) to start competition algorithm.

Discrete ICA

The original version of Imperialist competitive algorithm operates on real values. However, with a simple modification the Imperialist competitive algorithm can be made to operate on discrete problems.

Modification of Moving the colonies toward the imperialist (assimilating):

Imperialists countries started to improve their colonies. This fact has been modeled by moving all the colonies toward the imperialist. Through this movement some parts of a colony's structure will be similar to the empire's structure. The assimilating operator is shown with an example in Fig. 4

1) Select several cells (round {40% maximum number of cells}) randomly in imperialist array (cells {1,2,5,8});
2) Find number of selected cells in the colony's array and replace them with numbers of same position in imperialist array (cells {1,2,5,8});
3) If the new generated colony don't satisfy constraints go to step 1, if not continue.

Imperialist	2	3	0	4	1	5	0	0	1
Colony	1	5	3	2	0	3	0	0	4

Shifted colony	2	3	3	2	1	5	0	0	4

Fig. 4. Modification of moving colonies toward imperialist

VALIDATION TESTS AND PARAMETER ADJUSTMENT

The proposed DICA method has been implemented in Matlab7.1 and tested on three electrical transmission networks, which are as reported in [2, 6, 5]. In these analyses, static TEP procedure is tested on the following three test systems; 6-bus system originally proposed by Garver , IEEE 24-bus system and Brazilian 46-bus system.

ICA Parameters Tuning*:* For a specific problem, ICA's have a set of parameters which should be adjusted empirically over the different simulations. Nevertheless, we observed that there is an interval for each parameter upon which the best results were found for all the cases studied.

Garver 6-Bus System

The first test system investigated in this research is the well-known Garver's system. Generally, it comprises of 6 buses, 15 possible branches and 760 MW of demand. The data for the above system is given in [2].

In this case, the optimal solution of the static TEP problem was found. The investment cost of this optimal solution equals to v = US$ 200,000 with the following topology: $n_{2-6} = 4, n_{3-5} = 1, n_{4-6} = 2$

ICA Parameters Tuning: zeta(ξ) (0.04-0.06), revolution rate (0.10-0.20), number of imperialists (4-6), number of countries (40-60), number of iterations (30-50).

IEEE 24-Bus System

The second test system is the IEEE 24-bus system. It has 24 buses, 41 possible branches and 8550 MW of total demand. These electrical system data consist of transmission line data, load data and generation data that these data are available in the Appendix.

The solution for four generation plans is presented in Table I. In [6] presented a novel constructive heuristic algorithm that works directly with the DC model. The principal advantage of the algorithm works directly with the solution given by the DC model with relaxed integer variables. The resulting information is of excellent quality for use as a sensitivity index. In [16] a new transmission planning model was developed to deal with power flow patterns and a decision analysis scheme was incorporated to minimize the cost of the selected plan, that The TNEP problem becomes a linear problem which can be solved by a customized dual simplex algorithm. In [17] a constructive heuristic algorithm was used to solve the transmission network expansion planning problem. For each step of the algorithm, a sensitivity index was used to add a single circuit to the system found by solving a relaxed TNEP problem.

TABLE I
Computational performance comparison between the proposed DICA and other methods

line	case A					case B				case C					case D			
-	[16]	CHA IPM [17]	CHA SNOPT [17]	[6]	DICA	[16]	CHA IPM [17]	CHA SNOPT [17]	DICA	[16]	CHA IPM [17]	CHA SNOPT [17]	[6]	DICA	[16]	CHA IPM [17]	CHA SNOPT [17]	DICA
01-05	1	1	1	1	1	-	1	1	1	1	1	-	-	-	-	-	-	-
02-08	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
03-09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
03-24	1	1	1	1	1	1	1	1	1	1	1	-	-	-	1	1	1	1
06-20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
07-08	3	2	2	2	2	1	1	1	1	2	2	2	2	2	2	2	2	2
10-11	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	1
10-12	-	-	-	-	-	1	-	-	-	1	1	1	1	1	1	1	1	-
10-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
12-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-
14-16	1	1	1	1	1	1	2	2	1	-	-	1	1	1	1	1	1	1
14-23	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-
15-21	1	1	1	1	-	1	1	1	-	-	-	-	-	-	-	-	-	-
15-24	1	1	1	1	1	1	1	1	1	-	-	-	-	-	1	1	1	-
16-17	2	2	2	2	1	2	2	2	1	1	1	1	1	-	1	1	1	-
16-19	1	1	1	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-
17-18	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-
20-23	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-
21-22	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Cost ×10^3 US$	545	438	438	438	396	451	494	494	336	292	292	218	218	214	376	376	376	299

ICA Parameters Tuning : zeta (ξ) (0.04 - 0.06), revolution rate (0.15-0.25), number of imperialists (6-8), number of countries (80-100), number of iterations (80-100).

As the empirical solution of this test case indicates, the total investment cost of the DICA method is less expensive than other methods on the IEEE 24-Bus System

TABLE II
Generation and load data

Bus	Case A	Case B	Case C	Case D	Load
1	576	465	576	520	324
2	576	576	576	520	291
3	0	0	0	0	540
4	0	0	0	0	222
5	0	0	0	0	213
6	0	0	0	0	408
7	900	722	900	812	375
8	0	0	0	0	513
9	0	0	0	0	525
10	0	0	0	0	585
11	0	0	0	0	0
12	0	0	0	0	0
13	1773	1424	1457	1599	795
14	0	0	0	0	582
15	645	645	325	581	951
16	465	465	282	419	300
17	0	0	0	0	0
18	1200	1200	603	718	999
19	0	0	0	0	543
20	0	0	0	0	384
21	1200	1200	951	1077	0
22	900	900	900	900	0
23	315	953	1980	1404	0
24	0	0	0	0	0

Brazilian 46-Bus System

The third test system is the Brazilian 46-bus system. The system comprises 46 buses, 79 circuits, 6880 MW of total demand. The electrical system data, which consist of transmission line, load and generation data, are available in [5]. This system represents a good test to the proposed approach because it is a real-world transmission system.

In this case, the optimum solution was found by branch and bound algorithm in [18] and an expansion investment cost equals to v = US$ 154.42 million. This optimum solution was also found by only DICA in this paper and presented the following topology:

$$n_{5-6}=2, n_{6-46}=1, n_{19-25}=1, n_{20-21}=1, n_{24-25}=2, n_{26-29}=3, n_{28-30}=1, n_{29-30}=2, n_{31-32}=1, n_{42-43}=2$$

In [18] the number of Non Linear Programs solved were 8081 where the optimum solution was found at the about 150th iteration.

ICA Parameters Tuning: zeta(ξ) (0.04-0.06), revolution rate (0.20-0.30), number of imperialists (10-12), number of countries (120-150), number of iterations (150-200).

Topology of test systems A(6-bus Garver) and C(Brazilian 46-Bus System) can be found in Appendix.

conclusion

Application of Discrete Imperialist competitive algorithm for the solution of Transmission Network Expansion Planning problem was illustrated in this paper. This method is easy to combine with power flow calculations. The DICA algorithm has been demonstrated to have superior features, including high-quality solution, stable convergence characteristic, and good computation efficiency compared to the other approaches.

References

[1] G. Latorre, R. D. Cruz, J. M. Areiza and A. Villegas, “Classification of publications and models on transmission expansion planning,” *IEEE Trans. Power Syst.*, vol. 18, no. 2, pp. 938-946, May 2003.

[2] L. L. Garver, “Transmission network estimation using linear programming,” *IEEE Trans. Power App. Syst.*, vol. PAS-89, no.7, pp.1688-1697, Sep./Oct. 1970.

[3] H. K. Youssef and R. Hackam, “New transmission planning model,” *IEEE*

Trans. Power Syst., vol. 4, pp. 9–18, Feb. 1989.

[4] L. Bahiense, G. C. Oliveira, M. Pereira, and S. Granville, "A mixed integer disjunctive model for transmission network expansion," *IEEE Trans. Power Syst.*, vol. 16, pp. 560–565, Aug. 2001.

[5] S. Haffner, A. Monticelli, A. Garcia, J. Mantovani and R. Romero, "Branch and bound algorithm for transmission system expansion planning using transportation model," *IEE Proc. Gener. Transm. Distrib.*, vol. 147, no.3, pp. 149-156, May 2000

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

[7] 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.

[8] T. Al-Saba and I. El-Amin, "The application of artificial intelligent tools to the transmission expansion problem," *Elsevier Science*, *Electric Power Systems Research*, vol. 62, pp.117-126, 2002.

[9] 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.

[10] R. A. Gallego, A. B. Alves, A. Monticelli, and R. Romero, "Parallel simulated annealing applied to long term transmission network expansion planning," *IEEE Trans. Power Syst.*, vol. 12, pp. 181–188, Feb. 1997

[11] 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.

[12] J. L. Ceciliano and R. Nieva, "Transmission network planning using evolutionary programming," in *Proc. the 1999 Congress on Evolution Computation* (*CEC 1999*), Washington DC, U.S.A., vol. 3, pp. 1796-1803.

[13] E. Atashpaz-Gargari and C. Lucas, "Imperialist Competitive Algorithm: An Algorithm for Optimization Inspired by Imperialistic Competition," *IEEE Congress on Evolutionary Computation (CEC 2007)*, pp 4661-4667, 2007.

[14] R.Rajabioun, E.Atashpaz, C.Lucas**,** **"**Colonial Competitive Algorithm as a Tool for Nash Equilibrium Point Achievement," *Lecture Notes In Computer Science*,Vol. 5073, Proc. of the Intl. conf. on Computational Science and Its Applications, Part II, 2008, pp.680-695.

[15] B.Oskouyi, E. Atashpaz-Gargari, N. Soltani, C. Lucas,"Application of Imperialist Competitive Algorithm for Materials Property Characterization from Sharp Indentation Test," *in International Journal of engineering Simulation*.

[16] R. Fang and D. J. Hill, "A new strategy for transmission expansion in competitive electricity markets," *IEEE Trans. Power Syst.*, vol. 18, pp. 374–380, Feb. 2003.

[17] I. G. Snchez, R. Romero, J. R. S. antovani and M. J. Rider, "Transmission-expansion planning using the DC model and nonlinearprogramming technique," *Proc. IEE-Gen. Transm. Dist.*, vol. 152, pp. 763-769, Nov. 2005.

[18] M.J. RIDER, A.V. GARCIA, R. ROMERO, "Transmission system expansion planning by a branch-and-bound algorithm, " *IET Proc. Gener. Transm. Distrib.*, 2008, 2, (1), pp. 90–99

APPENDIX

Generation and load data for test system IEEE
24-bus given in Table II also circuit data is available in Table III.

TABLE III
Circuit data

From	To	Reactance p.u	Cost x1000	Capacity MW
1	2	0.0139	3	175
1	3	0.2112	55	175
1	5	0.0845	22	175
2	4	0.1267	33	175
2	6	0.192	50	175
3	9	0.119	31	175
3	24	0.0839	50	400
4	9	0.1037	27	175
5	10	0.0883	23	175
6	10	0.0605	16	175
7	8	0.0614	16	175
8	9	0.1651	43	175
8	10	0.1651	43	175
9	11	0.0839	50	400
9	12	0.0839	50	400
10	11	0.0839	50	400
10	12	0.0839	50	400
11	13	0.0476	66	500
11	14	0.0418	58	500
12	13	0.0476	66	500
12	23	0.0966	134	500
13	23	0.0865	120	500
14	16	0.0389	54	500
15	16	0.0173	24	500
15	21	0.049	68	500
15	24	0.0519	72	500
16	17	0.0259	36	500
16	19	0.0231	32	500
17	18	0.0144	20	500
19	22	0.1053	146	500
18	21	0.0259	36	500
19	20	0.0396	55	500
20	23	0.0216	30	500
21	22	0.0678	94	500
1	8	0.1344	35	500
2	8	0.1267	33	500
6	7	0.192	50	500
13	14	0.0447	62	500
14	23	0.062	86	500
16	23	0.0822	114	500
19	23	0.0606	84	500

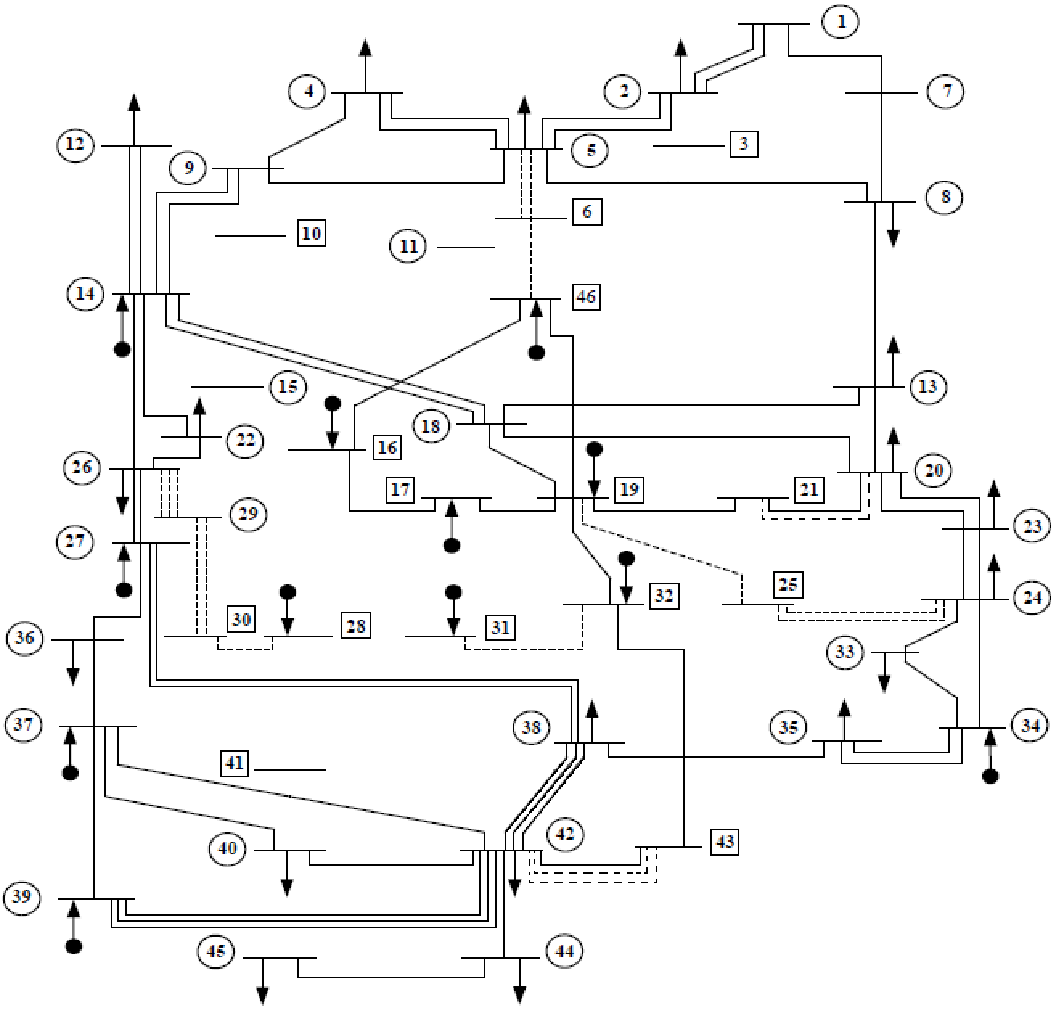

Fig. 1. Brezilian 46 bus system

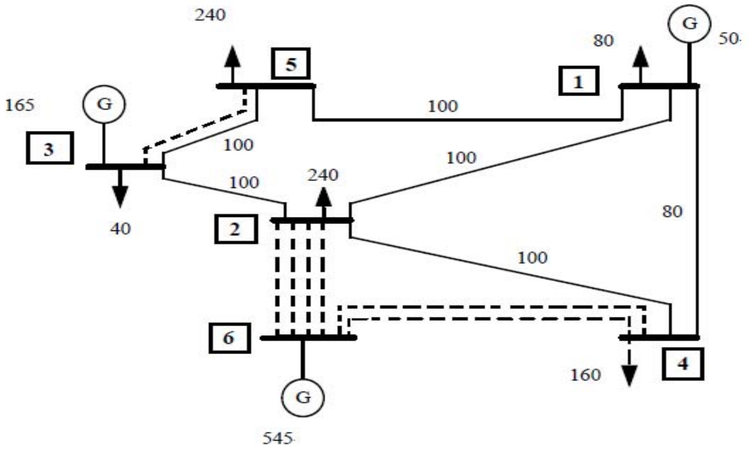

Fig. 1. Garver 6 bus system