Indonesian Journal of Electrical Engineering and Computer Science
Vol. 15, No. 1, July 2019, pp. 1~8
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v15.i1.pp1-8

An investigation on apportion of mathematical loss in transmission loss/cost allocation approach

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Article Info

Article history:

Received Nov 15, 2018
Revised Jan 21, 2019
Accepted Feb 28, 2019

Keywords:

Bilateral contact
Electricity market
Mathematical loss
Slack bus selection
Transmission loss

ABSTRACT

Cost allocation of highly non-linear transmission loss is complex and essential in competitive electricity market. In most of the existing transmission loss/cost allocation approaches, real power loss depends on selection of slack bus and hence the cost of transmission losses which are allocated to the generators and the loads also varies. In this paper, a complete analysis on the impact of slack bus selection on transmission loss allocation with and without mathematical loss is made. One of the existing approaches, proportional generation and proportional load (PGPL) method is taken to illustrate the impact. Mathematical loss is the loss without generation and load in the network and can be obtained from power flow solution by taking generation and load as zero. The cost incurred for this mathematical loss is allocated to the transmission lines while the cost of transmission loss due to bilateral contracts is allocated among the sources and the consumers. These loss/cost allocations with and without considering mathematical loss is shown using an IEEE 30 bus, 57 bus, 75 bus and 118 bus systems. The simulation results are obtained using MATLAB R2014a.

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1. INTRODUCTION

Competition is introduced in the electricity market mainly to reduce the price of electricity. It is the responsibility of the Independent System Operator (ISO) to fairly allocate the cost of transmission real power loss among the involved parties. Competitive electricity market can be of bilateral market, pool market or hybrid market. Most of the loss/cost allocation approaches are presented in the literature and it can be broadly classified into the following categories like proportional sharing (PS) methods, methods based on incremental loss coefficients and based on network equations in terms of current & power injections.

Proportional sharing methods uses converged load flow solution with linear proportional sharing procedure to allocate losses to the sources and the consumers. These procedures cannot be proved or disproved [1-4]. Marginal procedures assign losses to the sources and the consumers based on incremental transmission loss (ITL) coefficients. It is dependent on slack bus selection and results in over recovery of loss cost [5]. A priority list is prepared based on penalised quoted cost (PQC) for the sources to supply total system losses sequentially without considering reactive loads. This method uses ITL coefficients to compute penalty factor [6]. A modified PQC approach considering the reactive power demand of the loads is presented in [7]. Methods based on power or current injection is presented in [8-10]. Power injections are derived in terms of real and imaginary currents which are traced to find the contribution of each source to load [11]. Bailek's tracing method provides the details of contribution of each sources or load in power flowing through a particular line [12].

Transmission loss allocation based on relative electrical distance (RED) is presented in [13] which determine the location of loads to the generators. Graph theory approach for loss allocation in open access and bilateral market is discussed in [14-16]. It calculates the contribution of source and load to the line flows. A comparative study on graph theory method with PS method, Zbus method and modified Zbus method is presented in [17]. An analysis on different loss allocation methods like pro-rata, marginal loss, proportional sharing, Zbus, modified Zbus, RED, PGPL methods are widely discussed in [18-20].

Loss allocation procedure with impact of circulating currents among the generators and mutual inductance between transmission lines is presented in [21] and [22] respectively. Abhyankar et. al. [23] presented a new loss allocation method based on point of connection where charges are decentralised. Kyung-Il Min et. al. [24] developed a new algorithm where losses are allocated accurately to the respective buses based on path-integrals. This path results in increased accuracy considering the non-linearity of the system losses. A new tracing method combining hybrid artificial bee colony (ABC) algorithm and Support Vector Machine (SVM) to trace the active and reactive power is presented in [25].

A new methodology in [26] to dispatch reactive power and energy simuatneously in a multiobjective framework. It considers four objectves like maximization of social welfare, maximization of load served, minimization of loss and volatge stability enhancement index. Francesco Arci1 et al. presented a forecating methodolgy using artificial neural networks for Irish electricity market. Results shows that artificial neural network based load forecating is more accurate than other methods [27]. Adline K. Bikeri et al. presented a study on effect of generating companies' market power on unit committment decision. This paper combines the bidding strategy and unit committment problem using particle swarm optimization [28].

The proposed approach is applicable for normal operation of the power system. During congestion, the proposed approach is not fair and a separate procedure has to be followed like generation rescheduling to alleviate or reduce congestion in the grid. Moreover, congestion occurs for a shorter period of time when compared with normal operation. Therefore, the scope of the paper is restricted to normal operation of the grid.

In all the above discussed papers, the loss allocation problems are addressed without considering the mathematical loss. Literally, transmission real power losses are allocated to the sources and loads. Ideally, system loss exists only when generators and loads exist. But the transmission system shows system loss even without generation and load which is referred as mathematical loss and the respective cost should be allocated to the transmission sector. This mathematical loss is dependent on choice of slack bus. The impact of slack bus selection on transmission loss allocation (with and without mathematical loss) is illustrated using proportional generation and proportional load (PGPL) method. This fact can be applied to any of the loss/cost allocation approach. By this method, the associated cost of the transmission loss is allocated to the generators, loads and transmission sector.

2. PROPORTIONAL GENERATION AND PROPORTIONAL LOAD METHOD

In PGPL method, cost is allocated to the respective buses based on generator and demand loss factors. Generator loss factor and demand loss factor is proportional to its active power generation and load respectively [29]. In this method, reactive loads are neglected. In transmission loss/cost allocation process 'N' buses are involved with 'NG' generator buses, 'ND' load buses and 'n' dummy buses. The total active power loss (Ploss) is obtained from the solved power flow solution which is computed from the loss given in (1).

$$P_{loss} = \sum_{i=1}^{N_G} \sum_{j=1}^{N_G} P_{Gi} B_{ij} P_{Gj} + \sum_{i=1}^{N_G} B_{i0}\, P_{Gi} + B_{00} \tag{1}$$

where, PGi - real power generation at bus 'i',

a. Bij, Bi0& B00 - AC loss coefficients

b. The AC loss coefficients are computed from the results obtained from the load flow solution. Total cost for meeting the loss is calculated using incremental cost of loss using (2).

$$TC_{loss} = P_{loss} * \lambda \tag{2}$$

where, λ - incremental cost of loss in $/MWhr,

The total cost of real power loss is allocated to the respective buses based on loss factors. The generator loss factor of generator 'i' is given in (3).

$$LF_{Gi} = 0.5 \left(\frac{P_{Gi}}{\sum_{i=1}^{N_G} P_{Gi}} \right) \tag{3}$$

c. The demand loss factor of load 'j' is shown in (4).

$$\mathrm{LF}_{\mathrm{Dj}} = 0.5\left(\frac{\mathrm{P}_{\mathrm{Dj}}}{\sum_{\mathrm{j=1}}^{\mathrm{N_D}} \mathrm{P}_{\mathrm{Dj}}}\right) \tag{4}$$

where, PDj - Real power load at bus'j'.

d. Cost allocation for 'NG' generators and 'ND' loads are given in (5) and (6) respectively.

$$\mathrm{GC}_{\mathrm{i}} = \mathrm{LF}_{\mathrm{Gi}} * \mathrm{TC}_{\mathrm{loss}} \tag{5}$$

$$\mathrm{LC}_{\mathrm{j}} = \mathrm{LF}_{\mathrm{Dj}} * \mathrm{TC}_{\mathrm{loss}} \tag{6}$$

In some cases, bus 'k' will have generation and load. In such case bus 'k' is considered as generator bus if generation is greater than demand or as load bus if it is vice-versa. Therefore, the real power generation and load of bus 'k' is given in (7) and (8) respectively.

$$\mathrm{P}_{\mathrm{Gk}} = \mathrm{P}_{\mathrm{Gk}} - \mathrm{P}_{\mathrm{Dk}} \text{ if } \mathrm{P}_{\mathrm{Gk}} > \mathrm{P}_{\mathrm{Dk}} \tag{7}$$

$$\mathrm{P}_{\mathrm{Dk}} = \mathrm{P}_{\mathrm{Dk}} - \mathrm{P}_{\mathrm{Gk}} \text{ if } \mathrm{P}_{\mathrm{Dk}} > \mathrm{P}_{\mathrm{Gk}} \tag{8}$$

If real power generation and load at bus 'k' are equal then the bus is treated as dummy bus without generation and load. PGPL method with the impact of reactive loads in active power loss allocation is addressed in [30].

3. RESULTS AND DISCUSSION

The impact of slack bus and mathematical loss on transmission loss allocation is demonstrated using an IEEE 30 bus system. It consists of 6 sources, 18 consumers and 6 dummy buses. The incremental or marginal cost of loss is assumed as 200 $/hr. The transaction data for IEEE 30 bus system is given in Table 1. The cost allocation to the sources and demands considering with and without mathematical loss is given in Table 3 and Table 2 respectively for different slack bus selection. The reactive power demand of the loads are neglected in real power loss/cost allocation. All node voltages are 1.0 p.u.

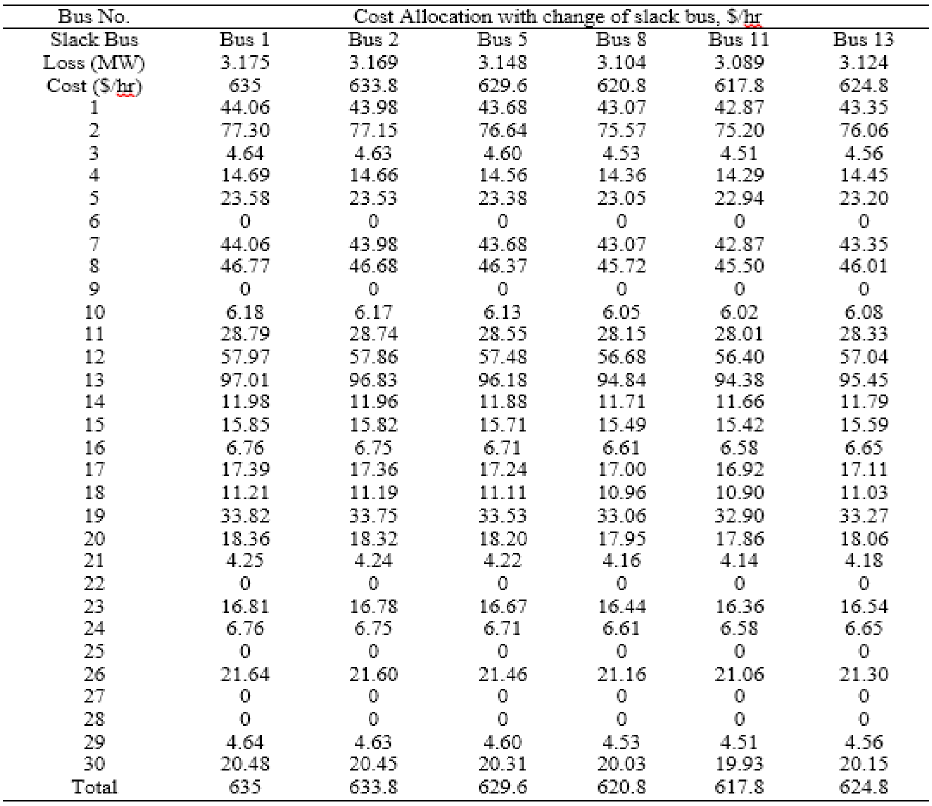
Table 1. Transaction Data for IEEE 30 Bus System

Generator bus No.	Load bus No.	Real Power Transaction (MW)
1	7	22.8
2	3,4,12	2.4, 7.6, 30.0
5	23,24	8.7,3.5
8	26,29,30	11.2,2.4,10.6
11	10,20,21	3.2, 9.5, 2.2
13	14,15,16,17,18,19	6.2,8.2,3.5,9.0,5.8,17.5

The mathematical loss for this system is 0.0354 MW with bus 1 as slack bus which is 1.15% of total loss. This loss and its associated cost (0.0354 MW * 200 $/MWhr = 7.08 $/hr) have to be borne by the transmission sector. The real power loss varies from 3.089 MW to 3.175 MW with change of slack bus. The total variation is 0.086 MW which contributes to 2.78% of total loss. In terms of cost, the total variation is 17.2 $/hr. Therefore, the mathematical loss and slack bus selection has a significant impact on loss allocation. The cost allocated to the respective buses for both the cases are given in table 2 and table 3. The cost allocation for dummy buses at bus 6, bus 8, bus 22, bus 25, bus 27 and bus 28 are zero.

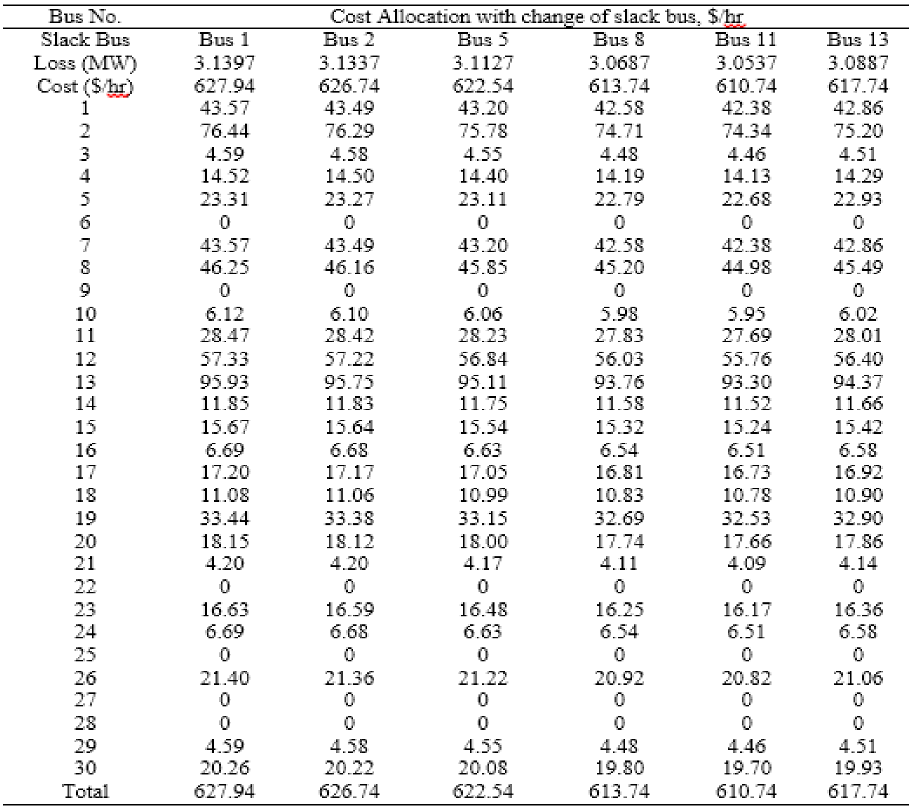
The real power loss, mathematical loss and their respective costs for IEEE 57, 75, and 118 bus system is given in Table 4 for all possible slack bus selection. For IEEE 57 bus system, the total real power loss significantly differs from 15.8234 MW to 46.309 MW. In this case, the loss increases thrice with change in slack bus. The loss is minimum for slack bus 12 and maximum with bus 6. Mathematical loss varies from 0.932 MW to 2.3297 MW. This contributes 2% to 5.03% of total loss.

Table 2. Cost Allocation without Mathematical Loss for IEEE 30 Bus System



Bus No.	Cost Allocation with change of slack bus, $/hr					
Slack Bus	Bus 1	Bus 2	Bus 5	Bus 8	Bus 11	Bus 13
Loss (MW)	3.175	3.169	3.148	3.104	3.089	3.124
Cost ($/hr)	635	633.8	629.6	620.8	617.8	624.8
1	44.06	43.98	43.68	43.07	42.87	43.35
2	77.30	77.15	76.64	75.57	75.20	76.06
3	4.64	4.63	4.60	4.53	4.51	4.56
4	14.69	14.66	14.56	14.36	14.29	14.45
5	23.58	23.53	23.38	23.05	22.94	23.20
6	0	0	0	0	0	0
7	44.06	43.98	43.68	43.07	42.87	43.35
8	46.77	46.68	46.37	45.72	45.50	46.01
9	0	0	0	0	0	0
10	6.18	6.17	6.13	6.05	6.02	6.08
11	28.79	28.74	28.55	28.15	28.01	28.33
12	57.97	57.86	57.48	56.68	56.40	57.04
13	97.01	96.83	96.18	94.84	94.38	95.45
14	11.98	11.96	11.88	11.71	11.66	11.79
15	15.85	15.82	15.71	15.49	15.42	15.59
16	6.76	6.75	6.71	6.61	6.58	6.65
17	17.39	17.36	17.24	17.00	16.92	17.11
18	11.21	11.19	11.11	10.96	10.90	11.03
19	33.82	33.75	33.53	33.06	32.90	33.27
20	18.36	18.32	18.20	17.95	17.86	18.06
21	4.25	4.24	4.22	4.16	4.14	4.18
22	0	0	0	0	0	0
23	16.81	16.78	16.67	16.44	16.36	16.54
24	6.76	6.75	6.71	6.61	6.58	6.65
25	0	0	0	0	0	0
26	21.64	21.60	21.46	21.16	21.06	21.30
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	4.64	4.63	4.60	4.53	4.51	4.56
30	20.48	20.45	20.31	20.03	19.93	20.15
Total	635	633.8	629.6	620.8	617.8	624.8

Table 3. Cost Allocation with Mathematical Loss for IEEE 30 Bus System



Bus No.	Cost Allocation with change of slack bus, $/hr					
Slack Bus	Bus 1	Bus 2	Bus 5	Bus 8	Bus 11	Bus 13
Loss (MW)	3.1397	3.1337	3.1127	3.0687	3.0537	3.0887
Cost ($/hr)	627.94	626.74	622.54	613.74	610.74	617.74
1	43.57	43.49	43.20	42.58	42.38	42.86
2	76.44	76.29	75.78	74.71	74.34	75.20
3	4.59	4.58	4.55	4.48	4.46	4.51
4	14.52	14.50	14.40	14.19	14.13	14.29
5	23.31	23.27	23.11	22.79	22.68	22.93
6	0	0	0	0	0	0
7	43.57	43.49	43.20	42.58	42.38	42.86
8	46.25	46.16	45.85	45.20	44.98	45.49
9	0	0	0	0	0	0
10	6.12	6.10	6.06	5.98	5.95	6.02
11	28.47	28.42	28.23	27.83	27.69	28.01
12	57.33	57.22	56.84	56.03	55.76	56.40
13	95.93	95.75	95.11	93.76	93.30	94.37
14	11.85	11.83	11.75	11.58	11.52	11.66
15	15.67	15.64	15.54	15.32	15.24	15.42
16	6.69	6.68	6.63	6.54	6.51	6.58
17	17.20	17.17	17.05	16.81	16.73	16.92
18	11.08	11.06	10.99	10.83	10.78	10.90
19	33.44	33.38	33.15	32.69	32.53	32.90
20	18.15	18.12	18.00	17.74	17.66	17.86
21	4.20	4.20	4.17	4.11	4.09	4.14
22	0	0	0	0	0	0
23	16.63	16.59	16.48	16.25	16.17	16.36
24	6.69	6.68	6.63	6.54	6.51	6.58
25	0	0	0	0	0	0
26	21.40	21.36	21.22	20.92	20.82	21.06
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	4.59	4.58	4.55	4.48	4.46	4.51
30	20.26	20.22	20.08	19.80	19.70	19.93
Total	627.94	626.74	622.54	613.74	610.74	617.74

The real power loss considering with and without mathematical loss is shown in Figure 1 for different slack bus selection.

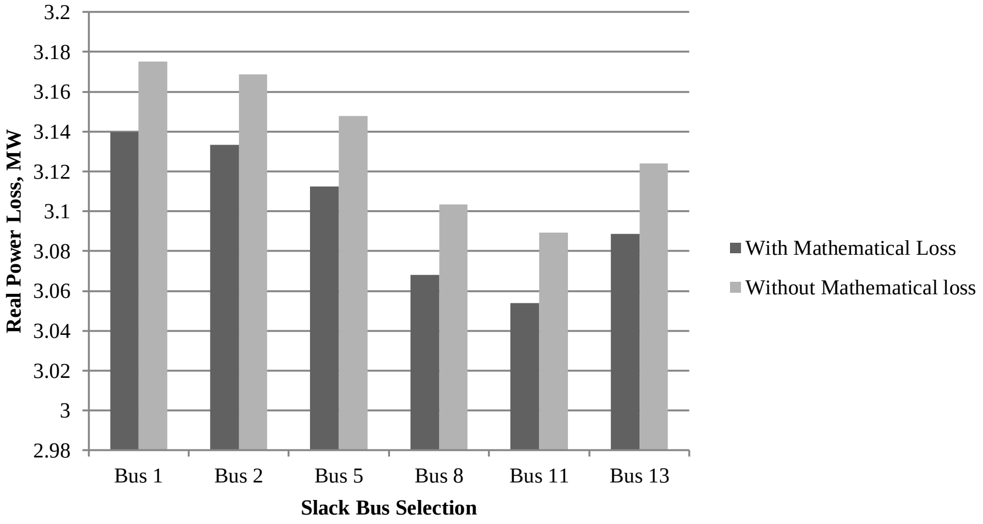


Figure 1. Transmission loss with and without mathematical loss for IEEE 30 bus system

Table 4. Real Power Loss for different IEEE Test Systems

System	Choice of Slack bus	Mathematical Loss (MW)	Cost borne by transmission sector ($/hr)	Real Power Loss in MW (with Mathematical loss)	Total Cost of Real Power Loss in $/hr (with Mathematical loss)
57	Bus 1	0.932	186.40	27.6875	5537.50
	Bus 2	1.8706	374.12	40.158	8031.60
	Bus 3	2.3297	465.94	36.0681	7213.62
	Bus 6	1.9155	383.10	46.309	9261.80
	Bus 8	0.9365	187.30	38.7136	7742.72
	Bus 9	1.8146	362.92	24.1088	4821.76
	Bus 12	0.935	187.00	15.8234	3164.68
75	Bus 1	23.2283	4645.660	172.8401	34568.02
	Bus 2	23.6209	4724.180	232.3998	46479.96
	Bus 3	23.2259	4645.180	218.0274	43605.48
	Bus 9	23.0735	4614.700	178.4886	35697.72
	Bus 10	22.8239	4564.780	175.2180	35043.60
	Bus 12	23.0142	4602.840	177.0151	35403.02
	Bus 13	23.2938	4658.760	183.0933	36618.66
	Bus 14	22.7821	4556.420	105.1023	21020.46
118	Bus 12	9.0448	1808.96	234.4094	46881.88
	Bus 25	9.5464	1909.28	287.5957	57519.14
	Bus 26	8.7572	1751.44	286.4532	57290.64
	Bus 31	8.8027	1760.54	289.9213	57984.26
	Bus 46	8.7900	1758.00	245.5988	49119.76
	Bus 49	8.7425	1748.50	170.4732	34094.64
	Bus 54	8.8193	1763.86	166.2434	33248.68
	Bus 59	8.8833	1776.66	165.8427	33168.54
	Bus 61	8.7212	1744.24	173.7503	34750.06
	Bus 65	8.9616	1792.32	168.6066	33721.32
	Bus 66	8.7425	1748.50	176.5316	35306.32
	Bus 69	8.7468	1749.36	168.6225	33724.50
	Bus 80	8.7414	1748.28	184.0204	36804.08
	Bus 100	8.7737	1754.74	256.9922	51398.44
	Bus 103	8.7993	1759.86	299.9042	59980.84

The real power loss considering with and without mathematical loss for IEEE 57 bus, 75 bus and 118 bus system is shown in Figure 2, Figure 3 and Figure 4 respectively. For IEEE 75 bus system, the real power loss varies from 105 MW to 232 MW but variation of mathematical loss is 1 MW. The mathematical loss contributes to 9.8% of total loss. IEEEE 75 bus system consists of 15 generators and slack bus selection is not feasible for all generators. The load flow results are presented for feasible set of slack bus. The generators with non-feasible solution of load flows are bus 4, bus 5, bus 6, bus 7, bus 8, bus 11 and bus 15.

In 118 bus system, the real power loss varies from 165.84 MW to 299.9 MW and mathematical loss varies around 1 MW. It consists of 19 generators and load flow solution is not feasible for three generators at bus 87, bus 89 and bus 111. In this case mathematical loss contributes to 3.18% of total loss. The main objective of this paper is to highlight the impact of slack bus selection and mathematical loss on transmission loss/cost allocation. Therefore, the cost allocation to the individual buses is not given for IEEE 57 bus, 75 bus and 118 bus systems.

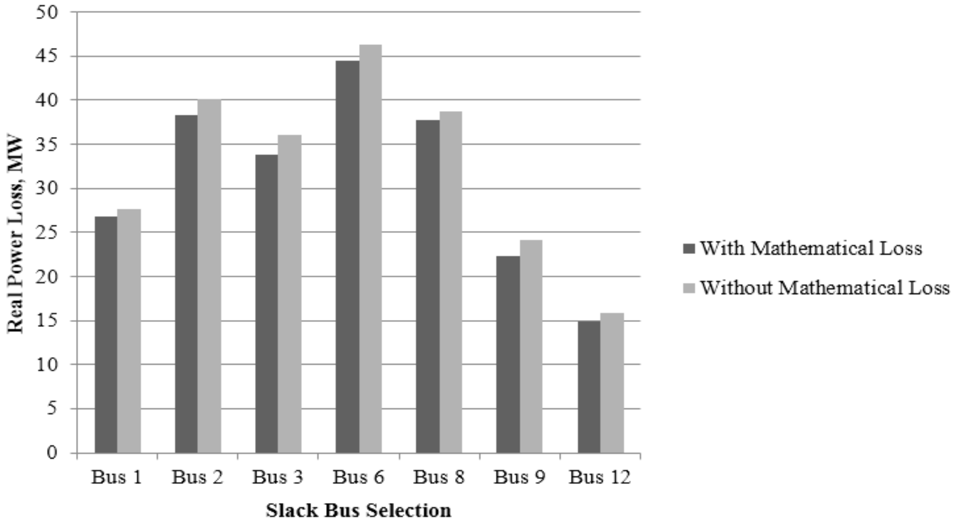


Figure 2. Transmission loss with and without mathematical loss for IEEE 57 bus system

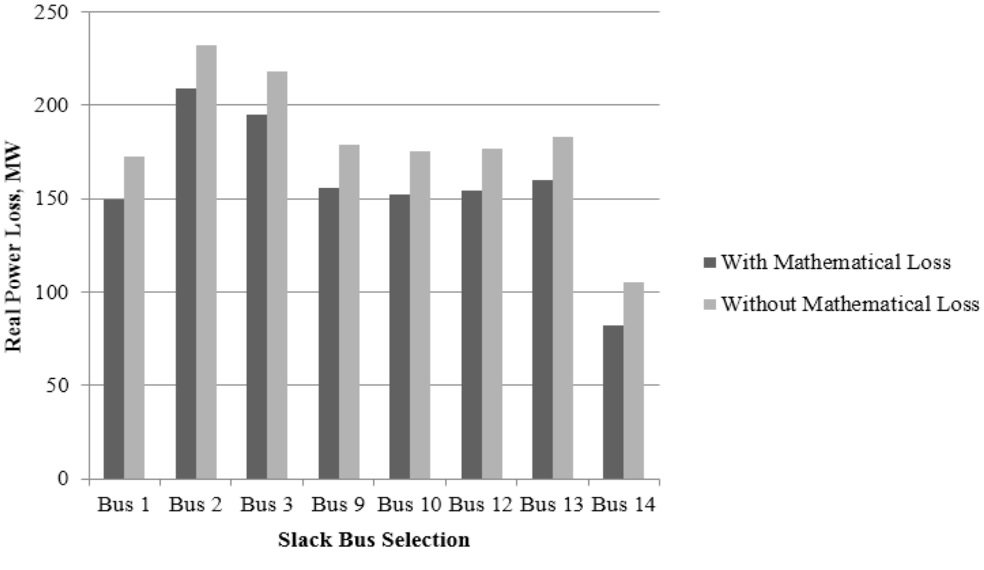


Figure 3. Transmission loss with and without mathematical loss for IEEE 75 bus system

The mathematical loss and real power loss for different IEEE test systems is shown in Figure 4. For all the systems, bus 1 is taken as slack bus to compute loss. The mathematical loss changes with system size.

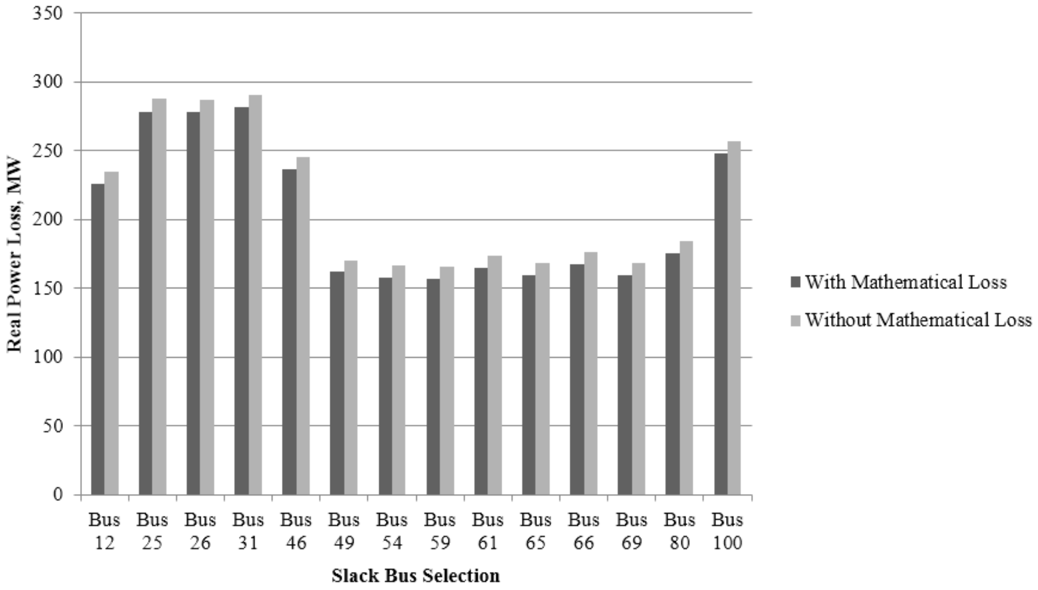


Figure 4. Transmission loss with and without mathematical loss for IEEE 118 bus system

4. CONCLUSION

Cost of transmission losses are shared by generators and loads in deregulated electricity market while the transmission sector is uncharged. This paper proposes a methodology to involve the transmission sector in real power loss or cost allocation process with a study on impact of slack bus selection and mathematical loss. To demonstrate the results, PGPL method is considered. This study is carried out for sample four test systems like IEEE 30 bus, 57 bus, 75 bus and 118 bus system. The results show that the slack bus selection and mathematical loss has a significant impact on transmission loss or cost allocation. Moreover, the mathematical loss varies with system size and hence cannot be ignored.

REFERENCES

[1] Bialek J. W. Tracing the flow of electricity. *IEE Proc.—Gener, Transm, and Distrib.* 1996; 143(4): 313–320.

[2] Kirschen D, Allan R, Strbac G. Contributions of individual generators to loads and flows. *IEEE Trans. Power Syst.* 1997; 12(1): 52–60.

[3] Bialek J. W. Topological generation and load distribution factors for supplement charge allocation in transmission open access. *IEEE Trans. Power Syst.* 1997; 12(3): 1185–1193.

[4] Strbac G, Kirschen D, Ahmed S. Allocating transmission system usage on the basis of traceable contributions of generators and loads to flows. *IEEE Trans. Power Syst.* 1998; 13(2): 527–534.

[5] Galiana F.D, Conejo A.J, Kockar I. Incremental transmission loss allocation under pool dispatch. *IEEE Trans. Power Syst.* 2002; 17(1): 527–534.

[6] Ahmed K.S, Karthikeyan S.P. Penalised quoted cost based approach on transmission loss allocation for a bilateral contract in deregulated electricity market. *IET Generation, Transmission & Distribution.* 2016; 10(16): 4078 – 4084.

[7] Ahmed K.S, Karthikeyan S.P. Modified penalized quoted cost method for transmission loss allocation including reactive power demand in deregulated electricity market. *Sustainable Energy, Grids and Networks*. 2018; 16: 370–379.

[8] Galiana F.D, Conejo A.J, Kockar I. Z-Bus Loss Allocation. *IEEE Transactions on Power Systems*. 2001; 16(1): 105–110.

[9] Nikoukar J, Haghifam M.R, Parastar A. Transmission cost allocation based on the modified Z-bus. *International journal of Electrical Power and Energy Systems*. 2012; 42: 31-37.

[10] Ya-Chin C, Chan-Nan L. An electricity tracing method with application to power loss allocation. *International journal of Electrical Power and Energy Systems*. 2001; 23: 13-17.

[11] Kirschen D, Strbac G. Tracing active and reactive power between generators and loads using real and imaginary currents. *IEEE Trans. Power Syst.* 1999; 14(4): 312–1319.

[12] Mahmood N, Seyed H.H, Behrooz V. A modified methodology in electricity tracing problems based on Bialek's method. *International journal of Electrical Power and Energy Systems*. 2014; 60: 74-81.

[13] Visakha K, Thukaram D, Lawrence J. Transmission charges of power contracts based on relative electrical distances in open access. *Electric Power System Research.* 2004; 70: 153-161.

[14] Felix F.W, Yixin N, Ping W. Power Transfer Allocation for Open Access Using Graph Theory—Fundamentals and Applications in Systems without Loop flow. *IEEE Trans. Power Syst.* 2000; 15(3): 923-929.

[15] Valerie S, Lim C, John D, McDonald F, Saha T.K. Development of a new loss allocation method for a hybrid electricity market using graph theory. *Electric Power Systems Research*. 2009; 79: 301–310.

[16] Bharti D, Mala D. A new graph theory based loss allocation framework for bilateral power market using diakoptics. *International Journal of Electrical Power and Energy Systems*. 2016; 77: 395–403.

[17] Ahmed K.S, Karthikeyan S.P., Sahoo S. K. Comparison of Graph theory approach with other methods on transmission loss allocation problem in Deregulated Electricity Market. *Applied Mechanics and Materials*. 2016; 839: 6-13.

[18] Conejo A.J, Arroyo J.M, Alguacil N, Guijarro A.L. Transmission Loss Allocation: A Comparison of Different Practical Algorithms. *IEEE Transactions on Power Systems*. 2002; 17(3): 571-576.

[19] Karthikeyan S.P, Saravanan B, Aman J, Indrajit R, Jacob R, Kothari D.P. A Comparative study on Transmission Network Cost Allocation Methodologies. *International Conference on Power, Energy and Control (ICPEC)*. 2013; 145–152.

[20] Ahmed K.S, Karthikeyan S.P. Comparison of various Transmission Loss/Cost Allocation Methods-A Review. *IEEE International Conference on Innovations in Power and Advanced Computing Technologies (i-PACT2017)*. 2017; 1–4.

[21] Abdelkader S.M. A New Method for Transmission Loss Allocation Considering the Circulating Currents between Generators. *12th Middle-East Power System Conference (MEPCON)*. 2008; 282–286.

[22] Ahmed K.S, Karthikeyan S.P. Impact of Transmission Line Mutual Inductance on Transmission Loss/Cost Allocation in Deregulated Electricity Market. *IEEE International Conference on Environment and Electrical Engineering (EEEIC 2017)*. 2017; 1–4.

[23] Abhyankar A.R, Khaparde S.A. Electricity transmission pricing: Tracing based point-of-connection tariff. *International Journal of Electrical Power and Energy Systems*. 2009; 31(1): 59–66.

[24] Kyung-Il M, Sang-Hyeon H, Su-Won L, Young-Hyun M. Transmission Loss Allocation Algorithm UsingPath-Integral Based on Transaction Strategy. *IEEE Transactions on Power Systems*. 2010; 25(1): 195 - 203.

[25] Mohd H.S, Mohd W.M, Hussain S, Saiful N.A.K. An application of artificial bee colony algorithm with least squares supportvector machine for real and reactive power tracing in deregulated power system. *International Journal of Electrical Power and Energy Systems*. 2012; 37(1): 67–77.

[26] Surender Reddy Salkuti. Multi-Objective based Optimal Energy and Reactive Power Dispatch in Deregulated Electricity Markets. *International Journal of Electrical and Computer Engineering (IJECE),* Vol. 8, No. 5, October 2018, pp. 3427-3435.

[27] Francesco Arci, Jane Reilly, Pengfei Li, Kevin Curran, Ammar Belatreche. Forecasting Short-term Wholesale Prices on the Irish Single Electricity Market. *International Journal of Electrical and Computer Engineering (IJECE),* Vol. 8, No. 6, December 2018, pp. 4060-4078.

[28] Adline K. Bikeri, Christopher M. Muriithi, and Peter K. Kihato. GENCO Optimal Bidding Strategy and Profit Based Unit Commitment using Evolutionary Particle Swarm Optimization Illustrating the Effect of GENCO Market Power. *International Journal of Electrical and Computer Engineering (IJECE),* Vol. 8, No. 4, August 2018, pp. 1997–2013.

[29] Ahmed K.S, Karthikeyan S.P. Proportional generation and proportional load based approach for transmission loss cost allocation in deregulated electricity market. *IEEE Region 10 Conference (TENCON 2016)*. 2016: 723-725.

[30] Ahmed K.S, Karthikeyan S. P. Proportional Generation and Proportional Load based Transmission Loss Allocation Approach considering Reactive Power Demand in Restructured Environment. *IEEE Region 10 Conference (TENCON 2017).* 2017: 992-997.