JOURNAL OF SOUTHERN COMMUNICATION ENGINEERING
ISLAMIC AZAD UNIVERSITY BUSHEHR BRANCH

E-ISSN: 2980-9231
https://jce.bushehr.iau.ir

https://doi.org/10.30495/jce.2022.1961298.1163

Vol. 14/ No. 53/Autumn 2024

Research Article

A Single Stage Dynamic Transmission Expansion Planning Model in the Competive Market

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Received: 22 June 2022
Revised: 4 September 2022
Accepted: 8 October 2022

Abstract

Transmission Expansion planning (TEP) recommends the most beneficial investment to construct/ reinforce the power system. In this short or middle time planning the annual load growth of the power system must be met considering the stability, security and reliability of the network. In the competitive market, the planners can include market behavior in the TEP to manage the congestion. Before traditional TEP, the local marginal pricing (LMP) is calculated offline without considering the dependency of the LMP on the network topology. But, the LMP is not constant during the TEP and must be included in the model dynamically. Here, the dynamic dependency of LMP to the transmission system topology is modeled as a single stage mixed-integer linear programming and solved by YALMIP and MOSEK software. The proposed model is more realistic; however, it takes more computation time. The single stage means the simultaneous calculation of LMPs and expansion planning in the model. The model has been applied to Garver 6-bus and the IEEE 24-bus network. The effect of interest rate, the load to generation capacity factor and load growth on the TEP model are analyzed. The model considers the contingency of line outages and presents a robust solution to guarantee system security. It offers flexible solutions at a higher cost.

Keywords: Transmission Expansion Planning, Competitive Market, Local Marginal Pricing, Line Congestion.

Highlights

- Presenting a new MILP model of Transmission Expansion Planning in the competitive market
- Presenting a dynamic Local Marginal Pricing (LMP)-based Planning without computing the LMP separately
- Integration of two optimization solvers called MOSEK and YALMIP to accelerate the computation accurately
- Implementing the model in Garver 6bus and IEEE 24bus networks
- Considering the contingency and present a robust model

Citation: H. Gorjipour, M. Najafi, and N. Moaddabi Pirkolachi "A Single Stage Dynamic Transmission Expansion Planning Model in the Competitive Market," *Journal of Southern Communication Engineering*, vol. 14, no. 53, pp. 15–28, 2024, doi: 10.30495/jce.2022.1961298.1163, [in Persian].

1. Introduction

Transmission expansion planning is an optimization issue that aims to handle network load growth by the construction of new transmission lines [1]. So far, many models of transmission expansion planning have been proposed, which generally can be divided into two categories: linear and non-linear models. Considering the placement of flexible AC transmission systems in the problem is one of the factors that lead to the nonlinearization of the problem, which has been solved by the multi-stage optimization of Bander's decomposition [2]. Considering the constraints related to AC power flow is another factor that has led to the nonlinear problem. Nonlinear problems can be divided into two sub-problems of linear integer programming and nonlinear programming [3]. Considering the nonlinear behavior of responsive loads is another influential factor in the nonlinearity of the problem model, which has been solved by the method of hierarchical analytical process based on the maximum like a hood with the ideal answer [4]. Adding the effects of contingencies to the problem has led to the extraction of risk-based nonlinear models. To solve it, McCormick's liberation methods and conical programming have been used [5]. Also, combining the constraints related to the resiliency of the transmission network in natural disasters is another factor that has made the model nonlinear, which has been solved by the orchestra symphony search algorithm in four steps [5]. The aim of this research is to present a one-step model of TEP in a competitive electricity market. In this method, unlike traditional methods, there is no need to calculates local margin pricing, and the program is designed in such a way that calculates both the expansion solution and local margin pricing, simultaneously. From the perspective of considering the electricity market in transmission expansion planning studies, this research can be divided into two groups based on the traditional unipolar electricity market and the competitive deregulated electricity market[6]. In unipolar electricity markets, TEP is merely done to benefit one of the actors, but in a competitive electricity market, the benefit of each participant in production, transmission 'and distribution is considered, to obtain a trade-off between different goals[7]. Gradually, with the expansion of the electricity market and its competitiveness, several attempts were made to manage the congestion of network lines and to consider the market structure in optimizing TEP. Most of these methods have led to nonlinearity. TEP in the presence of the electricity market based on double auctions is a non-linear model that has been done with the aim of increasing the participation of electricity generation and distribution companies which is solved as bi-level programming [8]. Another nonlinear model based on the German electricity market is presented in [9], which uses a non-reduced network model. The integration of transmission line congestion management and network losses in the presence of the electricity market is modeled nonlinearly, which is solved by combining fuzzy logic with a genetic algorithm. The integration of short-term demand response plan and renewable energy resource management into TEP has been modeled as a non-convex problem in [10] and solved using the non-dominant sorting method. [11] also presents a robust adaptive optimization for transmission network development planning in which nonlinear constraints are linearized and the problem is integrated into integer linear programming. A multi-objective model is also presented in reference [12], which includes costs related to investment, congestion, and load shedding. To solve this problem, a genetic algorithm based on non-dominant sorting and fuzzy logic has been used. Furthermore, optimal sizing and sitting of new technologies such as distributed generation and D-STATCOM are investigated in the expansion planning[13].

TEP models can be investigated in deregulated electricity markets from different viewpoints that are reviewed in [14] that includes nodal pricing, transmission congestion management, market risks, etc. Furthermore, several structures of the market based TEP models are classified into two groups in [15]. In the first group the simultaneous market such as perfect competition is included. Also, in the second group the sequential and hierarchical markets such as one leader and one (or more) follower is investigated. Several strategies can be adopted in the electricity market to reduce the local marginal pricing (LMP) differences for more competition in the network. One of the effective solutions is installing distributed generation near the loads to meet the surplus demands of the customers locally. Integration of wind generation in TEP planning is one of these approaches that is implemented in [16]. Another effective action is the contribution of the generation companies as investors in the TEP problem that is investigated in [17] to reduce the budget limitation of transmission expansion projects and reduce the time delay of them in the competitive market. In line with congestion management, the calculation of the local marginal pricing is required. The evolution of local marginal price calculation has been reviewed in [15] and a new iterative method is introduced. The important issue is how to calculate the LMP in the TEP problem. A bi-level approach was introduced in [18] that calculates the LMP in a different stage without considering any contingency in the planning. The LMP is calculated is one stage and the expansion planning is done in another stage assuming the fixed value for the LMP calculated before.

The aim of this research is to present a one-step model of TEP in a competitive electricity market. In this method, unlike traditional methods, there is no need to calculates local margin pricing, and the program is designed in such a way that calculates both the expansion solution and local margin pricing, simultaneously. Therefore, this method is solved by TEP software without the need to use bi-level programming. This method can provide global solutions to the problem. A comparison between traditional and competitive electricity market-based methods will also be presented in this paper. The test results of this method will also be presented in Garver 6-bus and IEEE 24-bus networks.

2. Innovation and contributions

In TEP, the issue is to determine the optimal location and time of reinforcement or construction of new lines, to reduce the costs of development and operation of the network taking into account various technical and economic constraints. In traditional TEP issues, the structure of the transmission network and the optimal power flow were usually not considered much. But in new models, power flow constraints always play a vital role in the problem.

Among the innovations of this paper, the following can be stated: The single stage means the simultaneous calculation of LMPs and expansion planning in the model. The aim of this research is to present a one-step model of TEP in a competitive electricity market

3. Materials and Methods

This method is solved by TEP software without the need to use bi-level programming. This method can provide global solutions to the problem. A comparison between traditional and competitive electricity market-based methods will also be presented in this paper. The test results of this method will also be presented in Garver 6-bus and IEEE 24-bus networks. The objective function of the proposed TEP model is the average of investment, operation, and reliability cost as follows

$$c_{TEP}^{Total} = \frac{1}{N^{cntg}} \times \sum_{cntg} \left(c_{TEP}^{Investment} + c_{TEP,cntg}^{Operation} + c_{TEP,cntg}^{\mathrm{Reliability}} \right) \tag{1}$$

The TEP in competitive electricity markets also includes the cost of network congestion, which is added as the following term in the objective function:

$$c_{TEP}^{Market} = c_{TEP}^{Total} + \sum_{y\in\Omega^{year}} \sum_{lv\in\Omega^{Level}} \sum_{ij\in\Omega^{Br}} P_{ij,lv,y} \left(Lmp_{i,lv,y} - Lmp_{i,lv,y} \right) \tag{2}$$

4. Results and Discussion

The results show that with a 0.1 increase in the interest rate, the investment cost increases by about 40% (the average value with a standard deviation of 9.02 %) and in the no-contingency and contingency constrained model, respectively.

the results in the current network without any load growth. Undoubtedly, load growth makes more line congestions and LMP variations. So, it is required to consider LMP in competitive markets to provide more congestion in the system pricing. Due to the page limits the results of LMP in several load growths in both networks are not investigated.

Considering LMP can lead to more liberalization of the transmission line and bring the price of the local margin of the buses closer to each other, which will make the network more competitive. But here the is no need for further liberalization. The network is inherently competitive. The difference originated from the difference of LMP in buses of the network. When LMP formulation is added to the TEP model, the optimization minimizes the difference of LMP in the buses and set the power plants operation set-points in a way that the cost of providing a 1MW electricity will be balanced in the network.

The LMP based models are converged to the solution with the same LMP value for buses.

5. Conclusion

In this paper, a method for entering the calculations of local margin pricing in the TEP problem is proposed, which eliminates the need for separate calculations of this price. The results of the implementation of this method are compared in the Gaver 6-bus and the IEEE 24-bus network in the competitive and traditional electricity market. The results show that in a competitive market, there is a greater tendency for lines that are more severely congested and even one per-unit of power must pass through them at a higher cost than other network lines. But in the traditional market, whichever line is cheaper is a better option for TEP unless the line capacity has reached its saturation threshold. For future studies, the presentation of a stochastic model of this method is on the agenda of the authors of this article to take into account the conditions related to the consideration of uncertainty in the problem and the method is closer to the real model.

6. Acknowledgement

We also thank Dr. Mojtaba Najafi, Department of Electrical Engineering, Bushehr Branch, Islamic Azad University, Bushehr, Iran. The article was extracted of thesis prepared by hamid gorjipour to fulfill the requirements required for earning the Doctor of electrical Engineering degree.

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Appendix

Table 1. The Garver 6-bus network data

Line					Bus	MW		$/MWh
No	From	To	MW	status	No	Load	Gen	Cost
1	1	2	100	1	1	80	50	36
2	1	4	80	1	2	240	0	-
3	1	5	100	1	3	40	165	30
4	2	3	100	1	4	160	0	-
5	2	4	100	1	5	240	0	-
6	2	6	100	0	6	0	545	20
7	3	5	100	1				
8	4	6	100	0	Total	760	760	

Table 2. The IEEE 24-bus network data

Line					Bus	MW		$/MWh
No	From	To	MW	Status	No	Load	Gen	Cost
1	1	2	175	1	1	108	192	39.83
2	1	3	175	1	2	97	192	39.83
3	1	5	175	1	3	180	0	--
4	2	4	175	1	4	74	0	--
5	2	6	175	1	5	71	0	--
6	3	9	175	1	6	136	0	--
7	3	24	400	1	7	125	300	43.66
8	4	9	175	1	8	171	0	--
9	5	10	175	1	9	175	0	--
10	6	10	175	1	10	195	0	--
11	7	8	175	1	11	0	0	--
12	8	9	175	1	12	0	0	--
13	8	10	175	1	13	265	591	48.58
14	9	11	400	1	14	194	0	--
15	9	12	400	1	15	317	155; 60	12.38; 56.56
16	10	11	400	1	16	100	155	12.38
17	10	12	400	1	17	0	0	--
18	11	13	500	1	18	333	400	4.42
19	11	14	500	1	19	181	0	--
20	12	13	500	1	20	128	0	--
21	12	23	500	1	21	0	400	4.42
22	13	23	500	1	22	0	300	0
23	14	16	500	1	23	0	310; 350	12.38, 11.84
24	15	16	500	1	24	0	0	--
25	15	21	1000	1				
26	15	24	500	1				
27	16	17	500	1				
28	16	19	500	1				
29	17	18	500	1				
30	17	22	500	1	Total	2580	3405	
31	18	21	1000	1				
32	19	20	1000	1				
33	20	23	1000	1				
34	21	22	500	1				

Table 3. Several scenarios defined in this study

Scenario	Contingency	$1\,ir$	k^{gen}/k^{load}
1	No Contingency	0	1
2			1.2
3			1.5
4		0.1	1
5			1.2
6			1.5
7	One line Outage	0	1
8			1.2
9			1.5
10		0.1	1
11			1.2
12			1.5

Table 4. New installed lines for the Garver 6-bus system

Scenario	Year 1	2	3	4	5
1	1-5(1),2-6(3) 3-5(1),4-6(3)	2-3(1)	2-6 (1)	--	--
2	1-5(1),2-3(1) 2-6(3),3-5(1) 4-6(3)	--	--	2-6 (1)	--
3	1-5(1),2-3(1) 2-6(3),3-5(1) 4-6(3)	2-6(1)	--	--	--
4,5	2-3(1),2-6(3) 3-5(1),4-6(3)	2-6(1) 4-6(1)	--	--	--
6	1-5(1),2-3(1) 2-6(3),3-5(1) 4-6(3)	2-6(1) 4-6(1)			
7	1-5(1),2-3(1) 2-4(1),2-6(3) 3-5(2),4-6(3)	2-6(1)	--	--	--
8,9,10,11,12	1-5(1),2-3(2) 2-4(1),2-6(3) 3-5(2),4-6(3)	2-6(1)	--	--	--

Table 5. Comparison of several scenario results for the Garver 6-bus system

Scenario	Investment Cost (M$)	Operation Cost (M$)	Total Cost (M$)	Load shed (MW)	Time (s)
1	0.0270	499.35	499.37	0	0.90
2	0.0270	497.84	497.87	0	0.89
3	0.0270	496.33	496.35	0	0.50
4	0.0286	612.99	613.02	0	0.55
5	0.0286	610.98	611.01	0	0.52
6	0.0306	609.01	609.04	0	0.51
7	0.0350	499.35	499.38	0	162.4
8	0.0350	497.84	497.88	0	139.1
9	0.0350	496.33	496.36	0	141.9
10	0.0353	612.99	613.03	0	155.4
11	0.0353	610.98	611.01	0	136.4
12	0.0353	609.01	609.04	0	152.1

Table 6. New installed line (with number) in each scenario for the IEEE 24-bus network

Scenario	Year 1	2	3	4	5
1	1-2(1), 3-9(2)	--	8-10(1)	1-3(1), 6-10(1)	4-9(1)
2	1-2(1), 3-9(2)	--	8-10(1)	3-9(1) 6-10(1)	4-9(1)
3	1-2(1), 3-9(2)	--	3-9(1) 8-10(1)	1-3(1) 4-9(1) 6-10(1)	4-9(1), 16-19(1)
4	3-9(1)		3-9(1)		
5	1-2(1) 3-9(2)		8-10(1) 16-19(1) 21-22(1)	1-3(1)	6-10(1)
6	1-2(1) 3-9(2)	1-2(1), 1-3(1) 3-9(1) 6-10(1) 8-10(1) 16-19(1) 21-22(1)	3-24(1) 4-9(1)		

Table 7. Comparison of several scenario results for the IEEE 24-bus network

Scenario	Investment Cost (M$)	Operation Cost (M$)	Total Cost (M$)	Load shed (MW)	Time (s)
1	0.0030	674.73	674.73	0	3.81
2	0.0030	667.05	667.06	0	4.23
3	0.0035	656.98	656.98	0	3.57
4	0.0038	828.28	828.28		3.40
5	0.0040	811.05	811.05	0	3.53
6	0.0057	804.643	804.649	0	3.67

Table 8. New installed line (with number) in each scenario for the Garver 6-bus system in the competitive market

Scenario	Year 1	2	3	4	5
1	2-3(1),2-6(3) 3-5(1),4-6(3)	1-5(1) 2-6(1)			--
2	1-5(1), 2-6(3),3-5(1) 4-6(3)	2-3(1), 2-6(1)	--		--
3	1-5(1),2-3(1) 2-6(3),3-5(1) 4-6(3)	2-6(1)	--	--	--
4	1-5(1), 2-3(1),2-6(3) 3-5(1),4-6(3)	2-6(1)	--	--	--
5	2-3(1),2-6(3) 3-5(1),4-6(3)	2-6(1)			
6	1-5(1),2-3(1) 2-6(3),3-5(1) 4-6(3)	2-6(1)			

Table 9. Comparison of several scenario results for the Garver 6-bus system in the competitive market

Scenario	Investment Cost (M$)	Operation Cost (M$)	Total Cost (M$)	Load shed (MW)	Time (s)
1	0.0270	499.36	499.39	0	49.3
2	0.0270	497.84	497.87	0	50.5
3	0.0270	496.34	496.37	0	51.4
4	0.0273	612.99	613.02	0	54.18
5	0.0253	610.98	611.01	0	53.57
6	0.0273	609.01	609.04	0	54.3

Table 10. New installed line (with number) in each scenario for the IEEE 24-bus network in the competitive market

Scenario	Year 1	2 3 4 5
1	1-2(2), 1-3(1) , 3-9(3) 3-24(1) ,4-9(1) ,6-10(1), 7-8(1) 8-10(1), 14-16(1), 15-24(1) 16-17(1), 16-19(1), 21-22(1)	
2	1-3(1), 3-9(1), 3-24(1), 7-8(1), 8-10(1), 14-16(1), 15-24(1), 16-17(1)	
3	1-2(3), 3-9(3), 3-24(3), 7-8(2), 8-10(3),12-23(2), 14-16(1), 15-24(2), 16-17(2),	12-13(1) 15-24(1) 16-19(1)
4	1-3(1), 3-9(1), 3-24(1), 7-8(1), 8-10(1), 12-23(1), 14-16(1), 15-24(1), 16-17(1),	
5	1-3(1), 3-9(1), 3-24(1), 7-8(1), 8-10(1), 12-23(1), 15-24(1), 16-17(1)	6-10(1)
6	1-3(1), 3-9(1), 3-24(1), 7-8(1), 8-10(1), 12-23(1), 14-16(1), 15-24(1), 16-17(1),	

Table (11): Comparison of several scenario results for the IEEE 24-bus network in the competitive market

Scenario	Investment Cost (M$)	Operation Cost (M$)	Total Cost (M$)	Load shed (MW)	Time (s)
1	0.0127	674.99	675.00	0	2104
2	0.0096	667.31	667.32	0	2599
3	0.0035	656.98	656.98	0	2362
4	0.0121	828.33	828.34	0	2655
5	0.0111	818.09	811.10	0	2776
6	0.0121	804.684	804.70	0	767

Declaration of Competing Interest: Authors do not have conflict of interest. The content of the paper is approved by the authors.

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Author Contributions: All authors reviewed the manuscript.

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