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Transmission Active Power Loss Allocation to Loads using Power Flow Tracing

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Abstract*—Now a day, the electrical network was restructured, to access power from any generator to any load. In real time, it is very difficult to make this type of transactions because of the transmission system constraints. Sometimes, the total active power losses may increase and finally system becomes unstable. Further, the cost of the total power losses should allocate either to the generators or loads. Normally, the voltage magnitude at generating plants was controlled but the voltage magnitude at load buses was not controlled. Hence it is always suggestible in analyzing the effect of loss allocations to loads. In this paper, a novel loss allocation strategy is proposed to allocate losses among the available loads. As the proposed methodology utilizes the process power flow tracing and increases the effectiveness of the problem solution. Numerical results are provided for the standard IEEE-5 bus, 30 bus and Indian-24 bus test systems with supporting validations using Bialek method.

Index Terms*—Trace usage based coefficients, Transmission power flow tracing, Proportional sharing principle, Bialek downstream algorithm.

I. INTRODUCTION

In the interconnected systems, power flows in the transmission lines in which how the power flows between generator/ loads and flows. The tracing of power permits the system operator to incorporate the level of system usage for pricing the transmission services. It also helps to estimate some of the resources required in the form of ancillary services. The first and foremost step in the power system is unbundling of transmission services. From which, the share of each source in each sink and power flows are determined. This method can be extended to not only for active power but reactive power also. In meshed network, the loads receive power from the sources through many paths of transmission lines. With the conventional load flow, it is not possible to know the share of each generator in each load and reach flow. Hence, the importance grows for the tracing of power in meshed network. In open electricity market, loss must be allocated for efficient transparent system in which the share of each generator in each load and line flows is to be determined. In the literature, many number of loss allocation techniques are exist but any technique does not give acceptable to all participants. In short, we need to know the contributions of individual generators and loads to line flows and to the losses in the transmission system. Similarly, the contractual obligations of utilities are maintained in deregulated system while allocating the loss to consumer/ Discom companies.

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A graph theory is applied in [1] to solve the problem of active power flow tracing; the same technique can be extended to reactive power tracing also. The power losses in the lines are given to one of the end buses in each line. If some power is injected at one of the two end nodes of a line, the two injections are treated as loads at the two nodes and the line is considered to be open circuit. The methodology developed in [2] is again considered in [3] for reactive power flow tracing in networks having convection lines, namely lines in which the reactive flows at the two ends have opposite directions; for these lines, an equivalent nominal-T line model replaces the nominal Π-model. At the central node, a fictitious reactive load is considered; it is equivalent to the summation of the reactive powers required by the shunt admittances of the nominal Π-model. The original system modified in this way is solved a second time and the results of the latter load flow are used for reactive power tracing. The mutual influence between active and reactive flows in the lines through the losses is dealt with in [4] where, for each line, the total differential of the active loss and its components (the partial differentials) are determined. Starting from these differentials, the complex power flows are determined on each line as the summation of components – allocated at the single generators – both of the powers sent to the loads and of the losses. The implementation of the methodology and the results of some applications are reported in [5]. Path integrals are used in loss allocation which is accurate. A new path-integral method has been discussed by integrating the partial differential of the system. The accuracy in loss allocation is enhanced by path-integral of nonlinearity. AC power flow improves the additional accuracy [6]. The major factors in the locational spot pricing is transmission loss allocation amounting 3-5% of total generation [7]. The Gencos are affected considerably by loss allocation which is fair and transparent manner. The transmission loss allocation does not include in the spot pricing since loss allocation is nonlinear and path dependency. In [8], an attempt is made that the difference between the sum of theoretically allocated losses and the actual system loss are reduced. The distributed slack bus is adopted to remove the slack-bus dependency in loss allocation. The proposed algorithm provides accurate loss allocation in the sense that the sum of allocated losses is exactly equal to the actual loss given by the ac power-flow. In [9] the concept of distributed slack bus is introduced. In this method loses allocated to busses are exactly equal to actual loss which is given by ac power flow. In [10-16], By using general conventional theories, based on sensitivity analysis, fail to establish loss allocation, the total loss allocation is not equal to the actual loss. Galiana [17, 18] initiated electric power transactions to determine the loss allocation by integrating loss with the system trajectory determined by the acceptance order of power transactions. Though accepting a

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pair of bilateral transactions has been treated as jumps in generation and load in the paired busses, resulting discrete integration which leads to allocations errors. In [19], the zonal loss factors are obtained with the help of nodal generation loss factors based on electrical proximity of the nodes to the centers. The loss allocation is done based on zone centers. Further, a method for automated zonal pattern with economic aspects is presented. The number of zones is determined. By performing an exhaustive search using this algorithm for the best initial root node, an optimal zonal pattern can be identified. Real power and real power loss of individual generators to system loads are allocated. Both allocation procedures are conducted independently and it is based on current operating point of the system, computed through AC load flow program [20]. The current of the load buses is obtained from Y-bus as a function of the generators' current and load voltage. Modified Y-bus is obtained. Finally, loss allocation is done based on modified Y-bus. In addition to generators contribution factors to the consumers are equally significant in optimizing the benefit to the market participants. In [21], A market participant who sends more losses must be charged more, on the other hand others who causes less network must be charged less. So, there are many loss allocation techniques in the literature such as pro-rata, marginal loss, proportional sharing assumptions, circuit theory and different techniques for bilateral trades Conejo et al. [22-24]. An incremental transmission loss (ITL) coefficient was recently presented by Leite da Silva and Costa [25]. However, this method depends on the location of the slack bus, and hence different slack buses will result in different ITLs. The incremental transmission loss (ITL) coefficients are determined and loss allocation is done based on ITLs. The disadvantage of this method is losses are depends on slack bus. Another drawback of the method is that it gives negative loss allocation. Finally, in [26] a method is used in which individual bilateral transactions are incremented along a path of variation. Individual bilateral transaction may elect to have its losses supplied by a separate slack generator. Once the path of variation and the loss suppliers are specified, the incremental contract loss allocations and their sums are calculated. The main difficulty in allocating line losses to loads, generators or to bilateral contracts is that, regardless of the approach, the final allocation always contains a degree of arbitrariness. This is due to the fact that the system transmission losses are a non-separable, nonlinear function of the bus power injections which makes it not possible to divide the system losses into the sum of terms, each one uniquely attributable to a generation or load. Thus, the issue of fairness will probably never be fully resolved by any loss allocation method. Nevertheless, it is possible to identify a number of characteristics in a loss allocation scheme that are, arguably, reasonable and necessary for the scheme to be equitable or, at least, acknowledged as equitable. These characteristics are also useful in the comparison of the various approaches proposed in the literature. In [2], transmission losses are allocated and costs are presented taking into account pool and bilateral contract hybrid deregulated power market. The transmission loss is allocated according to a mathematical relationship between the node power and the line power flow for a DC power network. By the proposed method, the authors not only can allocate total loss to either generator or load node, respectively, but also can distribute it to both generator and load nodes conveniently. In [27], reactive power flow tracing in electrical transmission networks is discussed. For such systems, the tracing methods used for real active power flows cannot be used directly, due to reactive power generated by the line non resistance parameters, these generated reactive power, which flows in the transmission lines, often being considerable amount to the powers delivered to the loads causing tracing of reactive power is more critical. In this paper, a novel transmission loss allocation strategy is presented to allocate losses among the loads alone. The proposed methodology utilizes the real time power flow conditions. The proportional sharing principle is used to trace the active power flow in the transmission lines and to the loads. Using Newton Raphson load flow solution, the total active power losses in a given system are calculated. To allocate these losses among loads, trace usage based coefficients are framed. The proposed methodology is tested on standard IEEE-5 bus, 30 bus and real time Indian-24 bus test system with supporting numerical results and are compared with the results of existing Bialek method.

II. POWER FLOW TRACING MECHANISM

Power flow tracing methodology [28] is normally used for calculating generator's share in line flows and loads. After finding generator's share in loads, traced-usage coefficients can be framed for the traced-usage methodology. In this section, procedure of power flow tracing and procedure to formation of traced-usage coefficients can be illustrated. Consider a bus having two inflows and two outflows as it is convenient to analyze and shown in Fig.1.

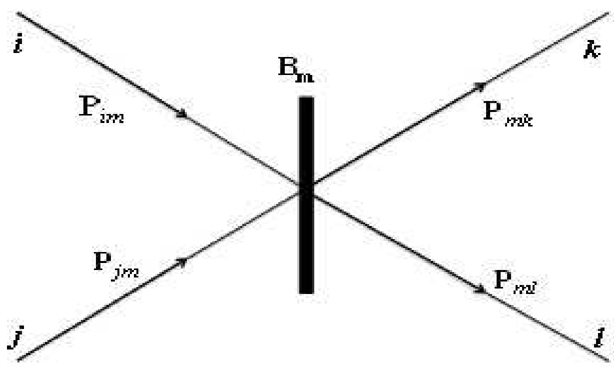

Fig. 1. Proportional Sharing Principal at Bus Bm

In Fig.1, Bm is the bus at which power flow tracing explanation is evaluated. i,j,k and l represents the buses which are connected to Bm through power lines. Pim and Pjm are power inflows to bus Bm. Pmk and Pml are power outflows from bus Bm. The following mathematical modeling is made, from Fig.1, the voltage at bus m can be expressed in terms of branch impedance Zmk and its current flow Imk, or of Zml and Imk:

$$V_m = Z_{mk} I_{mk} = Z_{ml} I_{ml} \tag{1}$$

Above equation can be alternatively expressed as the product of the total injected current into bus m and the equivalent impedance as seen from bus m.

$$V_m = \left(\frac{Z_{mk} Z_{ml}}{Z_{mk} + Z_{ml}} \right) I_T \tag{2}$$

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where, $I_T = I_{im} + I_{jm}$

By solving Eq's (1) and (2), gives

$$I_{mk} = \left(\frac{Z_{ml}}{Z_{mk}+Z_{ml}}\right) I_T \; ; \; I_{ml} = \left(\frac{Z_{mk}}{Z_{mk}+Z_{ml}}\right) I_T$$

An expression for the power flow in branch m-k may be derived as a function of the powers contributed by inflows i-m and j-m:

$$S_{mk} = V_m I_{mk}^* = V_m \left(\frac{Z_{ml}^*}{Z_{mk}^*+Z_{ml}^*}\right)\left(I_{im}^* + I_{jm}^*\right)$$

$$= \left(\frac{Z_{ml}^*}{Z_{mk}^*+Z_{ml}^*}\right)\left(S_{im} + S_{jm}\right) \qquad (3)$$

Where, $S_{im} = V_m I_{im}^*$ and $S_{jm} = V_m I_{jm}^*$

Similarly, the power flow in branch m-l is:

$$S_{ml} = \left(\frac{Z_{mk}^*}{Z_{mk}^*+Z_{ml}^*}\right)\left(S_{im} + S_{jm}\right) \qquad (4)$$

Impedances can be written as

$$Z_{mk} = \frac{V_m^2}{S_{mk}^*} \quad and \quad Z_{ml} = \frac{V_m^2}{S_{ml}^*} \qquad (5)$$

Eqn's (3) and (4) can be modified by using above Eqn (5)

$$S_{mk} = \left(\frac{S_{mk}}{S_{mk}+S_{ml}}\right) S_{im} + \left(\frac{S_{mk}}{S_{mk}+S_{ml}}\right) S_{jm} \qquad (6)$$

$$S_{ml} = \left(\frac{S_{ml}}{S_{mk}+S_{ml}}\right) S_{im} + \left(\frac{S_{ml}}{S_{mk}+S_{ml}}\right) S_{jm} \qquad (7)$$

The following power conservation relation should be noted as

$$S_{im} + S_{jm} = S_{mk} + S_{ml}$$

By using above relation, both Eqn's (6) and (7) can be rewritten as

$$S_{mk} = \left(\frac{S_{im}}{S_{im}+Sjm} + \frac{S_{jm}}{S_{im}+Sjm}\right) S_{mk}$$

$$S_{ml} = \left(\frac{S_{im}}{S_{im}+Sjm} + \frac{S_{jm}}{S_{im}+Sjm}\right) S_{ml}$$

Separation of real and imaginary components in above equations can be used to further process of loss allocation.

$$P_{mk} = \left(\frac{P_{im}}{P_{im}+Pjm} + \frac{P_{jm}}{P_{im}+Pjm}\right) P_{mk} \qquad (8)$$

$$P_{ml} = \left(\frac{P_{im}}{P_{im}+Pjm} + \frac{P_{jm}}{P_{im}+Pjm}\right) P_{ml} \qquad (9)$$

$$Q_{mk} = \left(\frac{Q_{im}}{Q_{im}+Qjm} + \frac{Q_{jm}}{Q_{im}+Qjm}\right) Q_{mk} \qquad (10)$$

$$Q_{ml} = \left(\frac{Q_{im}}{Q_{im}+Qjm} + \frac{Q_{jm}}{Q_{im}+Qjm}\right) Q_{ml} \qquad (11)$$

From these above four equations we can use only Eqn’s (8) and (9), which are real or active power values. This paper deals with active power loss allocation only so that in this concept, the active power will be traced. Reactive power tracing and reactive power loss allocation is under future work.

III. EXISTING BIALEK METHOD FOR LOSS ALLOCATION TO LOADS

The power flow tracing is transportation problem which determines how power injected by sources is distributed between the lines and sinks of the transmission network. The method works on only on loss less flows. The easiest way of obtaining loss less network from lossy network by assuming that a line flow is an average over the sending end and receiving end flows and by adding half of the line loss to the power injections at each node of the line. This proportional sharing principle starts with results of converged load flow solution. This algorithm comes in two versions i.e. upstream and downstream looking algorithm based on inflows and outflows from a node.

A. Downstream Looking Algorithm

The nodal through flow P_i is expressed as the sum of inflows

$$P_i = \sum_{j\in\alpha_i^d} |P_{i-j}| + P_{Li} \qquad \forall\, i = 1,2,\ldots,n \qquad (12)$$

Where α_i^d is the set of nodes supplying directly node i

This equation can be written as

$$P_i = \sum_{j\in\alpha_i^d} C_{li} P_l + P_{Li} \qquad (13)$$

Where, $C_{li} = \frac{P_{l-i}}{P_l}$

After rearranging Eqs (12) and (13), becomes

$$P_i - \sum_{j\in\alpha_i^d} C_{li} P_l = P_{Li} \text{ or simply, } A_d P = P_L \qquad (14)$$

Where A_d is the (n×n) downstream distribution matrix and P_L is the vector of nodal demands. The (i,l) element of A_d is equal to

$$[A_d]_{il} = \begin{cases} 1 & fori = l \\ -C_{li} = -\frac{P_{l-i}}{P_l} & forl \in \alpha_i^d \\ 0 & Other\ wise \end{cases} \qquad (15)$$

Note that A_d is sparse and non symmetric. If A_d^{-1} is exists then

$P = A_d^{-1} P_L$ and its ith element is

$$P_i = \sum_{k=1}^{n} [A_d^{-1}]_{ik} P_{Lk} \qquad \forall\ i = 1,2,\ldots,n \qquad (16)$$

This equation shows how the nodal power Pi is distributed between all the loads in the system. On the other hand the same Pi is equal to the sum of the generation PGi at node i and all inflows in lines entering node i. Hence, the inflow from node i from line i-j can be calculated, using proportional sharing principle

$$|P_{i-j}| = \frac{P_{i-j}}{P_i} P_i \text{ or } |P_{i-j}| = \frac{P_{i-j}}{P_i} \sum_{k=1}^{n} [A_d^{-1}]_{ik} P_{Lk} \qquad (17)$$

B. Loss Allocation to Loads:

After knowing, the contribution of loads in line flows, by using proportional sharing principle, contribution of loads in sending end and receiving end flows are determined.

$$\left|P_{i-l_{send,contri,load}}\right| = \frac{|P_{i-l_{send}}|}{|P_{i-l_{avg}}|} \left|P_{i-l_{avg,contri,load}}\right| \qquad (18)$$

$$\left|P_{i-l_{rece,contri,load}}\right| = \frac{|P_{i-l_{rece}}|}{|P_{i-l_{avg}}|} \left|P_{i-l_{avg,contri,load}}\right| \qquad (19)$$

Where,

$\left|P_{i-l_{send,contri,load}}\right|$ = Contribution of loads in sending end power flows

$\left|P_{i-l_{rece,contri,load}}\right|$ = Contribution of loads in receiving end power flows

$|P_{i-l_{send}}|$ = Sending end power flow

$|P_{i-l_{rece}}|$ = Sending end power flow

$\left|P_{i-l_{avg}}\right|$ = Average power flow

$\left|P_{i-l_{contri,avg}}\right|$ = Contribution of load in average flow by downstream looking algorithm Losses allocated to loads

$$=\left|P_{i-l_{send,contri,load}}\right| - \left|P_{i-l_{rece,contri,load}}\right| \qquad (20)$$

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C. Algorithm for Loss Allocation to Loads

1. Read input data such as bus data and line data.
2. Initialization of load flow data
3. Obtain the results of converged load flow solution.
4. Covert the lossy network into loss less network by considering average flow. i.e $P_{i\text{-}j}$=$P_{j\text{-}i}$
5. Modify the generators power and loads
6. Obtain the PG matrix with modified generated powers and PL matrix with modified load powers.
7. Form the downstream distribution matrix by Eqn (15)
8. Obtain the inverse of downstream distribution matrix
9. Determine the contribution of each generator in each line by Eqn (17)
10. Obtain the contribution of each generator in sending end and receiving end flows by Eqn's (18) and (19) respectively.
11. Obtain the difference of sending end and receiving end flows to get loss allocation to loads using (20).

IV. PROPOSED TRACE USAGE BASED LOSS ALLOCATION TO LOADS

After applying power flow tracing mechanism to the Load flow analysis, the results obtained are, the individual generator's active power contribution in Loads active power. Using this information, it is possible to frame Trace-Usage coefficients and these coefficients plays eminent role in transmission loss allocation in deregulated power systems by using proposed methodology. These coefficients can be formulated as

$$T_{ij}^{\beta} = \frac{\text{Active power sharing of } i^{th} \text{ generator in } j^{th} \text{ Load}}{\text{Total active power at } j^{th} \text{ load}} \tag{21}$$

In this approach, the loss allocation scheme adopted from [29]. In power system network, the standard loss formula [30] is expressed in terms of power utilized by consumers from each generator. This proposed method emphasis the allocation of total active loss to generators and loads by using the traced-usage coefficients.

A. Loss allocation Procedure to Loads

Consider a power system network with NG generators and NB load (no of buses) connected through a transmission lines. This method separated the non-linear system loss into the sum of NB terms and similarly the sum of NG terms. The main difficulty arises in allocation of loss component to generators and loads because of non linear nature of the loss equation in which the combined set of all traced-usage coefficients interact through the load flow terms. Thus, the loss allocation depends on path and the traced-usage coefficients of generators and loads. Consider the Generators set G=G_1, G_2, G_3,.....G_{NG} and the load set L=L_1 ,L_2, L_3,.....L_{NB}. An exact transmission loss formula using system parameters and bus injected powers is given [30] as follows

$$P_L = \sum_{i=1}^{NB}\sum_{j=1}^{NB}[A_{ij}(P_iP_j + Q_iQ_j) + B_{ij}(Q_iP_j - P_iQ_j)] \tag{22}$$

Where,

$$A_{ij} = \frac{R_{ij}}{|V_i||V_j|}cos(\delta_i - \delta_j); \quad B_{ij} = \frac{R_{ij}}{|V_i||V_j|}sin(\delta_i - \delta_j) \tag{23}$$

PL is the real power loss of the power system, Si is the injected power at bus $S_i = P_i + jQ_i$, $Z_{ij} = R_{ij} + jX_{ij}$ and Zij is the i-jth element of Zbus, Vi is the voltage magnitude of bus-i and δi is voltage phase angle of bus-i.

B. Loss Allocation to Loads

The injected real power at bus-i is given as

$$P_i = P_{Gi} - P_{Loadi} \tag{24}$$

Let T_{ij}^{β} be the traced-usage coefficient that is fraction of power supplied by the generation at ith bus to the load power at jth bus. The generation at ith bus can be expressed as the sum of usage amounts from different loads that is

$$P_{Gi} = \sum_{j=1}^{NB} T_{ij}^{\beta} P_{Load0j} \qquad where\ i = 1,2,....,NG \tag{25}$$

The injected powers at every bus can be rewritten as below by employ above Eqn's (24) and (25)

$$P_i = \sum_{j=1}^{NB} T_{ij}^{\beta} P_{Loadj} - P_{Loadi} \qquad where\ i = 1,2,....,NB$$

The above equation can be rewritten as

$$P_i = \sum_{j=1}^{NG} T_{ij}^{\eta} P_{Loadj} \qquad where\ i = 1,2,....,NB \tag{26}$$

where $T_{ij}^{\eta} = T_{ij}^{\beta}$ for $i \neq j$; $T_{ij}^{\eta} = T_{ij}^{\beta} - 1$ for i=j.

The injected powers at ith and jth bus can be given as

$$P_i = \sum_{p=1}^{NB} T_{ip}^{\eta} P_{Loadp} \qquad where\ i = 1,2,....,NB \tag{27}$$

$$P_j = \sum_{q=1}^{NB} T_{jq}^{\eta} P_{Loadq} \qquad where\ i = 1,2,....,NB \tag{28}$$

The above Transmission loss equation Eqn (22) can be modified by using equations Eq's (27) and (28) is follows as

$$\begin{aligned} P_L' = \sum_{p=1}^{NB}\Bigg\{ &\left[\sum_{q=1}^{NB}\left(\sum_{i=1}^{NB}\sum_{j=1}^{NB} A_{ij}T_{pi}^{\eta}T_{qi}^{\eta}P_{Loadp}P_{Loadq}\right)\right] \\ &+ \left[\sum_{i=1}^{NB}\sum_{j=1}^{NB} B_{ij}\left(T_{pj}^{\eta}Q_i - T_{pi}^{\eta}Q_j\right)P_{Loadp}\right] + \left[\frac{P_{Loadp}}{\sum_{p=1}^{NB} P_{Loadp}}\sum_{i=1}^{NB}\sum_{j=1}^{NB}(A_{ij}Q_iQ_j)\right]\Bigg\} \end{aligned} \tag{29}$$

In the above equation the last term is observed that the active power loss caused because of interaction of reactive power injections and it is very small compared to total active power loss. Hence it is assumed that the loss contribution because of interaction of reactive power can be shared to the Loads according to its Load capacity. The loss contribution component (Self Component) because of individual pth load alone is expressed as

$$\begin{aligned} P_L'^{(p,p)} = &\sum_{i=1}^{NB}\sum_{j=1}^{NB} A_{ij}T_{pi}^{\eta}T_{pj}^{\eta}P_{Loadp}^2 + \sum_{i=1}^{NB}\sum_{j=1}^{NB} B_{ij}\left(T_{pj}^{\eta}Q_i - T_{pi}^{\eta}Q_j\right)P_{Loadp} \\ &+ \frac{P_{loadp}}{\sum_{p=1}^{NB} P_{Loadp}}\sum_{i=1}^{NB}\sum_{j=1}^{NB} A_{ij}Q_iQ_j \end{aligned} \tag{30}$$

$P_L'^{(p,p)}$ is part of total loss caused by pth load that depends only on its load power value. The loss contribution component (Mutual Component) because of interaction of pth load and qth load is expressed as

$$P_L'^{(p,q)} = \sum_{i=1}^{NB}\sum_{j=1}^{NB} A_{ij}\left(T_{pi}^{\eta}T_{qj}^{\eta} + T_{qi}^{\eta}T_{pj}^{\eta}\right)P_{Loadp}P_{Loadq}, \quad p \neq q \tag{31}$$

$P_L'^{(p,q)}$ is part of total loss caused by interaction of pth load and qth load. The loss contribution of load at pth bus is given by adding the half of the amount of mutual loss component because of interaction of load-p and load-q to the self component.

$$P_L'^{p} = P_L'^{(p,p)} + \frac{1}{2}\sum_{q=1,q\neq p}^{NB} P_L'^{(p,q)} \tag{32}$$

The above procedure can be used for other generators to

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compute its loss contribution. The total active power loss is

$$P'_{Tloss} = \sum_{p=1}^{NB} P'^{p}_{L} \tag{33}$$

V. ALGORITHM AND FLOW CHART FOR PROPOSED METHOD

Step1: Tracing Mechanism

Perform Tracing mechanism on the results of optimum load flow analysis, we can obtain

- Generators Contribution in active power flow of each transmission line
- Generators Contribution in active power of each Load

Step2: Formation of Trace-Usage Coefficients

By considering the result of generators contribution in each load, Trace-Usage coefficients can be framed using Eqn (21).

Step3: Frame A and B matrices

Form the matrices A and B as per Eq's (23) and by using data obtained by optimum power flow.

Step4:

Set iteration count $\varepsilon = 0,\ \delta_{ploss} = 0,\ [PL]^{\varepsilon} = 0.0 \text{ and } \delta = 10^{-8}$

Step5:

Calculate loss contribution by each generator as P_L^P as per Eqn (32).

Step6:

Calculate the total loss P_{Tloss} as per Eqn (33).

Step7:

Set $\varepsilon_{ploss} = [P_L]^{\varepsilon+1} - [P_L]^{\varepsilon}$

Step8:

Update the loss contribution for P_L^P where p=slack bus according to [29].

Step9: Stopping criteria for loss allocation

Repeat steps from 5 to 8 when it is satisfies either $\delta_{ploss} \leq \delta$ or until the maximum number of iterations reached.

Step10:

Output the result of Loss Allocation to loads and print the result of Load's Loss Allocation.

The corresponding flow chart of the proposed methodology is shown in Fig.2.

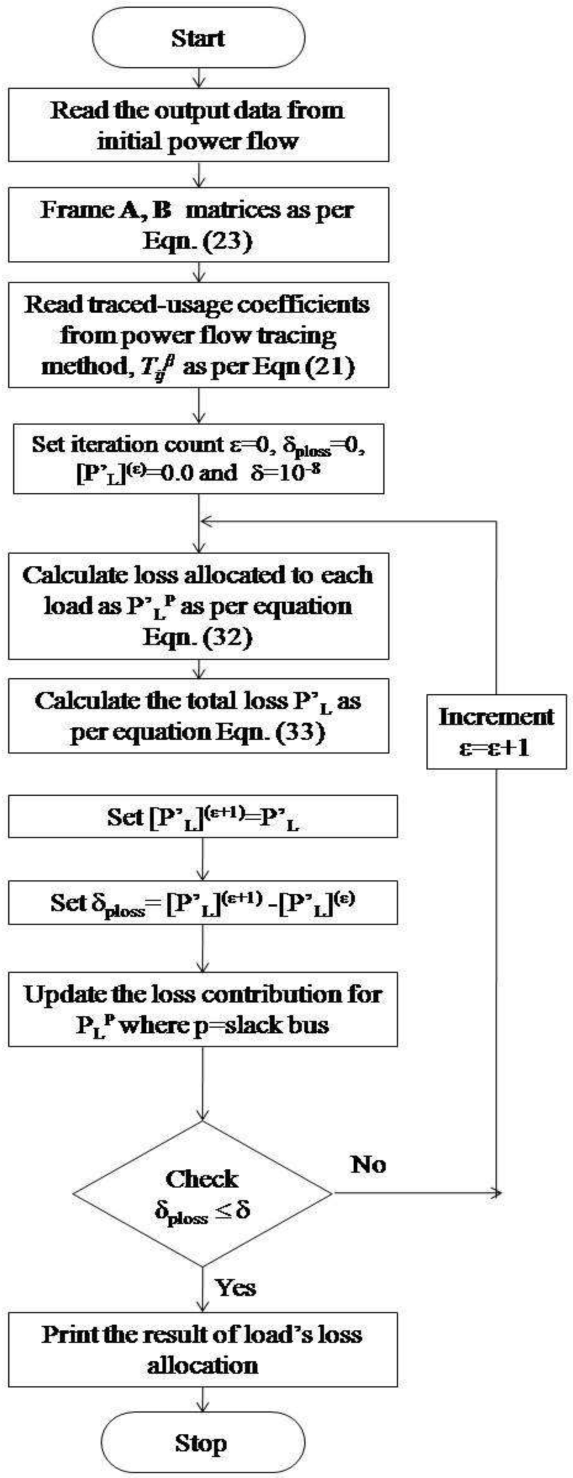

Fig. 2. Flow Chart of Tracing based Loss Allocation among Loads

VI. RESULTS AND ANALYSIS

The proposed method is tested on three different examples namely, IEEE-5 bus, IEEE-30 bus and Indian-24 bus systems on a PC with Intel core i3-370M Pentium processor with 2.40GHz frequency and 3GB RAM and installed with MATLAB environment. After obtaining transmission power losses in a given system using Newton Raphson load flow, these losses should be allocated among loads. To perform this, procedure described in section 2 is used for Bialek method and section 4 for Tracing based method.

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A. Example-1:

An IEEE-5 bus network with seven transmission lines and six generators is considered [31].

1) Loss Allocation to Loads:

For this system, the total losses are 7.5135 MW, and these losses are allocated to four loads at buses 2, 3, 4 and 5. The procedure described in section 5 is used to allocate losses among the loads. For this system, there are four loads and respective loss allocations using existing and proposed methods are tabulated in Table.1. From this table, it is identified that, maximum losses are allocated to load at bus-5 as the amount of load at this bus is high i.e. 120 MW when compared to other buses. The minimum losses are allocated to load at bus-2 i.e. 40 MW, this is because of the less load and has an availability of local generation. Hence, it very clear that, maximum amount of load at bus-2 is supplied from the generator at the same bus. The graphical representation of loss allocations to all loads is shown in Fig.3.

Table. 1. Loss Allocation with Existing and Proposed Methods to Loads for IEEE-5 Bus System

S. No	Bus No	Loss allocations (MW)		
		Usage based	Bialek	Tracing based
1	2	0.1676	0.1785	0.24377
2	3	2.0717	0.5271	0.636986
3	4	2.5986	1.4795	1.409643
4	5	2.6756	5.3284	5.223124
Total power loss (MW)		7.5135	7.5135	7.513523

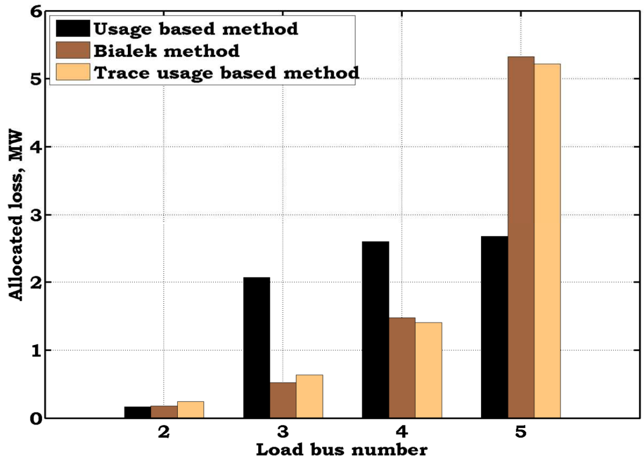

Fig. 3. Variation of Loss Allocation with Existing and Proposed Methods to Loads for IEEE-5 Bus System

B. Example-2

An IEEE-30 bus system with six generators, forty one transmission lines, four tap changing transformers and two shunt compensating devices is considered [32, 33].

1) Loss Allocation to Generators:

For this system, the total losses are 7.4366 MW, and these losses are allocated to twenty one loads and respective loss allocations using existing and proposed methods are tabulated in Table.2. From this table, it is identified that, maximum losses are allocated to load at bus-5 as the amount of load at this bus is high i.e. 94.2 MW when compared to other buses. The minimum losses are allocated to load at bus-3 i.e. 2.4 MW, this is because of the availability of local generation and very less load. The graphical representation of loss allocations to loads is shown in Fig.4.

Table. 2. Loss Allocation with Existing and Proposed Methods to Loads for IEEE-30 Bus System

S. No	Bus No	Loss allocations (MW)	
		With Bialek	Tracing based
1	2	0.27739	0.279808
2	3	0.049179	0.055171
3	4	0.20584	0.208843
4	5	2.569	2.67314
5	7	0.95861	0.90529
6	8	0.38773	0.388783
7	10	0.096526	0.102262
8	12	0.12116	0.11811
9	14	0.12993	0.117562
10	15	0.20139	0.183194
11	16	0.069644	0.062507
12	17	0.20887	0.186809
13	18	0.1033	0.096063
14	19	0.29043	0.277002
15	20	0.055251	0.056793
16	21	0.41695	0.411245
17	23	0.10262	0.089439
18	24	0.29404	0.260025
19	26	0.17561	0.171315
20	29	0.11474	0.160088
21	30	0.60842	0.633155
Total power loss (MW)		7.43663	7.4366

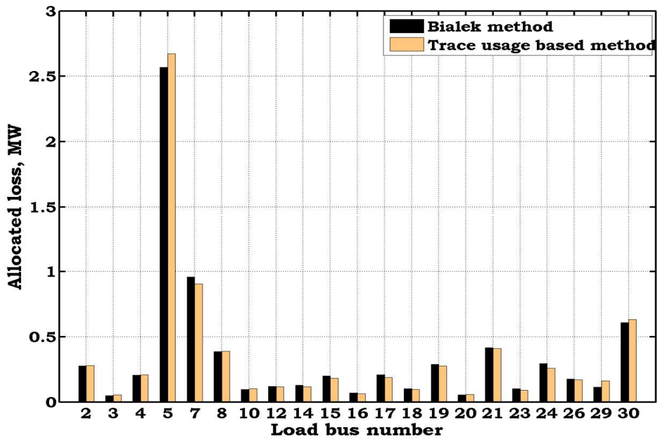

Fig. 4. Variation of Loss Allocation with Existing and Proposed Methods to Loads for IEEE-30 Bus System

C. Example-3

A real time Indian-24 bus system with twenty seven transmission lines, four generating units is considered.

1) Loss Allocation to Generators:

For this system, the total losses are 44.3339 MW, and these losses are allocated to three generators which are connected at buses 1, 2, 3 and 4. The procedure described in section 2.2 is used to allocate losses among the loads. For this system, there are fourteen loads and respective loss allocations using existing and proposed methods are tabulated in Table.3. From this table, it is identified that, maximum losses are allocated to load at bus-16 as the amount of load at this bus is high i.e. 230 MW when compared to other buses. The minimum losses are allocated to load at bus-21 i.e. 73 MW, this is because of the availability of local generation. The graphical representation of loss allocations to all loads is shown in Fig.5.

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Table. 3. Loss Allocation with Existing and Proposed Methods to Loads for Indian-24 Bus System

S. No	Bus No	Loss allocations (MW)	
		With Bialek	Tracing based
1	6	1.9092	1.99913
2	7	8.8754	8.793948
3	9	1.3945	1.413014
4	10	4.4686	4.457155
5	11	0.91117	0.859775
6	12	1.2633	1.230362
7	13	5.5646	5.398661
8	16	10.514	10.41549
9	17	2.8703	2.830825
10	19	1.4879	1.6059
11	20	0.81275	0.945773
12	21	0.65554	0.754431
13	23	1.4217	1.446431
14	24	2.185	2.182986
Total power loss (MW)		44.3339	44.3339

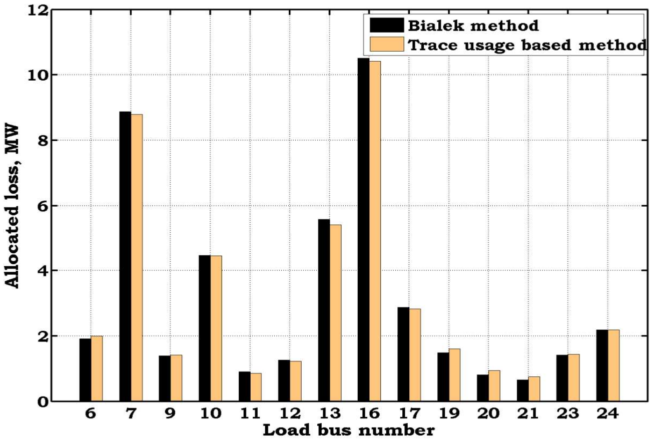

Fig. 5. Variation of Loss Allocation with Existing and Proposed Methods to Loads for Indian-24 Bus System

VII. CONCLUSION

A novel loss allocation methodology has been proposed by formulating trace usage based coefficients. These coefficients are formulated using the real time power flow condition of the given system. In this methodology, power flow tracing mechanism has been adapted to frame trace usage coefficients. This mechanism in turn uses proportional sharing principle. Using this methodology, the total active power losses in a given system are allocated among the loads. The proposed methodology has been tested in standard IEEE-5 bus, 30-bus and real time Indian-24 bus test systems with supporting numerical results and validations with the results of existing Bialek method.

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