Tracing based Loss Allocation to Generators in Deregulated Power Systems

N. V. Subba Rao, G. Kesava Rao, S. Sivanaga Raju

Abstract— Deregulation is the major trend in the electric power industry throughout the world. The main focus in deregulated system operation is to optimize the system welfare by introducing competition, mainly, among generators. The grid operator is required to know how the power offered by the generators is reaching the load; for which the power flow is to be traced along the lines. Tracing of electricity plays very important role in the open market, as it increases the clarity in open market and promote efficient system. In this paper, tracing based loss allocation methodology is developed to allocate the transmission losses to generators alone. This method works based on the principle of power flow tracing which in turn uses proportional sharing principle. The effectiveness of the proposed loss allocation methodology is tested on standard IEEE-5 bus, IEEE-30 bus and real time Indian-24 bus systems and the loss allocation results are also compared with the existing Bialek method.

Index Terms—Proportional sharing principle, Power flow tracing, Loss allocation, Bialek method, Tracing based coefficients.

I. INTRODUCTION

In the present scenario of electrical power systems, there is a huge demand in electricity changing from vertically integrated utilities to deregulated electricity market. Consumers choose power at competitive price for which they consume. In this open market system, generators and loads give their options to the independent grid operator (IGO), and this IGO distributes the required power to generators and loads subjected to network constraints including losses, organizes/operates the system, schedules the power generation, allocating losses to the participants such as generators or/and loads. For system reliability and system security, the IGO has desertion powers with which maintain the system in always working mode by maintaining ancillary services. In tracing technique with proportional sharing principle, graph method has been used [1]. This technique is simple to understand for tracing reactive power. The tracing of real power and reactive power was done separately. In [2], transmission losses are allocated and costs are presented taking into account pool and bilateral contract hybrid deregulated power market. The second order response and localized response is proposed in [3]. According to this procedure, 50% losses allocated to generators and 50% losses allocated to loads.

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In [7], Charging for use of transmission system is done based on margin cost methods. Tracing of active power and reactive power are given. [4,5] as far as reactive flows are concerned, the lines are considered as sources or sinks; this is very different from the behavior of active power flows for which the lines are always simple 'carriers with losses'. In [6], a methodology for active power flow tracing is outlined; the authors say that such methodology is also suitable for reactive power tracing; but the applications only concern active power flow tracing. In the interconnected systems, power flows in the transmission lines in which how the power flow between generator/ loads and flows is given by sensitive analysis [8]. 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 [9-11]. References [4, 5, 12-15] proposed power tracing algorithms. The convection line is one which has the directions of reactive power is opposite at two ends. In [14], these convection lines are handled. In [16], a tracing algorithm is proposed which did not describe as to how to extend the same to cases where the reactive power flows from both ends of the line. The most famous scheme is tracing of electricity [4] which simple and understandable to market participants. In [17], the matrix power series has been used to get inversion of upstream and downstream tracing distribution matrices giving some important inferences. In [18], an attempt was made to get relationship between the generator (or loads) and power flows by means of sensitivity analysis, that is by determining how the flow is influenced a change in a nodal generation/ demand in a particular line [8,19]. In [20,21], electricity tracing technique is proposed under the assumption that nodal inflows are shared proportionally between the nodal outflows, allowing one to trace the flow of electricity on interconnected network. In [22], the advantage of our approach over Bialek's method is that there is no need to calculate matrices for upstream and downstream distribution, and nodal demand and generation which leads to faster computation. The loss compensation schemes to balance actual loss and recovered loss is employed by IGO [23]. The transmission loss compensation schemes considered as ancillary services are presented in [24-26]. The major factors in the locational spot pricing is transmission loss allocation amounting 3-5% of total generation [27]. In [28], an attempt is made that the difference between the sum of theoretically allocated losses and the actual system loss are reduced. In [29] 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 [30-36], By using general conventional theories, based on

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sensitivity analysis, fail to establish loss allocation, the total loss allocation is not equal to the actual loss. Galiana [37,38] initiated electric power transactions to determine the loss allocation by integrating loss with the system trajectory determined by the acceptance order of power transactions. Bialek suggested upstream and downstream looking algorithms for tracing. These give good results for real power. As far as the reactive power is concerned, fictitious nodes, acting as reactive power source or sink, are introduced. As extra node is added, this method takes long time for computation. To get rid of this problem, a new algorithm is proposed in [4] which no extra node is added hence, system size remains the same. The advantage of our approach over Bialek method is that there is no need to calculate matrices for upstream and downstream distribution, and nodal demand and generation which leads to faster computation. From the careful review of the literature, it is identified that, no loss allocation methodology has considered the real time power flow conditions for a given system. In this paper, the real time power flow conditions are traced using proportional sharing principle and tracing methodology. The total power losses in a given system are allocated to generators alone by formulating trace usage coefficients. The loss allocation results obtained using the proposed methodology are compared with the existing Bialek method for standard IEEE-5 bus, IEEE-30 bus and Indian-24 bus systems.

II. EXISTING BIALEK METHOD LOSS ALLOCATION

The proposed method of tracing is topological in nature. This problem deals with a general transportation problem of the flows are distributed in a interconnected system. The electrical network is assumed to be connected and described by a set of busses and transmission lines, transformers, sources and sinks. Practically, the one requirement for the input data is Kirchhoff's first law must be satisfied for all nodes in the network. The Kirchhoff's first law is equally applicable to both active and reactive power flows.

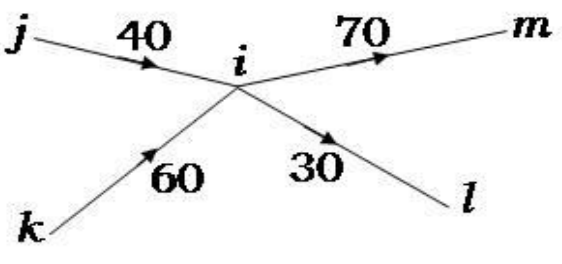

Fig. 1. Principle of Proportional Sharing

The proportional sharing principle has been used to trace the flow of electricity. This method is explained in Fig.1. Four lines are connected to bus i, two with inflows and two without flows. The total power flow through node is 40+60=100MW in which 40% is supplied by line j-i and 60% by line k-i. As the electricity is indistinguishable and each of the outflows down the line from node i is dependant only on the voltage gradient and impedance of the line, it can be assumed that each MW leaving the node contains the same proportion of the inflows as the total nodal flow Pi. Hence, the 70 MW out flowing in the line i-m consists of 70*40/100=28 MW supplied by line j-i and 70*60/100=42 MW supplied by line k-i. Similarly the 30MW out flowing in line i-l consists of 30*40/100=12 MW supplied by line j-i and 30*60/100=18 MW supplied by line k-i. 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. The downstream looking algorithm will look at the nodal balance of outflows on the other hand upstream looking algorithm will look at the nodal balance of inflows.

A. Upstream Looking Algorithm

The total flow P_i through node-i (the sum of inflows or outflows) may be expressed, when looking at the inflows, as

$$P_i = \sum_{j\in\alpha_i^u} |P_{i-j}| + P_{Gi} \qquad \forall\ i = 1, 2, \ldots, n \tag{1}$$

Where α_i^u is the set of nodes supplying directly node i (i.e power must flow towards node i in the relevant lines), P_{i-j} is the line flow into node i in line j-i, and P_{Gi} is the generation at node i. As the losses have been eliminated $|P_{j-i}| = |P_{i-j}|$. The line flow $|P_{j-i}| = |P_{i-j}|$ can be related to the nodal flow at node j by substituting

$$P_{i-j} = C_{ji}P_j$$

Where, $C_{ji} = \frac{P_{i-j}}{P_i}$ and $P_i = \sum_{j\in\alpha_i^u} C_{ji}P_j + P_{Gi}$ (2)

After rearranging Eqns (1) and (2), becomes

$$P_i - \sum_{j\in\alpha_i^u} C_{ji}P_j = P_{Gi}$$

or simply, $A_u P = P_G$ (3)

Where A_u is the (n×n) upstream distribution matrix, P is the vector of nodal through flows and P_G is the vector of nodal generations. The (i,j) element of A_u is equal to

$$[A_u]_{ij} = \begin{cases} 1 & for i = j \\ -C_{ji} = -\frac{P_{j-i}}{P_j} & for j \in \alpha_i^u \\ 0 & Other\ wise \end{cases} \tag{4}$$

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

$P = A_u^{-1}P_G$ and its ith element is

$$P_i = \sum_{k=1}^{n} [A_u^{-1}]_{ik} P_{Gk} \qquad \forall\ \ i = 1, 2, \ldots, n \tag{5}$$

This equation shows that the contribution of the kth system generator to the ith nodal power is equal to $[A_u^{-1}]_{ik}P_{Gk}$. Note that the same P_i is equal to the sum of the load demand P_{Li} and outflows in lines leaving node i. A line outflow in line i-l from node i can be therefore calculated, using proportional sharing principle

$|P_{i-l}| = \frac{P_{i-l}}{P_i}P_i$ or

$$|P_{i-l}| = \frac{P_{i-l}}{P_i} \sum_{k=1}^{n} [A_u^{-1}]_{ik} P_{Gk} \quad (6)$$

B. Loss Allocation to Generators:

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

$$\left|P_{i-l_{send,contri,gen}}\right| = \frac{|P_{i-l_{send}}|}{|P_{i-l_{avg}}|} \left|P_{i-l_{avg,contri,gen}}\right| \quad (7)$$

$$\left|P_{i-l_{rece,contri,gen}}\right| = \frac{|P_{i-l_{rece}}|}{|P_{i-l_{avg}}|} \left|P_{i-l_{avg,contri,gen}}\right| \quad (8)$$

Where,

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

$\left|P_{i-l_{rece,contri,gen}}\right|$ = Contribution of generators 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 generator in average flow by upstream looking algorithm

Losses allocated to generators

$$=\left|P_{i-l_{send,contri,gen}}\right| - \left|P_{i-l_{rece,contri,gen}}\right|$$

III. PROPOSED TRACING BASED LOSS ALLOCATION

The study of existing methods presents loss allocation in deregulated power systems under open access. These methodologies calculates the portion of real power transmission loss contributions from the generators and simultaneously the portion of real power transmission loss allocated to the loads using their contract obligations with the generators in the open access environment. A power flow procedure is used to calculate power loss in the system. It is desirable to take network loss effect of injection power at each node for calculating contribution of transmission loss by each generator and loss allocated to loads and loss allocations to both generators and loads. In this thesis, a tracing based usage coefficients are formulated to implement the loss allocation procedure to generators, loads and both. This methodology starts from a converged load flow solution. Result obtained from the load flow is utilized to further process in this existing methodology to allocate transmission losses to individual generators and individual loads.

A. Power Flow Tracing Mechanism

Power flow tracing methodology [39] 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.

B. Mathematical Modeling of Proportional Sharing Principal

Consider a bus having two inflows and two outflows as it is convenient to analyze and shown in Fig.2.

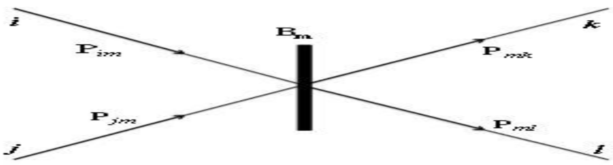

Fig. 2. Proportional Sharing Principal at Bus Bm

In Fig.2, 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.2, the voltage at bus m can be expressed in terms of branch impedance Zmk and its current flow Imk, or of Zml and Imk:

$$V_m = Z_{mk} I_{mk} = Z_{ml} I_{ml} \quad (9)$$

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.

$$V_m = \left(\frac{Z_{mk} Z_{ml}}{Z_{mk} + Z_{ml}}\right) I_T \quad (10)$$

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

By solving Eq's (9) and (10), 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:

$$S_{mk} = V_m I_{mk}^* = V_m \left(\frac{Z_{ml}^*}{Z_{mk}^* + Z_{ml}^*}\right) (I_{im}^* + I_{jm}^*)$$
$$= \left(\frac{Z_{ml}^*}{Z_{mk}^* + Z_{ml}^*}\right) (S_{im} + S_{jm}) \quad (11)$$

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

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

$$S_{ml} = \left(\frac{Z_{mk}^*}{Z_{mk}^* + Z_{ml}^*}\right) (S_{im} + S_{jm}) \quad (12)$$

Impedances can be written as

$$Z_{mk} = \frac{V_m^2}{S_{mk}^*} \quad and \quad Z_{ml} = \frac{V_m^2}{S_{ml}^*} \quad (13)$$

Eqn's (11) and (12) can be modified by using above Eqn (13)

$$S_{mk} = \left(\frac{S_{mk}}{S_{mk} + S_{ml}}\right) S_{im} + \left(\frac{S_{mk}}{S_{mk} + S_{ml}}\right) S_{jm} \quad (14)$$

$$S_{ml} = \left(\frac{S_{ml}}{S_{mk} + S_{ml}}\right) S_{im} + \left(\frac{S_{ml}}{S_{mk} + S_{ml}}\right) S_{jm} \quad (15)$$

The following power conservation relation should be noted as

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

By using above relation, both Eqn's (14) and (15) 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.

$$P_{mk} = \left(\frac{P_{im}}{P_{im}+Pjm} + \frac{P_{jm}}{P_{im}+Pjm}\right) P_{mk} \quad (16)$$

$$P_{ml} = \left(\frac{P_{im}}{P_{im}+Pjm} + \frac{P_{jm}}{P_{im}+Pjm}\right) P_{ml} \quad (17)$$

$$Q_{mk} = \left(\frac{Q_{im}}{Q_{im}+Qjm} + \frac{Q_{jm}}{Q_{im}+Qjm}\right) Q_{mk} \quad (18)$$

$$Q_{ml} = \left(\frac{Q_{im}}{Q_{im}+Qjm} + \frac{Q_{jm}}{Q_{im}+Qjm}\right) Q_{ml} \quad (19)$$

From these above four equations we can use only Eqn's (16) and (17), 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.

IV. FORMATION OF TRACE USAGE COEFFICIENTS

After applying power flow tracing mechanism to the Load flow analysis or optimum power flow analysis, the results obtained are

- The individual generator's active power contribution in branches active power flows.
- The individual generator's active power contribution in Loads active power.

The active power results considered only because this projects concentrates only on active power loss allocation. The further concept utilizes only second result means the generators contribution in loads active power. This gives the results actually what happens in the power system network means how much amount of power generation in any generator meets which load and contributes which amount. By getting this information we can frame Trace-Usage coefficients and these coefficients plays eminent role in transmission loss allocation in deregulated power systems by using proposed methodology.

A. Trace-Usage Coefficients

- T_{ij}^{α} is defined as the fraction of power received by the load at ith bus to the power generated at jth bus.
- T_{ij}^{β} is defined as the fraction of load power at jth bus supplied by the generation at the ith bus.

$$T_{ij}^{\alpha} = \frac{\text{Active power sharing of } i^{th} \text{ generator in } j^{th} \text{ Load}}{\text{Total active power generation of } i^{th} \text{generator}} \quad (20)$$

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

These T_{ij}^{α} trace-usage coefficients are related to generators, rows indicates generators and columns indicates loads. It gives the details of how much of its generation transfers to loads. These T_{ij}^{β} trace-usage coefficients are related to loads, rows indicates loads and columns indicates generators. It gives the details of how much of its load met by the generators.

V. LOSS ALLOCATION PROCEDURE TO GENERATORS

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 [40] as follows

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

Where,

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

P_L is the real power loss of the power system, S_i is the injected power at bus $S_i = P_i + jQ_i$, $Z_{ij} = R_{ij} + jX_{ij}$ and Z_{ij} is the i-jth element of Z_{bus}, V_i is the voltage magnitude of bus-i and δ_i is voltage phase angle of bus-i,

A. Loss Allocation to Generators

The injected real power at bus-i is given as

$$P_i = P_{Gi} - P_{Loadi}$$

Let T_{ij}^{α} be the traced-usage coefficient that is fraction of power generated at jth bus received by the load at ith bus. The load at ith bus can be expressed as the sum of usage amounts from different generators that is

$$P_{Loadi} = \sum_{j=1}^{NG} T_{ij}^{\alpha} P_{Gj} \qquad where\ i = 1, 2, ..., NB$$

The injected real power can be modified by using above equation as follows

$$P_i = P_{Gi} - \sum_{j=1}^{NG} T_{ij}^{\alpha} P_{Gj} \qquad where\ i = 1, 2, ..., NB$$

The above equation can be rewritten as

$$P_i = \sum_{j=1}^{NG} T_{ij}^{\chi} P_{Gj} \qquad where\ i = 1, 2, ..., NB$$

where $T_{ij}^{\chi} = -T_{ij}^{\alpha}$ for $i \neq j$ (non-generation buses); $T_{ij}^{\chi} = 1 - T_{ij}^{\alpha}$ for $i = j$ (generation buses).

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

$$P_i = \sum_{p=1}^{NG} T_{ip}^{\chi} P_{Gp} \qquad where\ i = 1, 2, ..., NB \quad (24)$$

$$P_j = \sum_{q=1}^{NG} T_{iq}^{\chi} P_{Gq} \qquad where\ i = 1, 2, ..., NB \quad (25)$$

Rearrange the Eqn (22) as components of self power (active or reactive) and mutual-power components

$$P_L = \sum_{i=1}^{NB}\sum_{j=1}^{NB}[A_{ij}(P_iP_j) + B_{ij}(Q_iP_j - P_iQ_j)] + [A_{ij}Q_iQ_j] (26)$$

The above Transmission loss Eqn (26) can be modified by using Eqn's (24) and (25) as follows as

$$P_L = \sum_{p=1}^{NG}\left\{\left[\sum_{q=1}^{NG}\left(\sum_{i=1}^{NB}\sum_{j=1}^{NB} A_{ij}T_{pi}^{\chi}T_{qi}^{\chi}P_{Gp}P_{Gq}\right)\right] + \left[\sum_{i=1}^{NB}\sum_{j=1}^{NB} B_{ij}\left(T_{pj}^{\chi}Q_i - T_{pi}^{\chi}Q_j\right)P_{Gp}\right] + \left[\frac{P_{Gp}}{\sum_{p=1}^{NG} P_{Gp}}\sum_{i=1}^{NB}\sum_{j=1}^{NB}(A_{ij}Q_iQ_j)\right]\right\} \quad 27)$$

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

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loss. Hence it is assumed that the loss contribution because of interaction of reactive power can be shared to the generators according to its generation. The loss contribution component (Self Component) because of individual p^th generator alone is expressed as

$$P_L^{(p,p)} = \sum_{i=1}^{NB}\sum_{j=1}^{NB} A_{ij} T_{pi}^{\chi} T_{qi}^{\chi} P_{Gp}^2 + \sum_{i=1}^{NB}\sum_{j=1}^{NB} B_{ij}\left(T_{pj}^{\chi} Q_i - T_{pi}^{\chi} Q_j\right) P_{Gp} + \frac{P_{Gp}}{\sum_{p=1}^{NG} P_{Gp}} \sum_{i=1}^{NB}\sum_{j=1}^{NB} A_{ij} Q_i Q_j \quad (28)$$

$P_L^{(p,p)}$ is part of total loss caused by p^th generator that depends only on its generation. The loss contribution component (Mutual Component) because of interaction of p^th generator and q^th generator is expressed as

$$P_L^{(p,q)} = \sum_{i=1}^{NB}\sum_{j=1}^{NB} A_{ij}\left(T_{pi}^{\chi} T_{qj}^{\chi} + T_{qi}^{\chi} T_{pj}^{\chi}\right) P_{Gp} P_{Gq}, \quad p \neq q \quad (29)$$

$P_L^{(p,q)}$ is part of total loss caused by interaction of p^th generator and q^th generator. It is common practice that the above term can be allocated to each generator of pair (p,q) as half of the absolute value of $P_L^{(p,q)}$ rather than the total amount to individual generators.

$$P_L^p = P_L^{(p,p)} + \frac{1}{2} \sum_{q=1, q\neq p}^{NG} P_L^{(p,q)} \quad (30)$$

The above procedure can be used for other generators to compute its loss contribution. The total active power loss is

$$P_{Tloss} = \sum_{p=1}^{NG} P_L^p \quad (31)$$

VI. ALGORITHM AND FLOW CHART FOR TRACING BASED LOSS ALLOCATION TO GENERATORS

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 as per Eqn (20) and (21).
Step3: Frame A and B matrices
Form the matrices A and B as in Eqn (22) 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 (30).
Step6:
Calculate the total loss P_{Tloss} as per Eqn (31).
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 [1C29].
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 generators and print the result of Generator's Loss Allocation.

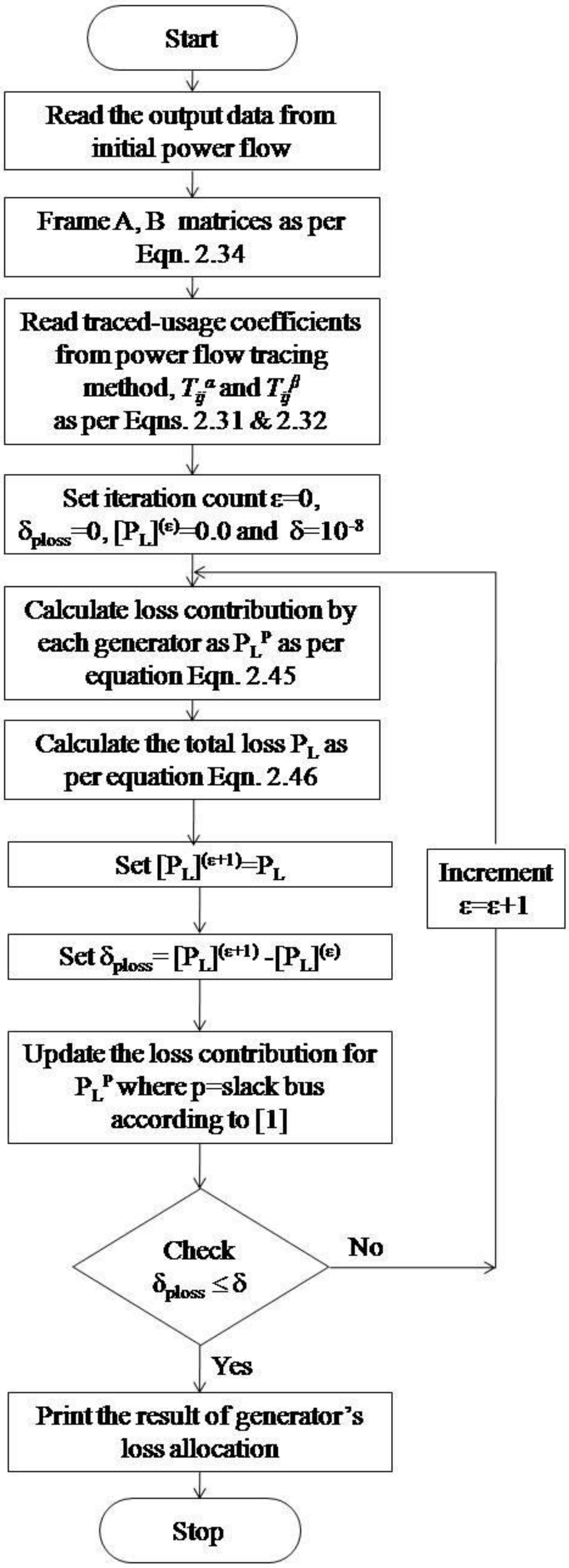

Fig. 3. Flow Chart of Tracing based Loss Allocation to Generators

VII. 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 to either generators or/and loads. To perform this, procedure described in section 2 is used for Bialek method and section 3 for Tracing based method.

A. Example-1:

An IEEE-5 bus network with seven transmission lines and six generators is considered [41].

1) Loss allocation to generators:

Initially using the procedure given in section 2.1 for Bialek method and section 5 for tracing based method, the total losses obtained are allocated to generators alone. For this system, the total losses are 7.5135 MW, and these losses are allocated to three generators which are connected at buses 1, 2 and 3. The corresponding loss allocations are tabulated in Table.1. From this table, it is observed that, maximum losses are allocated to generator placed at bus-1 in both methods. This is because of the amount of generation is highest when compared to other generators. It is also observed that, with tracing based method, the loss allocated to generators' at buses 1 and 2 is decreased and generator at bus-3 is increased. This is because of the effectiveness of the proposed method for redistribution of transmission line flows which depends on voltage magnitudes and system constraints. The graphical representation of loss allocations to all generators is shown in Fig.4.

Table. 1. Loss Allocation using Bialek and Tracing based Methods to Generators for IEEE-5 Bus System

S. No	Bus No	Loss allocations (MW)	
		Existing Bialek	Proposed Tracing based
1	1	3.6271	3.458709
2	2	3.2097	3.152288
3	3	0.6767	0.902526
Total power loss (MW)		**7.5135**	**7.513523**

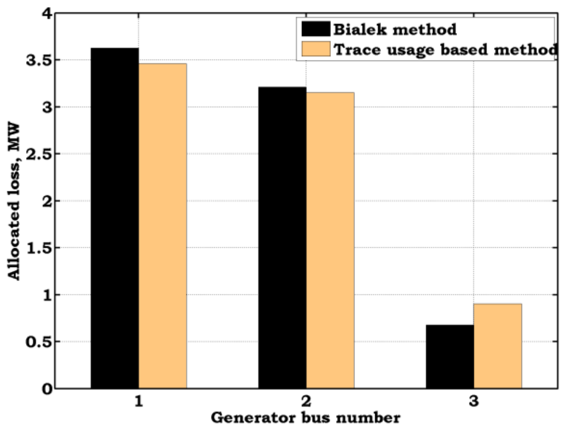

Fig. 4. Variation of Loss Allocation using Bialek and Tracing based Methods to Generators for IEEE-5 Bus System

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 [42,43].

1) Loss allocation to generators:

Initially using the procedure given in section 2.1 for Bialek method and section 5 for tracing based method, the total losses obtained are allocated to generators alone. For this system, the total losses are 7.4366 MW, and these losses are allocated to three generators which are connected at buses 1, 2, 5, 8, 11 and 13. The corresponding loss allocations are tabulated in Table.2. From this table, it is observed that, maximum losses are allocated to generator placed at bus-1 in both methods. This is because of the amount of generation is highest when compared to other generators as this is a slack bus. It is also observed that, with tracing based method, the loss allocated to generator-1 is decreased; this is because of the effectiveness of the proposed method for redistribution of transmission line flows which depends on voltage magnitudes and system constraints. The graphical representation of loss allocations to all generators is shown in Fig.5.

Table. 2. Loss Allocation using Bialek and Tracing based Methods to Generators for IEEE-30 Bus System

S. No	Bus No	Loss allocations (MW)	
		Existing Bialek	Proposed Tracing based
1	1	5.957	5.946218
2	2	0.9261	0.926722
3	5	0	0.029848
4	8	0.022926	0.045987
5	11	0.15596	0.157575
6	13	0.37469	0.330262
Total power loss (MW)		**7.4366**	**7.4366**

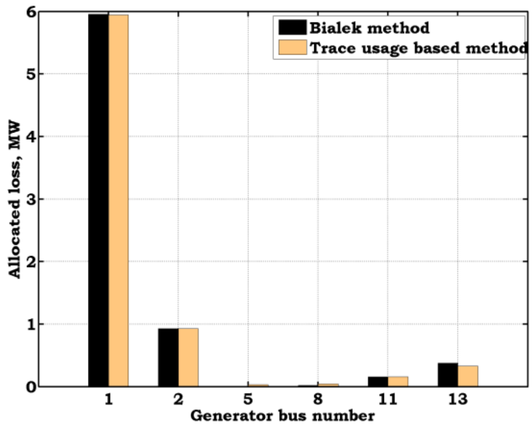

Fig. 5. Variation of Loss Allocation using Bialek and Tracing based Methods to Generators for IEEE-30 Bus

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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:

Initially using the procedure given in section 2.1 for Bialek method and section 5 for tracing based method, the total losses obtained are allocated to generators alone. 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 corresponding loss allocations are tabulated in Table.3. From this table, it is observed that, maximum losses are allocated to generator placed at bus-1 in both the methods. This is because of the amount of generation is highest when compared to other generators. It is also observed that, with tracing based method, the loss allocated to generators at buses 2 and 3 is increased and for the remaining generators is decreased. This is because of the effectiveness of the proposed method for redistribution of transmission line flows which depends on the voltage magnitudes and system constraints. The graphical representation of loss allocations to all generators is shown in Fig.6.

Table. 3. Loss Allocation using Bialek and Tracing based Methods to Generators for Indian-24 Bus System

S. No	Bus No	Loss allocations (MW)	
		Existing Bialek	Proposed Tracing based
1	1	26.6801	26.54418
2	2	1.5615	1.766423
3	3	3.4077	3.760981
4	4	12.6846	12.26233
Total power loss (MW)		**44.3339**	**44.3339**

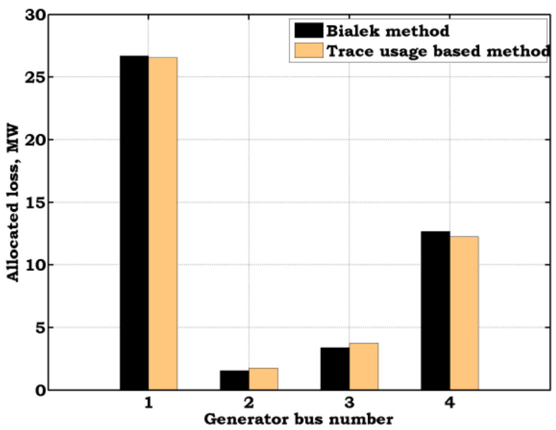

Fig. 6. Variation of Loss Allocation using Bialek and Tracing based Methods to Generators for Indian-24 Bus System

VIII. CONCLUSION

In this paper, a novel loss allocation methodology to allocate total power system losses to generators has been proposed. This methodology has been developed based on power flow tracing mechanism, which in turn uses the proportional sharing principle. The tracing based loss coefficients are formulated to calculate the amount of loss allocations. This methodology works based on the real time conditions rather than the contract/uncontrolled conditions. The proposed methodology has been tested on IEEE-5 bus, IEEE-30 bus and Indian-24 bus test systems. The results are compared with the results obtained using Bialek method.

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