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Economic pricing techniques for transmission network in deregulated electricity market

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Abstract: The aim of deregulation is to introduce an element of competition into electrical energy delivery and thereby allow market forces to price energy at low rates for the customer and higher efficiency for the suppliers. The necessity for deregulation is to provide cheaper electricity, to offer greater choice to the customer in purchasing the economic energy, to give more choice of generation and to offer better services with respect to power quality i.e. constant voltage, constant frequency and uninterrupted power supplythis paper provides a methodology to apportion the cost of the transmission network to generators and demands that use it. How to allocate the cost of the transmission network is an open research issue as available techniques embody important simplifying assumptions,which may render controversial results. In this paper three techniques namely Z_{bus}method, $Z_{bus}avg$method and Relative Electrical Distance (RED) method for the network cost allocation is compared. It has been successfully applied on an IEEE 24 bus-Reliability Test System (RTS) and the results obtained are compared.

Keywords: Transmission network cost allocation, active power flow, generator cost contribution, load cost contribution, Z_{bus},Z_{bus}avg and RED.

I. INTRODUCTION

Deregulation word refers to un-bundling of electrical utility or restructuring of electrical utility and allowing private companies to participate. The aim of deregulation is to introduce an element of competition into electrical energy delivery and thereby allow market forces to price energy at low rates for the customer and higher efficiency for the suppliers.In the traditional pro rata method [1], [2] bothgenerators and loads are charged a flat rate per megawatthour, disregarding their respective use of individual transmission lines. Flow-based method [3] estimates the usage of the lines by generators and demands and charges them accordingly. Some flow-based methods use theproportional sharing principle [4], [5], which implies thatany active power flow leaving a bus is proportionally madeup of the flows entering that bus, such that Kirchhoff'sCurrent Law is satisfied. Other methods that use generationshift distribution factors [6] are dependent on the selectionof the slack bus and lead to controversial results. The usagebasedmethod reported in [7] and [8] uses the so-calledequivalent bilateral exchanges (EBEs).

II. PROBLEM STATEMENT

A. Background of Z_{bus} and $Z_{bus}avg$ technique

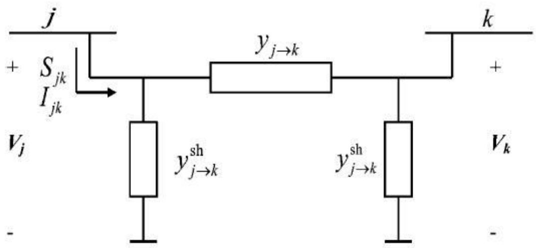

Figure 1. Π equivalent circuit of line section *jk*

Consider the complex power flow S_{JK}computed at bus *j* and flowing through the line connecting bus *j* to bus *k* asshown in Figure 1.As the power flow solution is known, weselect the direction of the complex power flow so that $P_{JK}>0$

The complex power flow$S_{jk}$is

$$S_{jk} = V_j I_{jk}^* \quad (1)$$

This complexpower flow equation can be written as

$$S_{jk} = V_j \sum_{i=1}^{n} (a_{jk}^{i} I_i)^* = \sum_{i=1}^{n} V_j (a_{jk}^{i*} I_i^*) \quad (2)$$

$$\text{Here } a_{jk}^{i} = (Z_{ji} - Z_{ki})Y_{jk} + Z_{ji}Y_{jk}^{sh} \quad (3)$$

We know that the power flow through any line is

$$P_{jk}^{i} = \text{Real}\,\{V_j a_{jk}^{i*} I_i^* \} \quad (4)$$

B. Transmission cost allocation using Z_{bus}

$$U_{jk}^{i} = |P_{jk}^{i}| \quad (4)$$

Total usage of the line jk is

$$U_{jk} = \sum_{i=1}^{n} U_{jk}^{i} \quad (5)$$

If bus i contains only generation, the usage allocated to generation i pertaining to line jkis

$$U_{jk}^{Gi} = U_{jk}^{i} \quad (6)$$

If bus i contains only demand,the usage allocated to demandi pertaining to line jkis

$$U_{jk}^{Di} = U_{jk}^{i} \quad (7)$$

For the sake of simplicity and for each line, total annualized line cost in $/h, C jk, which includes operation , maintenance and building costs is considered. The corresponding cost rate for line jkis then

$$r_{jk} = C_{jk}/U_{jk} \quad (8)$$

In this way, the cost of line jkallocated to the generator located at bus i is

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

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

$$C_{jk}^{Di} = r_{jk} U_{jk}^{Di} \quad (10)$$

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

$$C^{Gi} = \sum_{(j,k)\epsilon\Omega_L} r_{jk}\ U_{jk}^{Gi} (11)$$

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

$$C^{Di} = \sum_{(j,k)\epsilon\Omega_L} r_{jk}\ U_{jk}^{Di} \quad (12)$$

Equation (2) is written in such a manner that $P_{jk} \geq 0$, that is, in the direction of the active power flows. However, (2) can also be written in the direction of the active power counter-flows, which leads to distance parameters a^{i}_{jk} . It is correct to write Equation (2) in both the ways. However, (3) shows that distance parameters are not generally symmetrical with respect to line indexes, i.e., $a_{jk}^{i} \neq a_{kj}^{i}$,which results in different usage allocations depending on whether (2) is written in the direction of the active powerflows or counter-flows**.**

Now, to address these two types of power flows, twoZ_{bus} based techniques are used. The first one is denoted byZ_{bus} and is based on (2) written in the direction of the active power flows. This is a common way as the actual activepower flows directions are used. This selection generallyresults in higher usage allocation to generators versusdemands. The second technique denoted by Z_{bus}^{avg} provide the average value of allocated cost (usage) using the Z_{bus} technique with (2) written in the direction of the activepower counter-flows. This technique smoothens the trend ofallocating higher network usage to generators versusdemands.

C. Background of RED technique

Consider a system where n is the total number of buses with 1, 2. . . g, where g is the number of generator buses and g + 1, . . . , n, remaining (n - g) are the load buses. For a given system, the network admittance matrix is given by

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (13)$$

Where I_G,I_L and V_G,V_L represent complex current and voltage vectors at the generators and load nodes.

$[Y_{GG}], [Y_{GL}], [Y_{LG}]$ and $[Y_{LL}]$are corresponding portions of network Y-bus matrix

$$[I_G] = [Y_{GG}][V_G] + [Y_{GL}][V_L] \quad (14)$$

$$[I_L] = [Y_{LG}][V_G] + [Y_{LL}][V_L] \quad (15)$$

Pre-multiplying (23) by $[Y_{LL}]{-1}$

$$[V_L] = [Y_{LL}]^{-1}[I_L] - [Y_{LL}]^{-1}[Y_{LG}][V_G] \quad (16)$$

Substituting [V_L] in (14), we obtain below equation no(17)

$$[I_G] = [Y_{GG}][V_G] + [Y_{GL}]\{[Y_{LL}]^{-1}[I_L] - [Y_{LL}]^{-1}[Y_{LG}][V_G]\}$$

From the equations (16) and (17) can be written as

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y'_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \quad (17)$$

$$[F_{LG}] = -[Y_{LL}]^{-1}[Y_{LG}]$$

$$\text{Where}[K_{LG}] = [Y_{GL}][Y_{LL}]^{-1}$$

$$[Y'_{GG}] = \{[Y_{GG}] - [Y_{GL}][Y_{LL}]^{-1}[Y_{LG}]\}$$

The elements of $[F_{LG}]$ matrix are complex. Its columns correspond to the generator bus numbers and rows correspond to the load bus numbers. This matrix gives the relation between load bus and source bus voltages. Ideal generation proportions are obtained from $abs[F_{LG}]$matrix, also known as desired generation proportions matrix $[D_{LG}]$ as

$$[D_{LG}] = abs\{[F_{LG}]\} \quad (18)$$

D_{LG}] gives the information about the location of load nodes with respect to generator nodes, which is popularly termed as RED. The [RED] is obtained from the $[D_{LG}]$ matrix as

$$[RED] = M - [D_{LG}] \quad (19)$$

Where, M is the unity matrix of size L X G, G is the number of generator buses and L is the number of load buses.

D. Evaluation of the power contract transmission matrix and transmission cost matrix

Evaluation of the power contract transmission matrix and transmission cost matrixThe power contract transmission matrix $[P_{LG}]$ is calculated from the transaction details between the generatorand the load from which$[C_{LG}]$transmission cost matrix iscalculated using the following expression

$$[C_{LG}] = \{X + [RED]\} \quad (20)$$

where the transmission charges are directly proportional to the relative electrical distances and it is assumed that the charges for the consumers are Rsx. The transmission charges are calculated by each element of $[C_{LG}]$matrix multiplied by the corresponding element of $[P_{LG}]$matrix.

III. IMPLEMENTATION AND RESULT

All the three methodologies are compared by testing it on a standard IEEE 24 bus reliability test system shown in fig.2.

A.Z-bus Technique

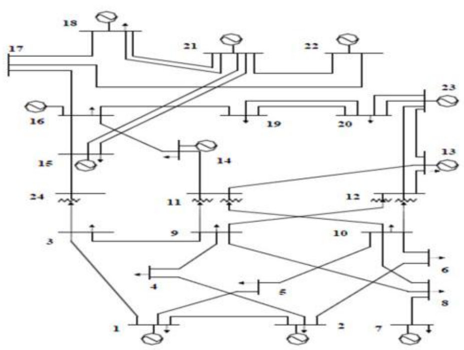

Fig. 2 RTS 24 Bus System

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TABLE I. GENERATOR COST CONTRIBUTIONS C_0 (k,i) IN $P_{jk}>0$ DIRECTION OF Z_{bus}TECHNIQUE

LINE/ GEN	GEN1	GEN2	GEN7	GEN13	GEN15	GEN16	GEN18	GEN21	GEN22	GEN23
1	1.5454	2.1819	0.2081	0.0057	0.0435	0.0144	0.0387	0.3168	0.2019	0.04077
2	5.9171	6.5095	0.9888	0.0195	5.0995	2.1063	1.3145	36.7163	22.8753	29.5241
3	6.6457	7.2634	1.6037	0.6195	0.4694	0.1381	0.5175	1.3723	0.2573	7.2106
4	3.4813	4.9031	2.6327	0.0743	2.1951	0.9758	0.3781	16.0133	9.9996	19.8214
5	8.2860	11.2595	1.6975	0.1162	3.4800	1.4237	0.6828	24.8784	15.4713	22.5651
6	0.9544	0.7765	4.1011	0.0834	2.4655	0.8803	1.0394	17.3398	10.7659	0.3210
7	0.8687	0.9995	0.5212	0.0090	2.6626	1.0610	0.7559	19.0127	11.8204	12.0753
8	2.7614	3.8892	2.0894	0.0575	1.7429	0.7742	0.2988	12.7110	7.9364	15.7257
9	6.4536	7.0535	1.5576	0.6020	0.4557	0.1343	0.5029	1.3309	0.2485	7.0061
10	2.8576	3.9557	0.0628	0.6793	0.9696	0.1263	0.4768	5.2477	2.7156	0.2940
11	0.0706	0.0865	38.3888	0.0119	0.1036	0.0511	0.0344	0.7917	0.5057	0.9766
12	0.3932	0.5306	20.4205	0.2973	2.2119	0.7839	0.0302	14.9544	8.9917	13.1907
13	0.3006	0.4155	22.3983	0.3028	2.0220	0.6996	0.0116	13.5628	8.1199	11.9299
14	0.7888	1.0481	2.2779	0.0687	1.5259	0.7630	0.2116	11.5114	7.2730	11.3855
15	0.8877	1.1743	2.5061	0.0285	0.9746	0.3627	0.2935	6.4991	3.8306	21.4688
16	0.0419	0.0455	0.0264	0.5086	1.8470	1.1043	1.0377	15.3081	10.1223	18.5739
17	0.0259	0.0212	0.1090	0.5969	1.6513	0.9692	0.8957	13.5882	8.9576	23.4659
18	0.4198	0.5192	0.7132	0.9166	0.2288	0.0405	0.0809	1.3178	0.7135	19.7509
19	0.2216	0.2858	0.5258	0.0168	1.0984	0.6290	0.4895	8.8903	5.8136	4.4636
20	0.4092	0.5158	0.8250	0.7974	0.8784	0.4900	0.3364	7.0215	4.5618	9.4417
21	0.6633	0.8381	1.3560	0.0826	1.5519	0.9090	0.7091	12.6715	8.3125	34.9946
22	0.5332	0.6741	1.0932	0.4059	1.2638	0.7565	0.6190	10.4177	6.8629	35.2611
23	0.1681	0.2193	0.4308	0.0116	1.0917	0.6190	0.4759	8.8006	5.7453	4.6935
24	0.0271	0.0230	0.0871	0.0185	1.0912	0.1880	0.1581	4.6432	2.0891	2.6753
25	0.1685	0.2044	0.2362	0.0159	0.4898	0.0065	0.4123	11.2728	5.8982	0.6095
26	0.1685	0.2044	0.2362	0.0159	0.4898	0.0065	0.4123	11.2728	5.8982	0.6095
27	0.6933	0.8114	0.5960	0.0009	1.4875	0.5895	0.4661	10.6385	6.6243	5.8392
28	0.1337	0.1687	0.2698	0.0267	0.2807	0.1182	0.5518	8.6076	7.0481	2.3139
29	0.0006	0.0048	0.0696	0.0309	0.5739	0.3097	0.2192	4.5336	2.9340	6.6243
30	0.0224	0.0334	0.0812	0.0105	0.3094	0.0693	0.5156	7.6331	1.3438	1.1311
31	0.8240	1.0214	1.4277	0.1284	0.1682	0.3781	0.1676	8.5001	57.1858	9.0696
32	0.0009	0.0020	0.0374	0.0068	0.3155	0.0579	0.4214	7.3918	1.3492	0.8553
33	0.0009	0.0020	0.0374	0.0068	0.3155	0.0579	0.4214	7.3918	1.3492	0.8553
34	0.0091	0.0160	0.0763	0.0279	0.4900	0.2658	0.1898	3.8793	2.5129	5.8397
35	0.0091	0.0160	0.0763	0.0279	0.4900	0.2658	0.1898	3.8793	2.5129	5.8397
36	0.0229	0.0308	0.0703	*0.0164*	0.2434	0.1344	0.0984	1.9403	1.2606	3.2450
37	0.0229	0.0308	0.0703	0.0164	0.2434	0.1344	0.0984	1.9403	1.2606	3.2450
38	0.4123	0.5059	0.6490	0.0535	0.6160	0.0915	0.0039	8.1982	42.1776	3.0886

Using Equation No 2, the cost of each line allocated to the load at various buses is computed *.B.Z_{bus}^{avg} Method*

The cost of each line allocated to the load and the generator located at various buses are calculated as per the discussion made earlier for Z_{bus}^{avg} method

TABLE II. COMPARISON OF BOTH Z_{bus}AND Z_{bus}^{avg} TECHNIQUES

	Z_{bus}Technique			**Z_{bus}^{avg}Technique**		
Bus No.	**CG in $**	**CD in $**	**TOTAL COST In $**	**CG^{avg} In $**	**CD^{avg} In $**	**TOTAL $COST^{avg}$ In $**
1.	47.2130	29.6454	76.8584	46.1091	28.9522	75.0613
2.	58.2409	32.8452	91.0861	56.1646	31.6742	87.8389
3.	0	182.7847	182.7847	0	193.0269	193.0269
4.	0	83.9559	83.9559	0	83.1586	83.1586
5.	0	67.6732	67.6732	0	68.2859	68.2859
6.	0	61.5377	61.5377	0	52.9137	52.9137
7.	110.551	57.5808	168.1359	112.6909	58.6932	171.3841
8.	0	163.0228	163.0228	0	169.1423	169.1423
9.	0	141.7184	141.7184	0	147.7805	147.7805
10.	0	76.4259	76.4259	0	80.6095	80.6095
11.	0	0	0	0	0	0
12.	0	0	0	0	0	0
13.	6.7154	9.5297	16.2451	7.4862	10.6236	18.1098

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14.	0	113.2145	113.2145	0	128.6278	128.6278
15.	43.6373	64.3396	107.9768	48.4550	71.4429	119.8979
16.	18.4858	11.9263	30.4121	21.2159	13.6877	34.9036
17.	0	0	0	0	0	0
18.	15.5568	12.9510	28.5078	17.9632	14.9543	32.9175
19.	0	122.1187	122.1187	0	138.0465	138.0465
20.	0	53.3961	53.3961	0	61.4568	61.4568
21.	361.9979	0	361.9979	402.1204	0	402.1204
22.	303.4934	0	303.4934	326.7817	0	326.7817
23.	376.6848	0	376.6848	427.7452	0	427.7452
24.	0	0	0	0	0	0

The above table gives the information about the cost allocated to different generators and loads for IEEE RTS 24bus system for the Z_{bus}based techniques. Though $Z_{bus}$the methods yield the same total transmission cost i.e TOTAL COST = $2627.246, it is inferred that the Z_{bus}technique allocates more usage to generators rather than
Demands and similarly allocates most of the cost to generators compared to demands. TheZ_{bus}^{avg} technique avoids the allocating most of the cost to generators than demands.

D.RED method.

Using Equation No 28, the desired load sharing/generation scheduling for the standard IEEE 24 bus RTS is calculated and is shown in Table III. All schedules are shown in MW with an assumption of same load of 250MW at each load bus.

Load Bus	**Power drawn from each Generator**										**Total Load (MW)**
No	**G1**	**G2**	**G7**	**G13**	**G15**	**G16**	**G18**	**G21**	**G22**	**G23**	
1	163.625	86.375	0	0	0	0	0	0	0	0	250
2	0	93.25	0	156.75	0	0	0	0	0	0	250
3	0	111.55	0	0	0	138.4495	0	0	0	0	250
4	0	87.775	0	0	162.225	0	0	0	0	0	250
5	0	58.35	0	0	0	0	191.65	0	0	0	250
6	0	126.675	0	0	0	0	0	123.325	0	0	250
7	149.725	0	100.275	0	0	0	0	0	0	0	250
8	0	149.725	65.825	0	0	0	34.4502	0	0	0	250
9	0	88.775	0	0	0	161.225	0	0	0	0	250
10	0	0	0	0	0	0	39.3497	210.6197	0	0	250
13	0	0	0	196.125	0	0	0	53.875	0	0	250
14	0	0	0	0	158.375	0	0	0	0	91.625	250
15	0	0	0	0	0	108.725	0	0	141.275	0	250
16	0	0	0	0	68.475	58.525	0	0	0	123	250
18	0	110.85	0	0	28.9499	0	0	0	0	110.1998	250
19	0	0	0	85.375	0	0	164.6235	0	0	0	250
20	0	0	0	99.7245	0	0	0	0	150.275	0	250
Total	313.35	913.325	166.1	537.9729	418.0244	466.925	464.5232	387.8192	291.55	324.825	4250

E. Evaluation of Transmission Charges

Total Generation of Generator 1 = 313.35MW
Total Generation of Generator 2 = 913.35MW
Total Generation of Generator 7 = 265.85MW
Total Generation of Generator 13= 438.25MW
Total Generation of Generator 15= 418.025MW
Total Generation of Generator 16= 466.925MW
Total Generation of Generator 18= 430.075MW
Total Generation of Generator 21= 387.82MW
Total Generation of Generator 22= 291.55MW
Total Generation of Generator 23= 324.825MW
Therefore, the total Generation cost = INR 1390745.915

The Transmission charges are considered as 10% of the Generation charges. Therefore, Transmission Charges = 10% X 1381256.50 = INR 138125.65. The transmission cost matrix □C_{LG}□ must be considered such that the Transmission Charges when evaluated come to approximately 10% of the Generation Charges. Here, in this case, the loss which has to be contributed by each generated is neglected. So the total amount of active power to be generated and transmitted by each generator to meet

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theload is given by $[P_{LG}]$. Therefore the total transmission costis given by $[P_{LG}] X [C_{LG}]$ which is calculated as shown in Table IV. It is to note that the authors have calculated only the transmission basic charges by RED method. Therefore, the Total Transmission Cost obtained will be the sum of all the elements of the above matrix = INR133133.9131 ≈ 10% of the Generation Charges.

It is to note that Table IV gives the total transmission cost by multiplying $[P_{LG}] X [C_{LG}]$ i.e (A generator's share in meeting a load)*(cost/MW in transferring the said share (power) for the distance between their location) . Hence, there is no need of any details for Table IV (row /column wise)

TABLE IV. EVALUATION OF TRANSMISSION BASIC CHARGES

363.05	467.78	461.42	469.63	479.81	456.21	401.97	448.25	469.33	499.99	499.99	499.99	499.99	499.99	461.67	499.99	499.99
467.76	366.91	458.40	467.26	478.23	452.74	499.99	444.15	466.90	499.99	377.00	499.99	499.99	499.99	458.66	466.49	499.99
461.47	458.42	373.54	460.82	473.95	443.48	499.99	433.18	371.09	499.99	499.99	499.99	439.77	467.58	450.54	499.99	499.99
469.68	467.25	460.82	363.93	479.51	455.51	499.99	447.44	468.83	499.99	500.01	397.24	499.99	455.55	442.28	500.00	500.00
279.85	278.21	273.95	279.49	252.80	270.44	299.99	252.40	279.26	285.57	299.99	300.01	299.99	299.98	474.13	239.62	299.99
456.26	452.70	443.44	455.51	470.44	374.95	499.99	424.09	455.02	396.09	473.44	499.99	500.02	500.01	443.83	499.99	499.99
402.00	499.99	499.99	499.99	499.99	499.99	370.08	473.56	499.99	499.99	499.99	499.99	499.99	499.99	499.99	499.99	460.16
448.39	444.18	433.22	447.49	452.45	424.18	473.64	388.27	446.89	494.60	500.03	500.04	500.04	500.05	433.66	477.35	473.89
469.33	466.88	371.19	468.83	479.27	455.00	499.99	446.79	364.28	499.99	499.99	499.99	429.87	464.23	460.61	499.99	499.99
499.94	499.95	499.94	499.95	485.51	396.04	499.95	494.48	499.95	316.28	454.56	499.93	499.95	499.96	499.95	473.99	499.94
500.00	377.02	500.00	500.00	500.00	473.42	500.00	500.00	500.00	454.61	334.53	500.00	500.00	500.00	500.00	433.02	500.00
500.00	500.00	500.00	397.23	500.00	500.00	500.00	500.00	500.00	500.00	500.00	366.08	500.00	411.54	441.27	500.00	500.00
500.00	500.00	439.78	500.00	500.00	500.00	500.00	500.00	429.88	500.00	500.00	500.00	372.89	474.54	500.00	500.00	415.07
500.00	500.00	467.58	455.56	500.00	500.00	500.00	500.00	462.26	500.00	500.00	411.54	474.54	404.02	437.85	500.00	500.00
461.71	458.65	450.53	442.29	474.12	443.83	500.00	433.61	460.63	500.00	500.00	441.27	500.00	437.85	398.92	500.00	500.00
499.99	446.46	499.99	499.99	439.63	499.99	499.99	477.30	499.99	474.07	474.07	499.99	499.99	499.99	499.99	362.43	499.99
499.10	499.10	499.10	499.12	499.13	499.10	459.29	472.86	499.10	499.10	499.10	499.10	414.17	499.10	499.10	499.10	369.34

IV. CONCLUSION

In this paper, three transmission network cost allocation methodologies are compared using standard 24 bus RTS. A complete analysis with a comparative study has been made on all the three techniques.Table I provides the transmission cost allocation to generators by Z_{BUS} technique. Table II shows the total transmission cost allocation for all the generators and demands by the first two techniques.From table II, it is inferred that both the above methods allocate most of the costs for using line 23 to generators 21, 22, and 23. This is because all the generators are electrically close to that line, and their productions are comparatively high.The RED method allocates the transmission charges based on the relative location of load nodes with respect to the generator nodes. This method is conceptually simple and can be implemented using the network configuration and generation/load conditions in a day-to-day operation of power systems. The main advantage of this method lies in its applicability to consider multiple contracts/transactions simultaneously. Comparing the overall transmission cost obtained in all the three techniques, RED method is very accurate in estimating and allocating the transmission cost in the transmission pricing scheme. From the results, it is also found that RED method is very effective in transmission cost allocation.

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