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Usage-Based Methodology for Transmission Network Cost Allocation

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ABSTRACT
This paper presents a procedure for allocating transmission cost to generators and loads. The procedure is based on the network Z-bus matrix. This work proposes three methods using bus impedance matrix Zbus. The three techniques are Zbus method, Zbus ^{avg} method and a newly proposed technique. The new method is very effective in transmission cost allocation A physically-based network usage procedure is proposed.. Case studies IEEE 24-bus system is used to illustrate the working of the proposed techniques using MATLAB programming.
Keywords - Impedance and Admittance matrix, Network usage, transmission cost allocation

I. NOMENCLATURE

C_{jk} Cost of line *jk* ($/h).
I_i Nodal current *i*(A).
I_{jk} Current through line jk (A).
n Number of buses.
P_{Di} Active power consumed by the demand located at bus i(W).
P_{Gi} Active power produced by the generator located at bus i(W).
P_{jk} Active power flow through line jk(W).
S_{jk} Complex power flow through line jk calculated at bus j(VA).
V_j Nodal voltage at bus j(V).
$y_{j\rightarrow k}$ Series admittance of the π equivalent circuit of line jk(S).
$y^{sh}_{j\rightarrow k}$ Shunt admittance of the equivalent circuit of line jk(S).
Z_{bus} Impedance matrix .(Ω)
Z_{ij} Element of the impedance matrix (Ω).
Ω_L Set of all transmission lines.
a^i_{jk} Electrical *distance* between bus i and line jk (adimensional).
C^{Di} Total transmission cost allocated to the demand located at bus i($/h) .
C^{Gi} Total transmission cost allocated to the generator located at bus i($/h).
C^{Di}_{jk} Transmission cost of line jk allocated to the demand located at bus i($/h).
C^{Gi}_{jk} Transmission cost of line jk allocated to the generator located at bus .
P^i_{jk} Active power flow through line jk associated with the nodal current (W).
r_{jk} Cost rate for line jk($/W &h) .
U_{jk} Usage of line jk (W).
U^{Di}_{jk} Usage of line jk allocated to the demand located at bus i(W).
U^{Gi}_{jk} Usage of line jk allocated to the generator located at bus (W).
U^i_{jk} Usage of line jk associated with nodal current i(W).

II. INTRODUCTION

Transmission cost allocation is a subject of considerable debate among various stakeholders in the electricity industry. In this paper a transmission cost allocation methodologies to apportion the cost of the transmission network to generators and demands is determined[1],[2]. The proposed technique consists of the following steps.

1) The active power flow of any transmission line is apportioned among all nodal currents.
2) Based on the above apportioning, the cost of any line is allocated to all generators and demands.
3) The procedure is repeated for all lines.

This paper is organized as follows: Section –II gives a methodology for cost allocation using Zbus. The case study is been done on IEEE 14 Bus system is discussed in section-III

III. COST ALLOCATION METHODOLOGY BASED ON USAGE

The usage of line jk due to nodal current i as the absolute value of the active power flow component Pjk , i.e.,

$$U^i_{jk} = \left|P^i_{jk}\right|. \quad (1)$$

That is, we consider that both flows and counter-flows do use the line. The total usage of line jk is then

$$U_{jk} = \sum_{i=1}^{n} U^i_{jk}. \quad (2)$$

If bus i contains only generation, the usage allocated to generation pertaining to line *jk* is

$$U_{jk}^{Gi} = U_{jk}^{i}. \quad (3)$$

On the other hand, if bus i contains only demand, the usage allocated to demand pertaining to line jk is

$$U_{jk}^{Di} = U_{jk}^{i}. \quad (4)$$

Else, if bus *i* contains both generation and demand, the usage allocated to the generation at bus *i* pertaining to line *jk* is

$$U_{jk}^{Gi} = [P_{Gi}/(P_{Gi} + P_{Di})]U_{jk}^{i} \quad (5)$$

and the usage allocated to the demand at bus i pertaining to line *jk* is

$$U_{jk}^{Di} = [P_{Di}/(P_{Gi} + P_{Di})]U_{jk}^{i}. \quad (6)$$

The corresponding cost rate for line *jk* is then

$$r_{jk} = C_{jk}/U_{jk}. \quad (7)$$

In this way, the cost of line *jk* allocated to the generator located at bus is

$$C_{jk}^{Gi} = r_{jk}U_{jk}^{Gi}. \quad (8)$$

Similarly, the cost of line jk allocated to the demand located at bus i is

$$C_{jk}^{Di} = r_{jk}U_{jk}^{Di}. \quad (9)$$

Finally, the total transmission cost of the network allocated to the generator located at bus i is

$$C^{Gi} = \sum_{(j,k)\in\Omega_L} r_{jk}U_{jk}^{Gi}. \quad (10)$$

In addition, similarly, the total transmission cost allocated to the demand located at bus i is

$$C^{Di} = \sum_{(j,k)\in\Omega_L} r_{jk}U_{jk}^{Di}. \quad (11)$$

IV. CASE STUDY

The IEEE 24-bus RTS depicted in Fig. 1 is considered for this case study.

Tables I–VI provide the transmission cost allocation to generators and demands for lines 23 (bus 14 to bus 16) and 11 (bus 7 to bus 8), respectively. These lines, 3, are selected for the two reasons below. In terms of transmission cost allocation, line 23 behaves as most lines throughout the system do, thus being a *representative* line of the network. Conversely, line 11, which is peripheral, exhibits clearly the proximity effect discussed in the example above.

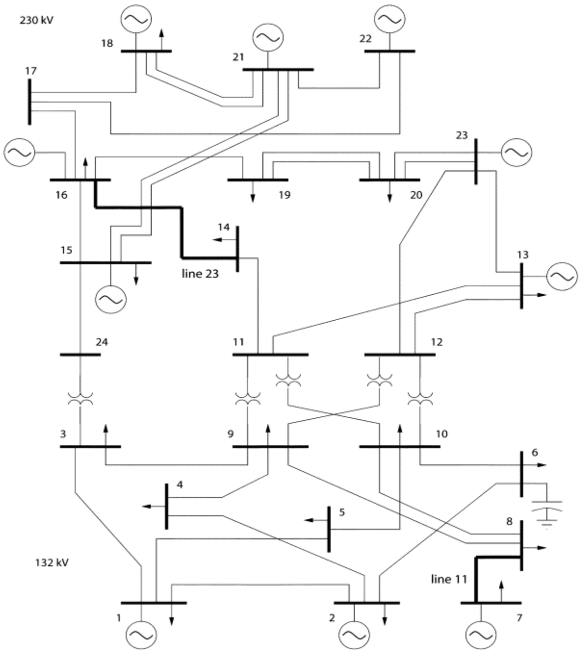

Fig 1 IEEE 24 Bus System

TABLE I
Line 23 TRANSMISSION COST ALLOCATION TO GENERATORS

Bus	Cost($/h)		
-	Zbus	Zbus avg	Modified Z^{avg}_{bus}
1	0.2018	0.232	0.5209
2	0.2916	0.3224	0.57
7	0.5663	0.6425	1.1794
13	0.0533	0.0665	1.0389
15	1.2825	1.3185	3.5077
16	1.1262	1.0638	2.7024
18	1.2408	1.2922	6.8452
21	12.7593	12.4819	6.7097
22	9.1876	8.6094	4.8982
23	6.8785	6.5398	3.558
Total	33.587	32.569	31.53

TABLE II
Line 23 TRANSMISSION COST ALLOCATION To DEMAND

Bus	Cost($/h)		
-	Zbus	Zbus avg	Modified Z^{avg}_{bus}
1	0.1267	0.1457	0.3381
2	0.1644	0.1818	0.3244
3	1.0745	1.0054	0.6703
4	0.3937	0.4682	0.2824
5	0.4488	0.523	0.3149
6	0.9689	1.1254	0.7078
7	0.295	0.3347	0.6203
8	1.2114	1.4029	0.8649

9	1.019	1.1935	0.716
10	1.5892	1.8089	1.103
13	0.0495	0.0618	0.9596
14	7.9214	8.1441	4.5137
15	1.8909	1.944	5.2362
16	0.7266	0.6863	1.7684
18	1.0329	1.0758	5.5717
19	4.386	4.2919	2.3387
20	2.113	2.038	1.1107
Total	25.411	26.43	27.38

V. RESULT ANALYSIS

Table VII shows that all methods allocate most of the costs of using line 23 to generators 21, 22, and 23. This is expected because all these generators are electrically close to that line, and their productions are comparatively high.

Table V shows that the, Z_{bus} , Z^{avg}_{bus}, modified Z^{avg}_{bus} and PS methods allocate most of the cost of line 23 to demand 11

TABLE III
Line 11 TRANSMISSION COST ALLOCATION TO GENERATORS

Bus	Cost($/h)		
-	Zbus	Zbus avg	Modified Z^{avg}_{bus}
1	0.00000	0.0305	0.0443
2	0.00000	0.0365	0.0447
7	40.1096	38.5351	39.2035
13	0.00000	0.0095	0.0711
15	0.00000	0.0407	0.0536
16	0.00000	0.0225	0.0383
18	0.00000	0.0397	0.1074
21	0.00000	0.319	0.1039
22	0.00000	0.1835	0.0685
23	0.00000	0.4361	0.142
Total	40.1096	39.653	39.87

TABLE IV
Line 11 TRANSMISSION COST ALLOCATION TO DEMANDS

Bus	Cost($/h)		
-	Zbus	Zbus avg	Modified Z^{avg}_{bus}
1	0.00000	0.0194	0.0281
2	0.00000	0.0208	0.0253
3	0.00000	0.1492	0.048
4	0.00000	0.0584	0.0189
5	0.00000	0.0558	0.018
6	0.00000	0.1053	0.0346
7	20.8904	20.2532	20.4439
8	0.00000	0.0784	0.0244
9	0.00000	0.1326	0.0427
10	0.00000	0.1473	0.0475
13	0.00000	0.0009	0.0651
14	0.00000	0.1584	0.0517
15	0.00000	0.0553	0.0835
16	0.00000	0.0008	0.0263
18	0.00000	0.0180	0.0837
19	0.00000	0.0728	0.0474
20	0.00000	0.1011	0.0328
Total	20.8904	21.42	21.129

Tables V and VI show that, for the Z_{bus} and $Z_{\text{bus}}^{\text{avg}}$ methods, almost 100% of the cost of line 11 is allocated to bus 7, split between its generation and demand.

Additionally, for the Z_{bus} and $Z_{\text{bus}}^{\text{avg}}$ methods, it can be noted that a relatively small portion of the total network cost is allocated to bus 7, because this bus is placed at the network boundary.Note also that for the Z_{bus} and methods, the amount of the cost of line 11 allocated

TABLE V
TOTAL TRANSMISSION COST ALLOCATION TO GENERATORS

Bus	Cost($/h)		
-	Zbus	Zbus avg	Modified Z^{avg}_{bus}
1	41.3522	43.7322	102.932
2	50..6569	53.5085	103.933
7	117.549	117.51	184.503
13	7.15621	7.44293	100.928
15	35.7738	35.4253	88.2683
16	20.812	20.2819	56.1084
18	39.1378	364.838	194.107
21	383.247	364.838	201.267
22	352.952	320.599	217.313
23	378.857	377.002	210.789
Total	1427.49	1379.2	1460.1487

to bus 8 (0.000117 and 0.0784$/h , respectively, demand only) is much smaller than that allocated to bus 7 (61.4 and 59.1$/h, respectively, demand plus generation). However, total network usage allocated to bus 8 (174.5 and 179.96$/h, respectively, demand only) is almost as high as the allocation to bus 7 (179.9 and 180.74$/h , respectively, demand plus generation).

Table V shows that the Z_{bus} and $Z_{\text{bus}}^{\text{avg}}$ methods allocate most of the total cost of the network to generators 21, 22, and 23, just like the other methods. Considering that these generators are the highest producers in the network and that they feed a significant amount of the demand of the system, this is an appropriate re- sult. For the demands, using the Z_{bus} and $Z_{\text{bus}}^{\text{avg}}$ methods, the net- work costs are mostly allocated to demands 3 and 8.

TABLE VI
TOTAL TRANSMISSION COST ALLOCATION TO DEMANDS

Bus	Cost($/h)		
-	Zbus	Zbus avg	Modified Z^{avg}_{bus}
1	25.9653	27.459	65.42257
2	28.5682	30.1763	58.7992
3	184.485	188.735	108.533
4	84.0901	88.7323	50.3883
5	68.6698	72.2478	39.4342
6	59.9801	77.2602	44.9461
7	61.2232	61.2032	96.3466
8	175.914	180.024	106.113
9	145.662	151.042	88.5755
10	72.2811	78.8505	45.8012
13	6.64702	.91334	92.9311
14	116.219	117.195	65.4797
15	52.7455	52.2317	134.839
16	13.4271	13.0851	37.6462
18	32.5822	32.3663	155.471
19	127.021	126.608	70.8302
20	89.622	88.6508	49.6119
Total	1394.50562	1392.781	1311.1687

Table VI. This happens because buses 3 and 8 have the highest demands, and they are located far away from the main genera- tors: 21, 22, and 23. Therefore, buses 3 and 8 use many of the lines in the network.

VI. CONCLUSION

Both the Z_{bus} , $Z^{\text{avg}}_{\text{bus}}$, and the modified Z^{avg}_{bus} procedures to allocate the cost of the transmission network to generators and demands are based on circuit theory. They generally behave in a similar manner as other techniques previously reported in the literature. However, they exhibit a desirable proximity effect according to the under- lying electrical laws used to derive them. This proximity effect is more apparent on peripheral rather isolated buses. For these buses, other techniques may fail to recognize their particular lo- cations. The $Z^{\text{avg}}_{\text{bus}}$ variant smooths the trend of the Z_{bus} method (as well as of other techniques) to allocate a higher line usage to generators versus demands.

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