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A Unified Approach to Transmission Network Cost Allocation

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Abstract: This paper presents a new algorithm to the problem of allocating the cost of the transmission network to generators and demands. A physically-based network usage procedure is based on circuit theory which exhibits a desirable proximity effect according to the underlying electric laws used to derive them. This procedure gives desirable apportioning properties and is easy to implement and understand. A case study based on the 4-bus system is used to illustrate the working of the proposed technique. Some relevant conclusions are finally drawn.

***Keywords:*- Deregulation, Network usage, Z_{bus}**

I.INTRODUCTION

All electric power utilities throughout the world were operated with an organizational model in which one controlling authority the utility operated the generation, transmission, and distribution systems located in a fixed geographic area and it refers to as vertically integrated electric utilities (VIEU). Economists for some time had questioned whether this monopoly organization was efficient. With the example of the economic benefits to society resulting from the deregulation of other industries such as telecommunications and airlines, electric utilities are also introducing privatization in their sectors to improve efficiency. During the nineties many electrical utilities and power Network Company's world wide have been forced to change their ways of doing business from vertically integrated mechanism to open market system. This kind of process is called as deregulation or restructuring or unbundling. 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 and the necessity for deregulation is

(i) To provide cheaper electricity.

(ii) To offer greater choice to the customer in purchasing the economic Energy.

(iii) To give more choice of generation.

(iv) To offer better services with respect to power quality i.e. Constant voltage, Constant frequency and uninterrupted power supply.

The benefits that the customers and government will get with the deregulated power systems are

(i) Cheaper Electricity

(ii) Efficient capacity expansion planning at GENCO level, Transco level and disco level.

(iii) Pricing is cost effective rather than a set tariff.

(iv) More choice of generation.

(v) Better service is possible.

Some of the transmission lines. Hence, ISO has to relieve that congestion so that the system is maintained in secure state.

Power wheeling costs:

1. Rolled-In-Embedded Method or Postage Stamp Method: The rolled-in method assumes that the entire transmission system is used in wheeling, irrespective of the actual transmission facilities that carry the transaction. The cost of

2. Contract Path Method: The second traditional method, called the contract path method, is based upon the assumption that the power transfer is confined to flow along a specified electrically continuous path through the wheeling company's transmission system [2]. Note that changes in flows in facilities that are not within the identified path are ignored. The embedded capital costs, correspondingly, are limited to those facilities that lie along the assumed path.

A brief description of the most significant proposals reported in the technical literature on the allocation of the cost of the transmission network among generators and demands follows.

i).In the traditional pro rata method, both generators and loads are charged a flat rate per megawatt-hour, is regarding their respective use of individual transmission lines.

ii).Other more elaborated methods are flow-based .These methods estimate the usage of the lines by generators and demands and charge them accordingly. Some flow-based methods use the proportional sharing principle which implies that any active power flow leaving a bus is proportionally made up of the flows entering that bus, such that Kirchhoff's current law is satisfied.

3. Other methods that use generation shift distribution factors are dependent on the selection of the slack bus and lead to controversial results.

4. The usage-based method uses the so-called equivalent bilateral exchanges (EBEs).

To build the EBEs, each demand is proportionally assigned a fraction of each generation, and conversely, each generation is proportionally assigned a fraction of each demand, in such a way as both Kirchhoff's laws are satisfied.

The technique presented in this project is related to the allocation of the cost of transmission losses based on Z_{bus} matrix approach. It should be emphasized that all transmission lines must be modeled to include actual shunt admittances and taps.

Doing so, the impedance matrix presents an appropriate behavior of all the elements of the transmission network. A salient feature of the proposed technique is its embedded proximity effect, which implies that a generator/demand uses mostly the lines electrically close to it. This is not artificially imposed but a result of relying on circuit theory.

This proximity effect does not take place if the equivalent bilateral exchanges (EBE) principle is used, as this principle allocates the production of any generator/demand proportionally to all loads/generators, which implies treating "close by" and "far away" lines in same manner .the proximity effect is ignored.

Other techniques require stronger assumptions, which diminish their practical interest. Applying the proportional sharing principle implies imposing that principle, and using the pro-rata criterion implies disregarding altogether network Locations. Particularly, it should be noted that the proposed methodology simply relies on circuit laws in identifying the contribution factors, while the proportional sharing technique relies on the proportional sharing principle.

II TRANSMISSION NETWORK COST ALLOCATION USING Z_{bus} TECHNIQUE:

This methodology starts from a converged load flow solution which gives the entire information pertaining to the network such as bus voltages, complex line flows, slack bus power generation etc. The purpose of the methodology presented in this work is to allocate the cost pertaining to the transmission lines of the network to all the generators and demands. Once a load flow solution is available, the proposed method determines how line flows depend on nodal currents. This result is then used to allocate network costs to generators and demands [3].

The equivalent circuit of a line having a line with primitive admittance j_{jk} and half line charging susceptance y_{jk}^{sh} connected between the buses j and k is shown in Fig.1 [10]. v_j and v_k represent the nodal voltages of buses j and k respectively.

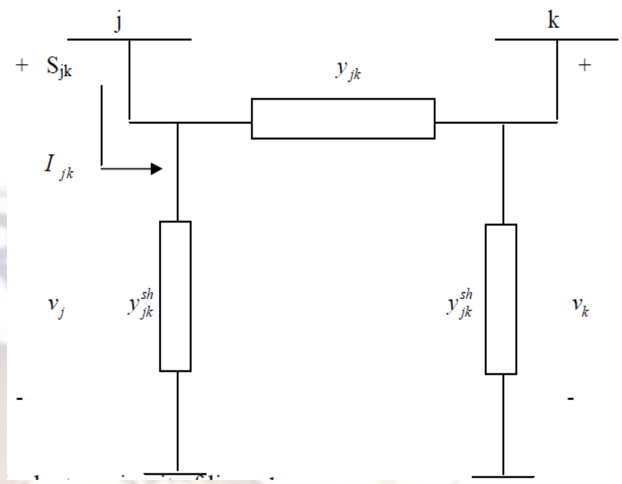

Fig. 1 Equivalent π- circuit of line *jk* .

From the load flow solution we can write expression for the complex line flow S_{jk} in terms of the node voltage and the line current I_{jk} through the line *jk* as

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

The voltage at node *j* in terms of the elements of bus impedance matrix Z_{bus} and the nodal current I_i is given by (from $V_{bus} = Z_{bus} I_{bus}$)

$$V_j = \sum_{i=1}^{n} Z_{jk} \qquad (2)$$

Where z_{ji} is the element ji of z_{bus} and 'n' is the total number of buses. Current through the line *jk* can be written as

$$I_{jk} = (V_j - V_K)\, y_{jk} + V_j\, y_{jk}^{sh} \qquad (3)$$

Substituting (2.2) in (2.3) and rearranging

$$I_{jk} = \sum_{i=1}^{n} [(Z_{ji} - Z_{Ki})\, y_{jk} + Z_{ji}\, y_{jk}^{sh}]\, I_i \qquad (4)$$

At this stage, we wish to make eq. (4) as dependent on P_{gen}, Q_{gen}, P_{load} and Q_{load} of the bus-i. This would help in building up the relevant mathematical support in identifying the contribution of each generator and load on the line flow jk.this aspect is considered in proposing new technique [4].

From the load flow analysis, the nodal current can be written as a function of active and reactive power generations at bus i (P_{gen}^i *and* Q_{gen}^i respectively) and the active and reactive load demands at bus i(P_{load}^i *and* Q_{load}^i respectively) as

$$I_i = \frac{(P_{gen}^i - P_{load}^i) - j\,(Q_{gen}^i - Q_{load}^i)}{V_i^*} \qquad (5)$$

Note that the first term of the product in (4) is constant, as it depends only on network parameters. Thus, (4) can be written as

$$I_{jk} = \sum_{i=1}^{n} a_{jk}^i\ I_i \qquad (6)$$

Where

$$a_{jk}^i = (Z_{ji} - Z_{Ki})\, y_{jk} + Z_{ji}\, y_{jk}^{sh} \qquad (7)$$

Observe that the magnitude of parameter a_{jk}^{i} provides a measure of the *electrical distance* between bus i and line jk.
Substituting (6) in (1)

$$S_{jk} = V_j \sum_{i=1}^{n} (a_{jk}^{i} I_i)^* = \sum_{i=1}^{n} V_j a_{jk}^{i*} I_i^* \quad (8)$$

Then, the active power through line jk is

$$P_{jk} = \hat{R}\{\sum_{i=1}^{n} V_j a_{jk}^{i*} I_i^*\} \quad (9)$$

or, equivalently

$$P_{jk} = \sum_{i=1}^{n} \hat{R}\{V_j a_{jk}^{i*} I_i^*\} \quad (10)$$

Note that the terms in the summation represent contribution due to each bus - I_i Thus, the active power flow through any line can be identified as function of the nodal currents in a direct way. Then, the active power flow through line jk due to the nodal current I_i is

$$P_{jk}^{i} = \hat{R}(V_j a_{jk}^{i*} I_i^*) \quad (11)$$

Transmission Cost Allocation:

Following (11), we define the usage of line jk due to nodal current as the absolute value of the active power flow component P_{jk}^{i} , i.e.,

$$U_{jk}^{i} = |P_{jk}^{i}| \quad (12)$$

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

$$U_{jk} = \sum_{i=1}^{n} U_{jk}^{i} \quad (13)$$

Then, we proceed to allocate the use of transmission line jk to any generator and demand. Without loss of generality, we consider at most a single generator and a single demand at each node of the network. Then, the usage of line jk apportioned to the generator or demand located at bus is stated below[5]. If bus i contains only generation, the usage allocated to generation pertaining to line jk is

$$U_{jk}^{Gi} = U_{jk}^{i} \quad (14)$$

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

$$U_{jk}^{Di} = U_{jk}^{i} \quad (15)$$

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

$$U_{jk}^{Gi} = [P_{Gi} / (P_{Gi} + P_{Di})] \quad (16)$$

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

$$U_{jk}^{Di} = [P_{Di} / (P_{Di} + P_{Gi})] \quad (17)$$

The complex power flow components through line jk due to individual power generations and load demands have been found out. Having found the of individual generators and demands in each of the line flows and the usage of line by those generations and demands, allocation of transmission cost among generators and demands can be found out. Let C_{jk} in \$/h, represents the total annualized line cost including operation, maintenance and building costs [6].
Then the per unit usage cost rate r_{jk} can be written as

$$r_{jk} = \frac{C_{jk}}{U_{jk}} \quad (18)$$

Using the per unit cost rate, we can write, C_{jk}^{Gi}, the allocated cost of line jk to the generator 'i' located at bus 'i' is

$$C_{jk}^{Gi} = r_{jk} U_{jk}^{Gi} \quad (19)$$

In the same way, we can write, C_{jk}^{di}, the allocated cost of line jk to the demand 'i' located at bus 'i' is

$$C_{jk}^{Di} = r_{jk} U_{jk}^{Di} \quad (20)$$

The total transmission network cost C^{Gi}, allocated to generator 'i' is

$$.C^{Gi} = \sum_{(j,k) fornl\ ines} C_{jk}^{Gi} \quad (21)$$

Where 'nline' represents the set of all transmission lines present in the system.

Similarly, the total transmission cost, C^{Di} , allocated to the demand 'i' is given as

$$C^{Di} = \sum_{(j,k) fornlines} C_{jk}^{Di} \quad (22)$$

III.TRANSMISSIONNETWORKCOST ALLOCATION USING Z_{bus}^{avg}TECHNIQUE:

Following (11), we define the usage of line jk due to nodal current as the absolute value of the active power flow component P_{jk}^{i} , i.e.,

$$U_{jk}^{i} = |P_{jk}^{i}| \quad (12)$$

Usage allocated to the line by interchanging the 'from bus' and 'to bus' i.e

$$U1_{jk} = \sum_{j=1}^{n} U1_{jk}^{i} \quad (13)$$

The factor per unit usage cost rate r1jk interchanging 'from bus' and 'to bus'

$$r1_{jk} = \frac{C_{jk}}{U1_{jk}} \quad (14)$$

The generation i cost contributions for using line jk Interchanging 'from bus' and 'to bus'

$$C1_{jk}^{Gi} = r_{1jk} U1_{jk}^{Gi} \quad (15)$$

The load cost contributions for using line jk Interchanging 'from bus' and 'to bus'

$$C1_{jk}^{Di} = r_{1jk} U1_{jk}^{Di} \quad (16)$$

The cost of contribution of generator i using all the lines in the network

$$C^{Gi} = \sum_{(j,k)\ nline} C^{Gi}_{jk} \quad (17)$$

The cost of contribution of generator i using all the lines in the network interchanging 'from bus' and 'to bus'

$$C1^{Gi} = \sum_{(j,k)\ nline} C^{Gi}_{j1k} \quad (18)$$

The cost of contribution of load i using all the lines in the network

$$C^{Di} = \sum_{(j,k)\ nline} C^{Di}_{jk} \quad (19)$$

The cost of contribution of load i using all the lines in the network interchanging 'from bus' and 'to bus'

$$C1^{Di} = \sum_{(j,k)\ nline} C1^{Di}_{jk} \quad (20)$$

The average cost contribution of generator i using the line jk

$$Cavg^{Gi}_{jk} = \frac{C^{Gi}_{jk} + C1^{Gi}_{jk}}{2} \quad (21)$$

The average cost contribution of load i using the line jk

$$Cavg^{Di}_{jk} = \frac{C^{Di}_{jk} + C1^{Di}_{jk}}{2} \quad (22)$$

The average cost contribution of generator i using all the lines in the network

$$Cavg^{Gi} = \sum_{(j,k)=fornilines} Cavg^{Gi}_{jk} \quad (23)$$

The average cost contribution of load i using all the lines in the network

$$Cavg^{Di} = \sum_{(j,k)=fornilines} Cavg^{Di}_{jk} \quad (24)$$

IV.TRANSMISSIO NNETWORK COST ALLOCATION MODIFIED Z^{avg}_{bus} TECHNIQUE:

Here equation (6) becomes

$$S_{jk} = \sum_{i=1}^{n} Factor^{i}_{jk} \left[(P^{i}_{gen} - P^{i}_{load}) + j(Q^{i}_{gen} - Q^{i}_{load})\right] \quad (6)$$

Where

$$Factor^{i}_{jk} = \frac{V_j\left[(Z_{ji} - Z_{ki})y_{jk} + Z_{ji} Y^{sh}_{jk}\right]^*}{V_i} \quad (7)$$

Thus , the active and reactive power flow S_{jk} through any line *jk* is represented as a function of the power generation and load at all buses
i.e

P^{i}_{gen} P^{i}_{load}, Q^{i}_{gen} and Q^{i}_{load} : i=1, 2,3….n

Then equation (6) becomes

$$S_{jk} = \sum_{j=1}^{n} (S1^{i}_{jk} + S2^{i}_{jk} + S3^{i}_{jk} + S4^{i}_{jk}) \quad (8)$$

Where

$$S1^{i}_{jk} = Factor^{i^*}_{jk} P^{i}_{gen},\ S2^{i}_{jk} = Factor^{i^*}_{jk} P^{i}_{load}$$
$$S3^{i}_{jk} = Factor^{i^*}_{jk} Q^{i}_{gen}\ S4^{i}_{jk} = Factor^{i^*}_{jk} Q^{i}_{load}$$

Note that, for a converged load flow solution, the magnitude of parameter "$Factor^{i}_{jk}$" provides a measure of the electrical distance between bus i and line jk .

Thus, the component of complex power flow due to bus i through a line *j k* associated with the bus power generation and demand at bus i can be written as

$$S^{i}_{jk} = S1^{i}_{jk} + S2^{i}_{jk} + S3^{i}_{jk} + S4^{i}_{jk} \quad (9)$$

Thus, usage of line *jk* by generator 'i' can be written as

$$U^{Gi}_{jk} = \left|\acute{R}(S1^{i}_{jk})\right| + \left|\acute{R}(S3^{i}_{jk})\right| \quad (10)$$

Similarly, the usage of line *jk* by demand 'i', is

$$U^{Di}_{jk} = \left|\acute{R}(S2^{i}_{jk})\right| + \left|\acute{R}(S4^{i}_{jk})\right| \quad (11)$$

The usage of line by bus ' i' U^{i}_{jk} is then given by

$$U^{i}_{jk} = U^{Gi}_{jk} + U^{Di}_{jk} \quad (12)$$

The total usage of line *jk* ,U_{jk} by all buses, then

$$U_{jk} = \sum_{i=1}^{n} U^{i}_{jk} \quad (13)$$

The complex power flow components through line *jk* due to individual power generations and load demands have been found out directly without much additional complexity and computation

Having found the contributions of individual generators and demands in each of the line flows and the usage of line by those generations and demands, allocation of transmission cost among generators and demands can be found out.

Let C_{jk} in $/h, represents the total annualized line cost including operation, maintenance and building costs [8].

Cost of each line, C_{jk} is considered to be proportional to its series reactance x_{jk} i.e

$$C_{jk} = x_{jk} X1000\$/h \quad (14)$$

Then the per unit usage cost rate r_{jk} can be written as

$$r_{jk} = \frac{C_{jk}}{U_{jk}} \quad (15)$$

Using the per unit cost rate, we can write, C_{jk}^{Gi}, the allocated cost of line jk to the generator 'i' located at bus 'i' is

$$C_{jk}^{Gi} = r_{jk} U_{jk}^{Gi} \quad (16)$$

In the same way, we can write, C_{jk}^{di}, the allocated cost of line jk to the demand 'i' located at bus 'i' is

$$C_{jk}^{Di} = r_{jk} U_{jk}^{Di} \quad (17)$$

The total transmission network cost C^{Gi}, allocated to generator 'i' is

$$.C^{Gi} = \sum_{(j,k) fornli\ nes} C_{jk}^{Gi} \quad (18)$$

Where 'nline' represents the set of all transmission lines present in the system.

Similarly, the total transmission cost, C^{Di}, allocated to the demand 'i' is given as

$$C^{Di} = \sum_{(j,k) fornlines} C_{jk}^{Di} \quad (19)$$

It is to be noted that complex power flow equation (8) can be written either in the direction of Active power flow i.e. $P_{jk} \geq 0^3$ or in the direction of active power counter flows [3].
This way to write equation (8) leads to electrical distance parameters $Factor_{jk}^{i}$ and $Factor_{kj}^{i}$ .However, equation(7) shows that distance parameters are not generally symmetrical with respect to line indexes, i.e.,$Factor_{jk}^{i} \neq Factor_{kj}^{i}$. Which results in different usage allocations depending on whether equation (8) is written in the direction of the active power flows or counter-flows [see equation (10)–(11)]. The proposed usage based technique takes the average value of allocated cost (usage) obtained

1) With eqn (8) written in the direction of the active power flows and

2) With eqn (8) written in the direction of the active power counter-flows.

V. ALGORITHM FOR TRANSMISSION NETWORK COST ALLOCATION USING MODIFIED Z_{bus}^{avg} TECHNIQUE:

1)

a. Read the system line data and bus data
   - Line data: From bus, to bus, line resistance, line reactance, half-line charging Susceptance and off nominal tap ratio.
   - Bus data: Bus no, Bus type P_{gen} ,Q_{gen} , P_{load} , Q_{load} and Shunt capacitor data.

b. Form Y_{bus} using sparsity technique.

2) Start

a. k_1=1 iteration count
b. Set |Δ P_{max} |=0.0, |Δ Q_{max} |=0.0
c. Cal P_{shed} (i), Q_{shed} (i), for i=1 to n

Where

$$P_{shed}(i) = P_{gen}(i) - P_{load}(i)$$

$$Q_{shed}(i) = Q_{gen}(i) - Q_{load}(i)$$

d) Calculate

$$P_{Cal}(i) = \sum_{i=1}^{n} |V_i||V_q||V_{iq}| \cos(\delta_{iq} - \Theta_{iq})$$

$$Q_{Cal}(i) = \sum_{i=1}^{n} |V_i||V_q||V_{iq}| \sin(\delta_{iq} - \Theta_{iq})$$

e) Calculate

$$\Delta P(i) = P_{shed}(i) - P_{Cal}(i)$$

$\Delta Q(i) = Q_{shed}(i) - Q_{Cal}(i)$ for i=1 to n Set ΔP_{Slack} =0.0, ΔQ_{Slack} =0.0,

f) Calculate
|Δ P_{max} | and |Δ Q_{max} | form [Δp] and [ΔQ] vectors

g) Is |Δ P_{max} | $\leq \in$ and |Δ Q_{max} | $\leq \in$
If yes, go to step no. "f"

3) Form Jacobean elements:
   i. Initialize A[i][j]=0.for i=1 to 2n , j=1 to 2n
   ii. Form diagonal elements
       H_{pp} , N_{pp} , M_{pp} & L_{pp}
   iii. Form off – diagonal elements
       H_{pq} N_{pq} , M_{pq} & L_{pq}
   iv. Form right hand side vector (mismatch vector)
       B[i] = ΔP[i] , B[i+n]= ΔQ[i] for i=1 to n

   V Modify the elements For p=slack bus;
       H_{pp} =1e20=10^{20}; L_{pp} =1e20=10^{20};

4) Use Gauss – Elimination method for following
   [A] [ΔX] = [B]

Update the phase angle and voltage magnitudes

i=1 to n For type=1 &2,

Calculate

$\delta_i = \delta_i + \Delta X_i$ &

$V_i = V_i + \{\Delta X_{(i+n)}\} V_i$

5) One iteration completed
Advance iteration count $k_1 = k_1 + 1$

If (k_1< itermax) then go to step 2(b) else print problem is not converged in "itermax" iterations, Stop.

6) Print problem is converged in 'iter'no. of iterations.

- Calculate line flows
- Bus powers, Slack bus power
- Print the converged voltages, line flows and powers.

7) Form the bus impedance matrix Z_{bus}.
(Z_{bus} is calculated using Y_{bus}^{-1})

8) Do for all the lines in the system, 1 to n line

A. If the active power-flow direction is 'from bus' to 'to bus'

a) Do for all the buses from 1 to n

i) Calculate $Factor_{jk}^{i}$, $S1_{jk}^{i}$, $S2_{jk}^{i}$, $S3_{jk}^{i}$, $S4_{jk}^{i}$

U_{jk}^{Gi}, U_{jk}^{Di} and U_{jk}^{i} using the equations given

eq. (7) to eq. (12)

ii) Obtain the values of $Factor1_{jk}^{i}$, $S11_{jk}^{i}$, $S21_{jk}^{i}$, $S31_{jk}^{i}$, $S41_{jk}^{i}$

$U1_{jk}^{Gi}$, $U1_{jk}^{Di}$ and $U1_{jk}^{i}$ by interchanging the 'from bus' and 'to bus'

and repeating step a)

End of Do loop

b) Find usage allocated to the line jk

$$U_{jk} = \sum_{i=1}^{n} U_{jk}^{i}$$

c) Find usage allocated to the line by interchanging the 'from bus' and 'to bus'

$$U1_{jk} = \sum_{i=1}^{n} U1_{jk}^{i}$$

Else

Assign 'from bus' as 'to bus' and 'to bus' as 'from bus' and repeat steps 1), 2) & 3)

End of if

B. Do for each bus, 1 to n

a) Determine the contributions of generators and loads paying for using the line jk , r_{jk} C_{jk}^{Gi} , C_{jk}^{Di} using equations (14), (15) and (16)

b) Find the factor per unit usage cost rate $r1_{jk}$ interchanging 'from bus' and 'to bus'

$$r1_{jk} = \frac{C1_{jk}}{U1_{jk}^{Gi}}$$

c) Find the generation i cost contributions for using line jk interchanging 'from bus' and 'to bus'

$$C1_{jk}^{Gi} = r1_{jk} U1_{jk}^{Gi}$$

d) Find the load cost contributions for using line jk inter changing 'from bus' and 'to bus'

$$C1_{jk}^{Di} = r1_{jk} \ U1_{jk}^{Di}$$

End of bus Do loop

End of line Do loop

9) Find the cost of contribution of generator i using all the lines in the network

$$C^{Gi} = \sum_{(j,k)\in nline} C_{jk}^{Gi}$$

10. Find the cost of contribution of generator i using all the lines in the network

Inter changing 'from bus' and 'to bus'

$$C1^{Gi} = \sum_{(j,k)\in nline} C1_{jk}^{Gi}$$

11. Find the cost of contribution of load i using all the lines in the network

$$C^{Di} = \sum_{(j,k)\in nline} C_{jk}^{Di}$$

12. Find the cost of contribution of load i using all the lines in the network

Inter changing 'from bus' and 'to bus'

$$C1^{Di} = \sum_{(j,k)\in nline} C1^{Di}_{jk}$$

13. Do for all lines

Do for all the buses

A) Find the average cost contribution of generator i using the line jk

$$Cavg^{Gi}_{jk} = \{C^{Gi}_{jk} + C1^{Gi}_{jk})\}/2$$

B) Find the average cost contribution of load i using the line jk

$$Cavg^{Di}_{jk} = \{C^{Di}_{jk} + C1^{Di}_{jk})\}/2$$

End of bus loop

End of line loop

14. Find the average cost contribution of generator i using all the lines in the network

$$Cavg^{Gi} = \sum_{jk=foralllines} Cavg^{Gi}_{jk}$$

15. Find the average cost contribution of load i using all the lines in the network

$$Cavg^{Di} = \sum_{jk=foralllines} Cavg^{Di}_{jk}$$

VI. CASE STUDY 4-BUS SYSTEM:

The proposed usage based technique has been illustrated with the help of a sample four bus, 5 line systems shown in Fig. 2 All the lines have equal per unit resistance, reactance and half line charging susceptance of 0.01275, 0.097, 0.4611 respectively. For the sake of simplicity either a single generator or a single load demand of 250 MW has been taken at each bus. Finally, cost of each line, C_{jk} is considered to be proportional to its series reactance x_{jk} i.e.

$$C_{jk} = x_{jk} \times 1000 \text{ \$/h.}$$

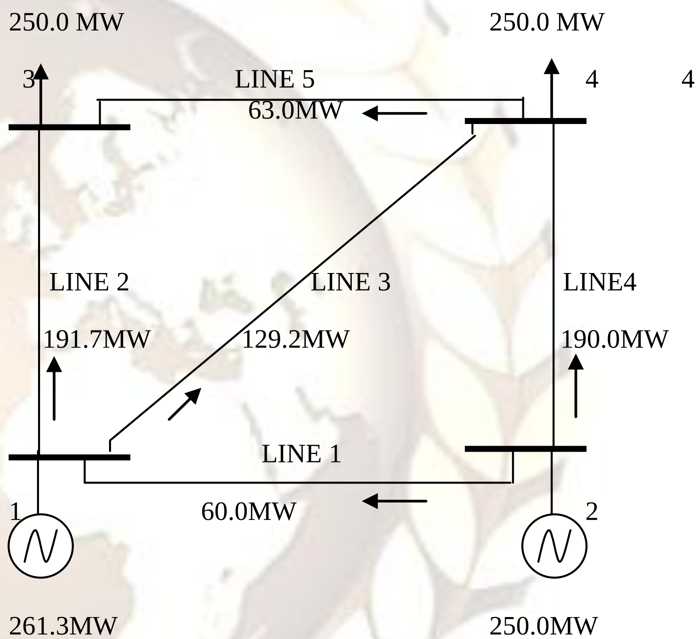

Fig.4. 2 Four Bus System

Comparison of Z_{bus} based techniques:

I) Using Z_{bus} technique :

Bus	CG	CD	TOTAL COST
1	128.3219	0	128.3219
2	183.331	0	183.331
3	0	78.31983	78.31983
4	0	95.02724	95.02724

II) Using Z_{bus}^{avg} Technique :

Bus No	CGAVG(I)	CDAVG(I)	TOTAL COSTAVG(i)
1	112.7502	0	112.7502
2	129.8906	0	129.8906
3	0	132.6402	132.6402
4	0	109.7191	109.7191

III) Using Z_{bus}^{avg} Technique:

Bus No	nCGAVG	nCDAVG	TOTAL AVGCOST
1	115.0558	0	115.0558
2	132.7739	0	132.7739
3	0	129.8807	129.8807
4	0	107.2896	107.2896

VII. CONCLUSION:

In the present open access restructured power system market, it is necessary to develop an appropriate pricing scheme that can provide the useful economic information to market participants, such as generation, transmission companies and customers. However, accurately estimating and allocating the transmission cost in the transmission pricing scheme is a challenging task although many methods have been proposed.

The Modified Z_{bus}^{avg} method contributes to seek an appropriate solution to this allocation problem using an usage-based procedure that relies on circuit theory. In this method the factors S1, S2, S3, S4 for forward flows and S11, S21, S31, S41 for reverse direction flows have offered very useful information about the contribution of generator buses and load buses towards the line flow of line jk. Rigorous calculations without any approximations are possible and cost allocation results would be more reliable and accurate compared to other methods.

For the above three techniques developed and implemented in MATLAB and applied to 4-bus system. This new procedure exhibits desirable apportioning properties and is easy to implement and understand. Case studies on 4-bus system are used to illustrate the working of the proposed techniques.

VII. REFERENCES

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