ISBN: 978-1-948012-16-4

Contemporary Issues in Computing (CIC)

DOI: <http://doi.org/10.26480/cic.01.2020.99.102>

ALLOCATING THE VARIABLE COST OF TRANSMISSION LINES DUE TO ELASTIC LOADS IN A CONGESTED POWER MARKET

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ARTICLE DETAILS

Article History:

Received 26 October 2020

Accepted 27 November 2020

Available online 03 December 2020

ABSTRACT

In a competitive power market, the elastic demand for electrical energy transmission is viewed as a prime competitor of generator. Remote generators are needed for transmission to compete with local generators. The value of the transmission is based on the difference of Locational Marginal Price (LMP) of the generators across the network. To maintain the well operation of power market, LMPs which provide the price sensitivity is calculated at every bus. The revenue collected by the transmission owners is a convex quadratic function of the amount of power transmitted. This revenue provides a sound impact on investment perspective for setting the price that producers and customers should pay for the network. In this paper for a three bus system, the LMPs are calculated at the buses and a demand function for the transmission has been modeled which computes the maximum revenue for the optimal transmission capacity in the system.

KEYWORDS

Elastic load, LMP, Power flow, Quadratic Revenue curve.

1. INTRODUCTION

With the advent of electricity as a business commodity, generation along with transmission was coupled in a regulated power market. But after deregulation in power market for the first time the generation part was separated from transmission part (Daniel et al., 2004). In this deregulated power market the pricing of transmission is most important for a highly efficient system. Since investments in new transmission equipment are costly and should therefore be handled in such a way that they should maintain the path of least-cost for long-term development. An economic coordination between generation and transmission is highly acceptable to obtain maximum welfare for the society which can be only be obtained by efficient pricing methodologies. The primary consideration of any transportation business is to buy a product at low price from one zone and sell it at higher price in other zone and power transmission is also same. This business is only profitable if the price difference between two zones is large.

With the growth of transmission network, congestion in power market takes place (Ziad: Tomas and Chris, 1999; Christie et al., 2000). Since our modern power network is filled up with elastic loads the toughest work for the system operator is to manage the congestion and provide the best quality of power in the most suitable way and to maintain a profit margin for both the power suppliers and the society be benefitted with the economic welfare (Paul et al., 2017; Paul et al., 2017; Paul et al., 2018; Paul et al., 2017). To minimize the congestion and to maintain the most efficient operation of power market, different factors are needed to take care, among which Location Marginal Price (LMP) is the most prominent pricing

signal [9-10] which provides the continuous sensitivity of nodal prices at every bus in a congested system for the power traders. In a congested system LMP is calculated by using of Linear Programming techniques while applying the Shift Factor (SF) based DC-Optimal power flow (DC-OPF) model.

For the transmission of power in the grid the Locational Marginal Pricing is utilized as the proficient and profitable market signals. Limiting the capacity of generation along with the upper transmission capacity of the transmission lines the supply of low pricing energy to serve the load demands are prevented which ultimately leads to the congestion (Hary et al., 1998; Lo and Yuen, 2000; Andrew, 2003; Christie et al., 2000; Momoh, 2000). The generation price for energy, price for congestion in line along with other auxiliary losses sums up to provide the LMP. The cost for transmission of electricity from high cost generators at a bus or node provides the congestion cost (Chao and Peek, 1996; Hsu, 1997; Xingwang et al., 2002; Xingwang et al., 2003). An understandable and exact signal for the price of electricity is provided by LMP.

In this article a three bus system is considered whose LMPs are calculated for a congested system and pricing demand functions are computed to obtain the maximum revenue for optimal transmission for a convex quadratic cost function. The calculated SRMC (Short Run Marginal Cost) of this congested three bus system having elastic loads are obtained. The variation of revenue earned for different transmission lines are computed which provides the entire economic characteristics of the system. The optimizations done for this three bus system can also be used in a large bus system.

Quick Response Code	This paper was presented at	Access this article online	
	International Conference on Contemporary Issues in Computing (ICIC-2020) - Virtual IETE Sector V, Salt Lake, Kolkata From 25th-26th July 2020	Website: www.intelcomp-design.com	DOI: 10.26480/cic.01.2020.99.102

2. TERMINOLOGIES

2.1 Shift Factor (SF)

A matrix whose each 'ij' element represents the incremental flow of power in the link 'ij' due to the injection of 1MW power through the node 'i' and taken out at the reference node is defined by Shift Factor. For an example a flow in the line 1 to 2 leads to injection of 1 MW power at node 1 and taken out it at node 2 is given by; $SF_{(1-2),I} - SF_{(1-2),II}$

2.2 Location Marginal Price (LMP)

Different LMP for each bus are created in the transmission line due to congestion. In normal scenario due to absence of the congestion, LMP at each bus are alike. For quick performances, DCOPF is used for calculating the LMPs. Only shortcoming is that in DC-OPF, system losses are not taken into consideration.

2.3 Mathematical Formulation

Figure 1: An illustration of a 3 bus system to understand the cost of transmission

In a power network if a unit megawatt of power is injected via node 1 where a marginal generator is located; and taken out at node 2 where LMP is to be calculated, there is an alteration in the flow of line connecting between the nodes i.e. 1 and 2.

$$\Delta Flow_{(I-II)1} = PTDF_{(I-II)1} - PTDF_{(I-II)2} \quad (1)$$

$$\begin{bmatrix} \Delta Flow_{(I-II)1} & \Delta Flow_{(I-II)1} \\ 1 & 1 \end{bmatrix} * \begin{bmatrix} \Delta P_1 \\ \Delta P_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \quad (2)$$

The direction of flow of power, in between the nodes '1' and '2' of a congested power line. The priority is to get the outputs of the marginal generators at nodes 1 and 2 by incremental amounts ΔP_A and ΔP_B so as to increase the flow in the congested line between the nodes by a unit of MW, while maintaining the balance of energy in the system. This quantity must suit the equation:

$$\begin{bmatrix} \Delta Flow_{(I-II)1} & \Delta Flow_{(I-II)1} \\ 1 & 1 \end{bmatrix} * \begin{bmatrix} \Delta P_1 \\ \Delta P_2 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad (3)$$

The Locational Marginal Price and Shadow Price for node pair 1 and 2 can be related by the formula stated as:

$$LMP_2 - LMP_1 = \sum_{\text{congested lines}} SP_{\text{congested lines}} * (\Delta Flow_{(I-II)1}) \quad (4)$$

The revenue function for transmission of power F from zone 1 to zone 2 is given as

$$\pi_t(F) = \pi_1(F) - \pi_2(F) \quad (5)$$

Where $\pi_t(F) = \pi_1$ is the value of transmission and $\pi_1(F), \pi_2(F)$ is the price of electrical energy in zone 1 and zone 2 respectively.

3. CASE STUDIES

Table 1: Generating unit information

Generators	Power Generation Capacity (MW)
A	500
B	2000
C	1000
D	2000

Table 2: Elastic load are taken as

Time Period	T ₁	T ₂	T ₃
LOAD D ₁	100	200	300
LOAD D ₂	900	1000	1500
LOAD D ₃	3000	2800	2500

Supply revenue function for power from bus 1 to bus 2:

$$\begin{aligned} \pi L_1(F1) &= LMP_2 * (D_2 - F1) - LMP_1 * (F1 + D_1) \\ &= LMP_2 * D_2 - LMP_2 * F1 - LMP_1 * F1 - LMP_1 * D_1 \\ &= LMP_2 * D_2 - LMP_1 * D_1 - (LMP_2 + LMP_1) * F1 \\ &= (LMP_2 * D_2 - LMP_1 * D_1) - (LMP_2 + LMP_1) * F1 \end{aligned}$$

Supply revenue function for power from bus 1 to bus 3:

$$\begin{aligned} \pi L_2(F2) &= LMP_3 * (D_3 - F2) - LMP_1 * (F2 + D_1) \\ &= (LMP_3 * D_3 - LMP_1 * D_1) - (LMP_3 + LMP_1) * F2 \end{aligned}$$

Supply revenue function for power from bus 2 to bus 3:

$$\begin{aligned} \pi L_3(F3) &= LMP_2 * (D_2 + F3) - LMP_3 * (D_3 - F3) \\ &= (LMP_2 * D_2 - LMP_3 * D_3) + (LMP_2 + LMP_3) * F3 \end{aligned}$$

Where the F1, F2, F3 are the flow of power through bus 1-2, 1-3 and 2-3 while D₁, D₂ and D₃ are the load demand at bus 1, bus2 and bus 3.

4. RESULT AND DISCUSSION

Table 3: Calculated LMPs for different buses

LMPs	BUS 1	BUS 2	BUS 3
Rs/MWhr	7.50	11.25	10

Table 4: Revenue earned for different value of load D1 & D2

Sl. No.	Time	D ₁ (MW)	D ₂ (MW)	Power transmitted (MW)	Maximum Revenue earned (Rs/hr)
1	T ₁	100	2000	580	6.308×10^6
2	T ₂	200	1500	414	3.152×10^6
3	T ₃	300	1000	245	1.080×10^6
4	T ₄	400	900	190	0.677×10^6

Figure 2: Revenue earned for different value of load D1 & D2

During the case of power transmission in line L_1 the revenue at highest point will be earned for 6308000Rs/hr at time period of T_1 when demand at D_1 is 100 while Demand at D_2 is 2000. In other time period cases i.e. at T_2 , T_3 and T_4 revenue earned are limited with increase of load across D_1 but decrease of load across D_2 .

Table 5: Revenue earned for different value of load D1 & D3

Sl. No.	Time	D_1 (MW)	D_3 (MW)	Power transmitted (MW)	Maximum Revenue earned (Rs/hr)
1	T_1	100	3000	856	12.22×10^6
2	T_2	200	2800	777	10.03×10^6
3	T_3	300	2500	653	7.394×10^6
4	T_4	400	2200	548	5.157×10^6

During the scenario of power transmission in line L_2 for flow F_2 maximum revenue will be earned for 12220000Rs/hr at time period of T_1 when demand at D_1 is 100 while demand at D_3 is 3000. In other time period cases i.e. at T_2 , T_3 and T_4 revenue earned are limited with increase of load across D_1 but decrease in D_3 .

Figure 3: Revenue earned for different value of load D1 & D3

Table 6: Revenue earned for different value of load D2 & D3

Sl. No.	Time	D_3 (MW)	D_2 (MW)	Power transmitted (MW)	Maximum Revenue earned (Rs/hr)
1	T_1	3000	2000	1000	13.75×10^6
2	T_2	2800	1500	1300	21.45×10^6
3	T_3	2500	1000	1500	27.19×10^6
4	T_4	2200	900	1300	20.48×10^6

Figure 3: Revenue earned for different value of load D2 & D3

In the third case for flow F_3 i.e. between D_3 and D_2 the revenue curves are obtained to be concave in nature which states that if the amount of power transmitted passes a certain limit of MW profit will generate up to infinity; but we know that every line do have a certain carrying capacity thus maximum profit will be earned when this line will be operated at maximum load. Depending upon this the maximum revenue generated is at 27.19×10^6 for transmission of 1500MW of power in between bus 2 and bus 3. But for line L_3 it is always expected to run at maximum load ability to generate maximum revenue.

5. CONCLUSION

The overall conclusive understanding that can be obtained from this paper is that congestion in power system creates congestion cost thus conferring different LMPs at different busses along with other line costs. These pricing signals in this present scenario are calculated for four generator price bids at various responsive elastic demands. Depending upon these LMPs a transmission revenue curve can be drawn for the transmission owners. From the transmission owners perspective the transmission price drops to zero when the power flow reaches a certain value i.e. the prices of two locations becomes zero. From the graphical view point it can be concluded that after the maximum demand for transmission the prices decrease. The revenue of the transmission owner becomes maximum for the certain power flow in various lines i.e. for transmission in Line L_1 maximum revenue generated at $\text{Rs}6.308 \times 10^6$ for transmission of 580MW while for Line L_2 maximum revenue generated for transmission of 856MW is obtained as $\text{Rs}12.22 \times 10^6$ but for L_3 outputs being concave in nature maximum revenue will be generated at infinity but since the maximum unit that can be transmitted is restricted by its load ability thus in this case, maximum revenue generated at $\text{Rs}27.19 \times 10^6$ for transmission of 1500MW. But for line L_3 it is always expected to deliver at maximum load ability to generate maximum revenue.

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