Congestion Cost Estimation in Deregulated Transmission Network Using Optimal Power Flow Tracing

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Abstract

This paper introduces a new method to calculate the congestion pricing considering the real power losses in the transmission line network. The power flow in the lines due to overloading is obtained by optimizing the real power using the Particle Swarm Optimization (PSO) algorithm. The overloading (congestion) of lines will produce negative power flow in some transmission lines. This negative power flow due to congestion has been applied to compute the congestion pricing. In this paper, the transmission line congestion pricing is calculated using the Flow-based pricing method and the Locational Marginal Pricing (LMP) based Pricing method. The proposed methods are tested and evaluated on IEEE 14bus system and IEEE 30 bus system.

Keywords: *Congestion, Flow-based pricing, Locational Marginal Pricing (LMP), Particle Swarm Optimization (PSO).*

1. Introduction

In a competitive electricity market congestion occurs when the transmission network is unable to accommodate the entire desired load. The transmission congestion is the inevitable result of high load requirements. Therefore, we can adjust the output of the generator by using the relative algorithm to satisfy the target. The condition of the constraint is to minimize the transmission cost or to violate the power flow. As Load increases in a power system network, congestion in the transmission line increases. Thus, the cost of the transmission line network increases correspondingly. However, our final goal is to reduce the congestion cost.

Ramesh Guguloth et al explained that in the competitive electricity market congestion occurs when the transmission network is unable to accommodate all of the desired transactions [1]. Fangxing Li et al discussed the LMP calculation using DC Optimal Power Flow (DCOPF) as well as AC Optimal Power Flow (ACOPF) and the calculations are done based on R/X ratio values [2]. N S Modi & B R Parekh proposed a paper in which the market efficiency is decreased during the event of congestion. Thus, congestion results in a reduction in price and market efficiency. Congestion can be managed by reactive power rescheduling to optimize the maximum benefit [3]. Bin Liu et al defined that the transmission congestion occurs as a result of high load requirement. Also, pointed out that with the increase in the rate of congestion, transmission adjustment cost will also increase [4].

Muhammad Bachtiar Nappu and Ardiaty Arief formulated the economic re-dispatch schedule using DCOPF with constraint and unconstraint conditions [5]. Jian yang proposed a new method in which congestion cost will be calculated from the difference in power flow [6]. J.Nikoukar& M.R. Haghifam demonstrated the power flow tracing methods such as down streaming algorithm and up streaming algorithm [7].

Cornelia Kawann& Manfred Sakulin evaluated the transmission cost from the fixed cost and line losses. However, the congestion cost can be calculated from the operational cost by considering the transmission capacity constraints [8]. Chan.S.Park found the transmission congestion cost by applying the flow-based pricing method and nodal based pricing method [9]. K.L. Lo et al focused only on negative power flow for the calculation of transmission congestion cost in the transmission lines [10]. A.K. Singh & C. S. Özveren applied the conventional MW-mile method to verify the congestion cost using the generator tracing principle [11].

Anup jana prepared a congestion cost calculation method using line-wise cost and line impact cost with and without constraint [12]. P. Rama chandran& R.Senthil calculated the Locational Marginal Pricing (LMP) values at contingency condition only. LMP values are used to locate the spot of congestion while increasing the load [13]. S.Venkatesan &M.S.Ramya obtained the congestion value under contingency conditions. The Optimal Power Flow (OPF) has been formulated by including IPP (Independent Power Producer) at buses and the Locational Marginal Pricing (LMP) values are also determined [14]. Jiawei Zhao et al worked out the congestion pricing of the transmission lines with the help of Uniform Marginal Pricing and LMP [15].

Murali Matcha et al established linear programming and OPF calculations for determining the LMP values [16]. A load following-based method has been applied with correlation factors for estimating transmission costs of each participant before entering into the market [17].

This paper proposes a method to calculate the transmission congestion pricing using Flow-based and Nodal based power flow. In the flow-based method of congestion pricing, the power flow in clockwise and counter-clockwise directions has been considered. In nodal based method, the congestion pricing has been attained by using LMP values. The LMP values are computed using MATPOWER software. The proposed methods are tested on IEEE 14 and IEEE 30 bus systems and the results are compared. The paper is summarized as follows: Section 2 explains the proposed methodology with flow diagram. Problem formulation using PSO algorithm is shown in Section 3. In Section 4, Congestion pricing methods are illustrated. Section 5 is dealt with result and discussion of test systems. Section 6 concludes the proposed paper.

2. Proposed Methodology

This paper introduces a new pricing method for the calculation of transmission congestion cost. The flow diagram of the proposed work is shown in Figure 1.

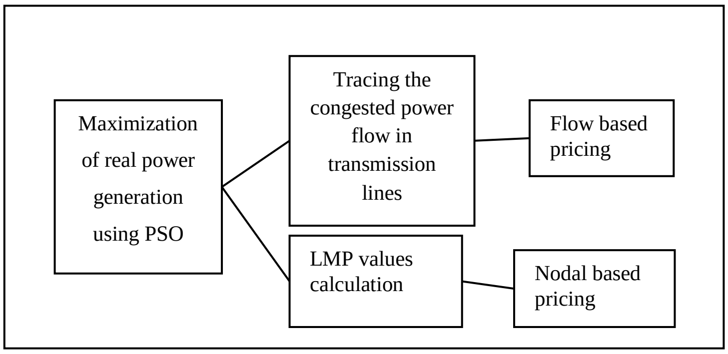

Figure1 Flow diagram of the proposed work

The congested power flow is traced by maximizing the real power generation at load buses. The power flow with optimal tracing process is done using Particle Swarm Optimization (PSO) algorithm. The real power generation is maximized by adding Non-Utility Generator (NUG) at the load buses. The power flow at overloaded condition from the transmission lines is utilized to determine the transmission congestion pricing. By applying Flow based pricing and Nodal based pricing, the congestion pricing on IEEE 14 and IEEE 30 bus systems are tested.

3. Problem Formulation

The congestion pricing is determined from the overloading of the transmission line. Thus, the overloading of the transmission line is obtained by maximizing the real power generation at load buses. The real power maximization is done using the PSO algorithm. The objective function for the real power maximization is formulated as,

$$\textit{Maximize, } P_{g,NUG} \tag{1}$$

Where,

$P_{g,NUG}$- real power generation by the addition of NUG

$_{NUG}$-Non-Utility Generator connected at load buses

The proposed objective function has to satisfy the following equality and inequality constraints,

Equality constraints,

$$(P_{gi} + P_{g,NUG}) - P_{di} - \sum_{i=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} + \delta_i - \delta_j) = 0 \tag{2}$$

$$Q_{gi} - Q_{di} - \sum_{i=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} + \delta_i - \delta_j) = 0 \tag{3}$$

Inequality Constraints

i) Real Power Limits: $P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max}$ (4)

ii) Reactive Power Limits: $Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}$ (5)

iii) Bus Voltage Limits: $V_i^{\min} \le V_i \le V_i^{\max}$ (6)

iv) Line Flow Limits: $S_{ij} \ge S_{ij}^{\max}$ (7)

Where,

$P_{g,NUG}$ - Real power generation of NUG in MW

$P_{d,k}$ - Real power demand at k^th^ bus in MW

$S_{ij}^{\max}$ - Maximum Line capacity in line i-j

$Q_{gi}^{\min}, Q_{gi}^{\max}$ - Minimum and maximum limits of reactive power at bus i

$P_{gi}^{min}, P_{gi}^{max}$ - Minimum and maximum limits of real power at bus i

V_i^{min}, V_i^{max} - Minimum and maximum limits of voltage at bus i

The equality constraints (2) satisfy the real power balance while adding real power generation using NUG at load buses. The constraints (3) represent the reactive power balance at load buses. The inequality constraints (4) and (5) show the upper and lower limits of the real and reactive power of the generator. The voltage limit constraint (6) presents the upper and lower boundary limit of bus voltage magnitude. Constraint (7) ensures that the line loading should exceed its maximum line flow limit to create congestion in transmission lines [18-19].

3.1 Implementation of PSO algorithm

The step by step procedure for maximizing real power generation using PSO is given as follows,

1. Run the OPF for the base case.
2. Set the bus counter as i=1, 2…n
3. Select the real power generation as the initial population.
4. Choose the population size and the number of iterations.
5. Real power generation on Non-Utility Generator (**NUG)** is taken as the control variable
6. Check the bus as a load bus or a generator bus. Add **NUG** to the load bus
7. Increment the bus count i=i+1; Repeat from step: 2
8. Increment the generation on **NUG** without violating equality and inequality constraints; then go to step: 9; otherwise go to step: 12
9. Initial searching points and velocities are randomly selected.
10. Pbest is set to each initial searching point. The best-evaluated value among Pbest is set to Gbest.
11. New position and velocities are calculated using equations

$$x^i_{k+1} = x^i_k + v^i_{k+1} \tag{8}$$

$$v^i_{k+1} = w_k v^i_k + c_1 r_1 (p^i_k - x^i_k) + c_2 r_2 (p^g_k - x^i_k) \tag{9}$$

Where,

V^i_{k+1} - Particle's new velocity

V^i_k - Particle's previous velocity

P^i_k - Past best position of particle *i*at time *k*

P^g_k -Past global best position in a swarm at time *k*

X^i_k- Particle *i*'s position at time *k*

X^i_{k+1} - Particles new position

W_k - Inertia weight

c_1, c_2-acceleration constant

r_1, r_2-uniform random numbers between 0 and 1

12. From the objective function, fitness value is evaluated.
13. Optimal generation is reached, stop.

4. Congestion Pricing Calculation

The congestion pricing in transmission lines is calculated using the Flow-based method and Nodal based method. The congestion pricing with Flow-based power flow is written as,

$$\boldsymbol{congestionpricing}_{\boldsymbol{flow-based}} = \left(\boldsymbol{P}^{\boldsymbol{c}}_{\boldsymbol{i-j}}\right) * \boldsymbol{B}_{\boldsymbol{k}} \quad (10)$$

Where,

$\left(P^{c}_{i-j}\right)$ – Power flow at congested case between the buses i and j

B_k- Bid rate at k^{th} bus; where k=1,2…n

In the flow-based method, two power flow values are needed to rate the congestion cost. The two power flows are obtained in transmission lines with and without congestion conditions. The congestion pricing with LMP-based power flow is written as,

$$\boldsymbol{congestionpricing}_{\boldsymbol{LMP-based}} = \left(\boldsymbol{P}^{\boldsymbol{c}}_{\boldsymbol{i-j}}\right) * (\boldsymbol{B}_{\boldsymbol{i}} - \boldsymbol{B}_{\boldsymbol{j}}) \quad (11)$$

Where,

$\left(P^{c}_{i-j}\right)$ – Power flow at congested case between the buses i and j

B_i - Bid rate at i^{th} bus; where, i=1,2…n

B_j - Bid rate at j^{th} bus; where, j=1,2…n ;i ≠j

In Nodal based pricing, the congested power flow in transmission lines is extracted from LMP values. The LMP values of buses are calculated by running the OPF using MATPOWER software. Then, congestion pricing is obtained by multiplying the power flow in the transmission line with the calculated LMP value.

5. Results and Discussions

The congestion pricing calculation is mainly dependent on the congested power flow in the transmission lines. Thus the congested power flow is obtained by maximizing the real power only at load buses. The maximization is done using the PSO algorithm. The simulation studies are carried over using MATLAB 7.11. Due to an increase in real power generation at load buses, power flow in the transmission line exceeds the power flow limit. Hence, it will produce congestion in transmission lines. The power flow during congestion is observed at each transaction. i.e real power flow from a particular generator bus to a particular load bus. The congestion will give negative power flow in some transmission lines. Here, two cases are considered for calculation. Firstly, the clockwise-CW*(positive) direction of power flow is applied, and secondly, the counter-clockwise-CCW * (negative) direction of power flow is applied.

5.1 IEEE-14 bus system

IEEE 14 bus system has 5 generator buses, 9 load buses, and 19 transmission lines. The power flow at the base case is obtained by running the Newton-Raphson load flow. The congestion in the lines is obtained by maximizing the real power generation using NUG values only at load buses. Therefore, the test system with 5 generator bus is modified with 6 generator bus and 8 load bus. In this restructured power system network, the load buses of the test system are modified as generator buses by inserting a NUG. The value of NUG is incremented in a step by step manner to increase the transmission line power flow limit. When the power flow in the line exceeds its specified value, the line is said to be in congestion. This congested power flow is relinquished to calculate the congestion pricing in the deregulated transmission line network. The transmission congestion pricing for IEEE 14 bus system using Flow-based and LMP based methods are given in Table 1**.**

Table 1. Transmission Congestion Pricing – IEEE 14 Bus System

Bus No.	Power flow (MW) at base case	Power flow (MW) at the congested case	Congestion Pricing Flow-based ($)			Congestion Pricing Nodal-based ($)		
			bid rate ($/MW)	Power flow (CW*)	Power flow (CCW*)	bid rate ($/MW) (LMP Based)	Power flow (CW*)	Power flow (CCW*)
4	344.35	133.4	30	4002		-2.123		-283.208
5	300.21	44.14	100	4414		-2.478		-109.378
7	423.62	-123.41	65		-8021.65	-2.534	312.720	
9	111.89	311.73	65	20262.4	20262.45	-2.286		-712.614
10	112.97	-1.08	30		-32.4	-2.292	2.475	
11	201.01	-88.04	30		-2641.2	-2.292	201.787	
12	366.63	-165.62	100		-16562	-2.292	379.601	
13	292.05	74.58	30	2237.4		-2.292		-170.937
14	239.37	52.68	65	3424.2		-2.292		-120.742
Total Congestion Pricing ($)				**34340**	**-6994.8**		**896.585**	**-1396.88**

From Table 1, the power flow at the base case is obtained by maximizing the real power generation. The Congestion pricing $_{\text{flow-based}}$ is calculated from congested power flow and bid rate value. The congestion pricing with the flow-based method gives a positive sign in the pricing calculation. The negative sign in the power flow indicates that the load is consuming more power through the transmission lines. Therefore, the negative sign indicates a penalty to the buyer bus (Load side) and an incentive to the seller bus (Generator side).The congestion pricing in IEEE 14 bus system gives a negative value of cost in both the power flows. The congestion cost due to nodal based approach is comparatively lesser than the congestion cost due to the Flow-based approach.

5.2 IEEE 30 BUS SYSTEM

The test system has 6 generator buses, 24 load buses, and 41 transmission lines. The congested power flow is achieved by maximizing the real power generation at load buses. The maximization is done using the PSO method. The test system is modified with 7 generator buses and 23 load buses for getting congested power flow in the transmission lines. The buses produce negative power flow due to overloading in the transmission lines. The buses are identified as bus number 6, 8,10,12,14,15,16,19 and 20.

In the nodal based method, LMP values with congested power flow are employed to determine the congestion pricing. Then, the Congestion pricing $_{\text{nodal-based}}$ is estimated from congested power flow and the LMP values. The power flow at congested cases produces negative power flow at buses 7, 10, 11, and 12. The LMP based method of pricing produces a negative indication of cost in all the transmission lines. The transmission congestion pricing for IEEE 30 bus system using Flow-based and LMP based methods are given in Table 2.

Table 2. Transmission Congestion Pricing – IEEE30 Bus System

Bus No.	Power flow (MW) at base case	Power flow (MW) at congested case	Congestion Pricing Flow-based ($)			Congestion Pricing Nodal-based ($)		
			bid rate ($/MW)	Power flow (CW*)	Power flow (CCW*)	LMP Value ($/MW hr)	Power flow (CW*)	Power flow (CCW*)
3	730.782	227.12	30	6813.6		-22.78		-5173.79
4	719.962	116.79	65	7591.35		6.439	752.010	
5	547.35	102.68	100	10268		5.93	608.892	
6	629.353	-22.92	30		-687.6	16452		-377079.84
8	768.974	-108.46	100		-10846	-10.84	1175.706	
9	730.117	391.05	65	25418.3		-14314		-5597489.7
10	823.262	-86.19	70		-6033.3	-460.6	39699.11	
11	801.125	30.74	30	922.2		4.578	140.72	
12	874.144	-24.33	100		-2433	3.687		-89.70471
14	795.455	-69.4	100		-6940	14.72		-1021.568
15	847.494	-21.25	65		-1381.25	18.788		-399.245
16	853.651	-13.44	30		-403.2	159.87		-2148.68
17	748.005	35.8	65	2327		9.736	348.54	
18	795.243	60.94	65	3961.1		-17.82		-1085.95
19	844.497	-7.91	30		-237.3	24.702		-195.39
20	831.572	-19.76	100		-1976	-24.61	486.29	
21	805.184	122.04	30	3661.2		-120.3		-14681.41
24	831.687	122.61	30	3678.3		-0.898		-110.103
25	826.608	66.18	65	4301.7		8.94	591.6492	
26	832.796	44.64	65	2901.6		8.963	400.1083	
28	805.372	345.37	100	34537		6.578	2271.843	
29	805.472	82.6	65	5369		8.156	673.685	
30	817.019	18.01	30	540.3		6.861	123.566	
Total congestion pricing ($)				**112290.65**	**-30937.65**		**47272.14**	**-5999475.39**

From Table 2, it is shown that the congestion pricing from clockwise power flow using Flow-based and LMP based congestion pricing for the IEEE 30 bus system evokes 11220.65$ and 47272.147 $respectively. Similarly, counter-power flow gives the congestion cost of -30937.65$ and-5999475.39$. Thus, the Nodal pricing method yields less cost as compared with the Flow-based pricing method.

6. CONCLUSION

In this paper congestion pricing calculation in deregulated transmission power market using flow-based and LMP based methods are proposed. The pricing calculations are done from optimized power flow. The congested power flow is obtained by optimizing real power using PSO. Then the optimized power flow is divided into clockwise and counter-clockwise power flow. The pricing for both the power flows is computed using Flow-based and LMP based pricing methods. While increasing the order of the system, the Flow-based method produces more cost than LMP based method. Otherwise, Nodal based method provides less cost than the Flow-based method. In this paper, real power values in the transmission line are considered. The congestion can be relieved by decrementing the NUG value. The main purpose of the paper is to make use of connected generators with utmost utilization. Therefore, no additional generators are included in the generator bus. But, the real power generation is added with load buses only, and that of the standard system is modified.

References

[1]RameshGuguloth, T. K. Sunil Kumar, "LMP Calculation and OPF Based Congestion Management in Deregulated Power Systems" 2016 IEEE IEEE ELEKTRO, 16-18 May 2016, Strbske Pleso, Slovakia.

[2]Fangxing Li, Rui Bo, Wenjuan Zhang, "Comparison of Different LMP Calculations in Power Market Simulation" Proceedings of 2006 International Conference on Power System Technology, Chongqing, China, 2006 pp.1-6.

[3]N S Modi, B R Parekh, "Transmission Network Congestion in Deregulated Wholesale Electricity Market" Proceedings of the International Multi Conference of Engineers and Computer Scientists, March 18 - 20, 2009, Hong Kong.

[4]Bin Liu, Nan Jiang, Yan Zheng and Yuanwei Jing, "Simulation of Cost Optimal Control of the Transmission Congestion Management in Electricity Systems" IEEE Chinese Control and Decision Conference, 23-25 May 2011, Mianyang, China.

[5]Muhammad Bachtiar Nappu and Ardiaty Arief, "Economic Re dispatch Considering Transmission Congestion for Optimal Energy Price in a Deregulated Power System" The 5th International Conference on Electrical Engineering and Informatics 2015 August 10-11, 2015, Bali, Indonesia, pp.573-578.

[6]Jian yang, "Tracing the flow of power in transmission network for use-of transmission system charges and congestion management" IEEE Power Engineering Society Winter Meeting, vol. 1, 1998, pp. 399-405.

[7]J.Nikoukar , M.R. Haghifam, "Transmission cost allocation based on the use of system and considering the congestion cost" Electrical Power and Energy Systems 43, 2012, pp. 961–968.

[8] Cornelia Kawann and Manfred Sakulin, "Congestion Pricing: Is a Load Flow-Based Pricing Approach Appropriate ?" Elsevier Science Inc., 1040-6190, 2000, pp.21-30.

[9]Chan.s.Park, Jorge valenzulea, Markhalpin, sevin Sozer and Pinar kaymaz, " Pricing transmission congestion in electric power networks". Electricity Transmission in Deregulated Markets: Challenges, Opportunities, and Necessary R&D Agenda, 2004, December 15-16.

[10]K.L.Lo, M.Y. Hassan and S. Jovanovic, "Assessment of MW-mile method for pricing transmission services: a negative flow-sharing approach" IET Gener. Transm. Distrib., 2007, 1, (6), pp. 904–911.

[11]A.K. Singh, C. S. Özveren, "Congestion Pricing In A Deregulated Market Using A.C. Power Transfer Distribution Factors" 50th International Universities Power Engineering Conference (UPEC) 1-4 Sept. 2015 Stoke on Trent, UK, United Kingdom.

[12]Anupjana, "A new approach to Transmission congestion cost calculation" Power System Technology and IEEE Power India Conference,2008, pp. 1-4.

[13]P.Ramachandran and R. Senthil, "Locational marginal pricing approach to minimize congestion in restructured power market" 2010, pp.143-153.

[14]Dr.S.Venkatesan, M.S.Ramya, "Optimal Placement of IPP Based On LMP in Competitive Power Market" International Conference on Circuit, Power and Computing Technologies, 2016, pp.1-8.

[15]Jiawei Zhao, Jianfeng Lu, Kwok Lun Lo, "Review of Methods to Calculate Congestion Cost Allocation in Deregulated Electricity Market" World Journal of Engineering and Technology, 2016, vol.4, pp.16-26.

[16]H.S. Jung, D. Hur and J.K. Park, "Congestion cost allocation method in a pool model" IEE Proc.-Gener. Transm. Distrib., Vol. 150, No. 5, September 2003, pp.604-610.

[17]Murali Matcha, Sailaja kumarimatam, SyduluMaheswarapu, " LMP calculation with distributed loss using GA based DCOPF" Journal of Electrical systems,2012,pp.292-303.

[18]Abido, MA, "Optimal power flow using particle swarm optimization", Electrical Power and Energy Systems, vol. 24, 2002, pp. 563-571.

[19]Ahmed, AA, Esmind & Germano Lambert-Torres, "Application of particle swarm optimization to optimal power systems", International Journal of Innovative Computing, Information and Control, vol. 8, no. 3(A), 2012, pp. 1705-1716.