Loss Allocation in Three Phase Radial Distribution System with Distributed Generation

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Abstract— Due to the liberalization of the electricity market and the introduction of distributed generation (DG), the importance of distribution loss allocation (LA) has incremented. This paper presents developing method for distribution power LA in radial systems. The proposed method, which based on the results of power flow and considers active and reactive power flows of lines for Loss Allocation (LA) is composed of three steps. In the first step, starting from the source nodes, the puissance loss allocated to all nodes is calculated and then the power loss allocated to the loads connected to each node is obtain. In the next step, the total power loss is allocated to the nodes in order to calculate the power loss allocated to the DGs predicated on the results of this step. In contrast to the precursor step, in this step, allocating power losses to the nodes commences from sink nodes, which are the nodes whose load is more than their generation. In the final step, normalization is executed. The application of the proposed method is illustrated on two distribution feeders, and the results are compared with Genetic Algorithm Loss Allocation method.

Key words: Loss allocation, distributed generation, radial distribution system

I. INTRODUCTION

The modern power distribution network is perpetually being faced with a very rapid growing load demand, this incrementing load is resulting into incremented burden and reduced voltage additionally effect on the operation of distribution networks. These power losses in distribution networks have become the most concerned issue in power losses analysis in any power networks. In the effort of reducing power losses within distribution networks, reactive power emolument has become increasingly consequential as it affects the operational, economical and quality of accommodation for electric power networks. Distributed generation (DG) allocation in distribution system is rudimental an intricate combinatorial optimization issue which requires concurrent optimization of multiple objectives for instance minimizations of authentic and reactive power losses, node voltage deviation etc. Presently, a sizably voluminous number of research papers are available on the subject of the DG allocation for power loss, voltage improvement. Most of the methods implemented for distribution LA, have been mainly proposed for transmission LA, which are listed below:

- direct loss coefficients method, presented in [3], which finds a direct cognation between the losses and nodal injections; both this method and marginal method are predicated on the results of Newton–Raphson power flow and, hence, have the imperfections of application of this type of puissance flow in concrete distribution systems where the number of nodes is sizably voluminous, the lines' resistance is negligible to their reactance, or consists of very long or very short lines [6];
- Circuit-based methods, which contain a group of methods as follows.
  1) Z-bus method [7], which is not applicable to distribution systems containing only overhead lines, since the Y-bus matrix is singular for such systems, due to the fact that the shunt admittance of such lines is negligible [8].
  2) The method predicated on a modified bus admittance matrix [9].
  3) Succinct method [10], which considers active and reactive flows for LA and is proved by Carpaneto et al. to be incapable of providing reliable results under particular circumstances [8].
  4) Branch current decomposition method (BCDM) [8], in which the loss allocated to each node is calculated predicated on the current of its upward branches (i.e., the branches that connect the node to the root node), the method presented in [12], which applies graph theory for LA; however, the method is not applicable when DGs subtend in the distribution systems;
- the exact method for authentic power LA [13], in which the consumers have to pay for losses;
- The method presented in [14], which allocates the losses to the consumers of a radial distribution system in a quadratic way, predicated on identifying the authentic and imaginary components of the current of each branch. Reference [15] and [16] present a comparative study of distribution LA methods. The following points should be considered in distribution LA:
  1) The slack node for distribution systems is always the node connecting transmission and distribution systems; however, in transmission LA, there are many alternatives for the slack node.
  2) Unlike the transmission LA methods, in which a fraction of loss may be allocated to the slack node, in distribution LA methods, no loss is assigned to the slack node.
  3) The methods utilized for transmission LA could be utilized in distribution systems; however, the loss allocated to the slack node in these methods should be redistributed among other nodes in proportion to the nodes’ currents.
  4) It is implicitly surmised that the loads and DGs have bilateral contracts with the distribution company.

This paper proposes an LA method that can be applied to radial medium voltage distribution systems with...
DGs. The method commences by assigning zero power losses to a categorical group of nodes. Then, the potency loss allocated to other nodes is calculated predicated on the potency loss of the lines connecting the zero assigned nodes and these nodes. Since this method results in over-instauration of total loss, normalization is executed at the end to compensate. The method is simple and is based on the results of power flow. This paper is organized as follows sections.

II. PROPOSED METHOD POSTULATIONS AND BASES

1) The distribution loss allocated to the node connecting the distribution and transmission network is set to zero.

2) Consider the node depict

In case \( P_{D1} + P_{D2} + \ldots \) the proposed method allocates zero losses to all loads connected to this node, since it signifies that the loads are locally alimented by the DGs and, hence, do not result in any potency loss.

\[
P_{Loss1,2} = r_{1,2} \frac{P_{L1,2}^2 + Q_{L1,2}^2}{|V_1|^2} = k (P_{D1,2}^2 + Q_{D1,2}^2)
\]

Where \( r_{1,2} \) is the resistance of the line, \( P_{L1,2} \) and \( Q_{L1,2} \) are the active and reactive power through the line; and \( V_1 \) is the voltage of node 1. As it is visually perceived, \( P_{Loss1,2} \) is composed of two terms. The first term, which is \( k P_{L1,2}^2 \), is due to the active permeates the line and the second term, which is \( k Q_{L1,2}^2 \), is due to the reactive flows. Let us denote these two terms, respectively, as \( P_{Loss1,2}^P \) and \( P_{Loss1,2}^Q \). Consequently, (1) can be indicted as

\[
P_{Loss1,2} = P_{Loss1,2}^P + P_{Loss1,2}^Q
\]

As \( P_{L1,2} = P_{D1,2} + P_{D2,2} + P_{Loss1,2} \), \( P_{Loss1,2} \) can be indicted as

\[
P_{Loss1,2} = k P_{L1,2}^2 = k (P_{D1,2} + P_{D2,2} + P_{Loss1,2})^2
\]

Which is identically tantamount to \( k (P_{D1,2} + P_{D2,2})^2 \), since it is customarily diminutive compared to \( P_{Loss1,2} \).

\[
\text{And that of load } P_{D2,2} \text{ is } (k P_{D2,2}^2 + P_{D2,2})
\]

A homogeneous formulation can be derived, in case the number of loads or lines connected to node 2 increases. Moreover, the same approach is applicable if we opiate to allocate \( Q_{Loss2,1,2} \) to \( Q_{D2,2} \) these formulae are the substratum for the proposed LA method, which is presented in the following section.

III. PROPOSED LA METHOD

The method is composed of three steps as follows.

A. Calculating The Loss Allocated To The Loads:

1) Loss due to active flows:

1. Designating the active source nodes, which are the nodes whose active generation exceeds their active demand;
2. Assigning zero active loss to the active source nodes;
3. Calculating the loss assigned to nodes other than the source nodes, because of active flows;
4. Calculating the loss allocated to the loads due to active flows.

2) Loss due to reactive flows:

1. Designating the reactive source nodes, which are the nodes whose reactive generation exceeds their reactive demand;
2. Assigning zero loss to the reactive source nodes;
3. Calculating the loss allocated to other nodes due to reactive flows;
4. Calculating the loss allocated to the loads due to reactive flows.

3) Total loss:

By summing up the loss allocated to loads due to active and reactive flows.

B. Calculating the loss allocated to the DGs:

1) Loss due to active flows:

1. Determining the active sink nodes, which are the nodes whose active demand exceeds their active generation;
2. Assigning zero loss to the active sink nodes;
3. Calculating the loss assigned to other nodes due to active flows;
4. Calculating the loss allocated to the DGs due to active flows.

2) Loss due to reactive flows:

1. Determining the reactive sink nodes, which are the nodes whose reactive demand exceeds their reactive generation;
2. Assigning zero loss to the reactive sink nodes;
3. The loss allocated to the DGs due to reactive flows.

3) Total loss:

By summing up the loss allocated to DGs due to active and reactive flows.
C. Normalization so that the losses allocated to the loads and DGs integrate up to the total active loss:

The loss allocated to each node when calculating the loss allocated to the loads is different from the values obtained when calculating the loss allocated to DGs. In any of the first and second steps, the loss allocated to each node is calculated predicated on the loss allocated to its adjacent nodes. The detailed description of the steps of the proposed method is provided in the three following subsections.

A. Calculating the Loss Allocated to the Loads

1) Loss Allocated to Loads Due to Active Flows:

In this step, the first loss assigned to any of the nodes due to active flows is calculated and then distributed between the loads connected to it. The procedure is predicated on the fact that the loss assigned to node \( k \) is dependent on the loss assigned to all nodes that are adjacent to this node and send active power to it. Let branch \( b_{n,k} \) connect node \( n \) to node \( k \) and \( P_{n,k}^a \), which is the active power flow at sending node \( n \) of this branch, be positive. Postulate that the loss allocated to node \( n \) due to active flows is denoted as \( L_n^p \) and is known. We optate to distribute \( L_n^p \) among: 1) all the loads that are connected to node \( n \) and 2) the branches connected to this node whose active power flow from this node is positive.

In this step, the loss assigned to the active source nodes, that is, the nodes whose active generation is more preponderant than their active load, is considered to be zero, since all of the loads connected to these nodes are supplied locally by the DGs connected to these nodes. While the node connecting the transmission and distribution systems should not be allocated any loss, the loss assigned to this node is get on with it zero, as well.

The procedure to calculate \( L_n^p \) is as follows.

1) Step 1: Assign zero \( L_n^p \) to each of the active source nodes, as well as the connection node of the transmission and Distribution systems.

2) Step 2: Loop over all nodes whose \( L_n^p \) is not obtained yet. If the loss assigned to all the nodes sending active power to this node was aforetime calculated, then obtain the loss assigned to this node utilizing.

3) Step 3: If there is a node whose \( L_n^p \) is not obtained yet, go back to Step 2; otherwise, stop the procedure.

For the proof of why can be \( L_n^p \) determined for all nodes utilizing the proposed method, imagine node \( n_2 \) is a node, whose \( L_n^p \) cannot be resolute. This should be due to the infeasibility of determining the loss due to \( L_n^p \) and \( L_k^q \), and for all nodes, which are later introduced. Furthermore, note that \( L_n^p \) is not the authentic loss allocated to node \( k \) rather of determining the loss due to active flows allocated to one, or some, of its adjacent nodes, that send(s) active power to node \( n_2 \), verbalize node \( n_2 \). Then which has the active power order dictate of \( P_{D,n} \), is calculated as

\[
P_{D,n} = \frac{(P_{D,n})^2 + P_{D,n} \left( \sum_{n \in D, k} P_{n,k} + \sum_{n \in A, k} 1 \right)}{\left( \sum_{n \in D, k} P_{n,k} + \sum_{n \in A, k} 1 \right)^2}
\]

Equation (5) is predicated on the fact that the loss assigned to a node should be distributed between all of the loads that are connected to it and the nodes receiving active power from it. As (5) shows \( L_{D1}^p \) dependent on \( L_{n}^p \), which has term \( P_{D,n}^k \) in it. As a result, the loss allocated to the loads is base on the power loss of the lines from which the loads are victual. Hence, the loss allocated to the loads connected to heavily loaded feeders will be more preponderant, compared to the ones annexed to lightly loaded feeders. The following equations show how the power loss allocated to the loads of this system is calculated: First, the loss assigned to the slack node is set to zero \( L_0^p = 0 \). Since node 2 is source node, the loss assigned to this node is zero as well. (5) is calculated as

\[
L_1^p = L_{Loss,1}^p + P_{Loss,1,1}^p
\]

\[
L_3^p = L_{Loss,2,3}^p
\]

\[
L_4^p = L_1^p + P_{Loss,1,4}^p
\]

After finding the loss assigned to the nodes due to active flows, the loss allocated to the loads can be obtained by using (5) as

\[
L_{D1}^p = 0,
\]

\[
L_{D2}^p = 0,
\]

\[
L_{D3}^p = 0,
\]

\[
L_{D4}^p = L_4^p.
\]

2) Loss Allocated to Loads Due to Reactive Flows:

After calculating the loss allocated to the loads due to active flows, the loss allocated to them due to reactive flows is calculated. The procedure to do this is very homogeneous to the antecedent section. First, the reactive source nodes, that is, the nodes whose reactive generation is more than their reactive load, are assigned zero reactive losses. Then \( L_n^q \) is calculated as shown at the bottom of the page. Similar to the previous section, the procedure could be applied to calculate the loss assigned to all nodes due to reactive flows. As a result, the loss allocated to load \( D1 \) is calculated similar to (5) as

\[
L_{D1}^q = \frac{(Q_{D1})^2 + Q_{D1} \left( \sum_{n \in D, k} Q_{D,n} + \sum_{n \in A, k} Q_{k,n} \right)}{\left( \sum_{n \in D, k} Q_{D,n} + \sum_{n \in A, k} Q_{k,n} \right)^2}
\]

3) Total Loss Allocated to Loads:

The total loss allocated to load \( D1 \) is obtained by adding (5) and (7) as

\[
L_{D1}^p + L_{D1}^q
\]

B. Calculating the Loss Allocated to the DGs

Likewise, in order to calculate the loss allocated to DG \( G \) which is connected to node, first \( L_k^p \) is obtained. \( L_k^p \) is the loss assigned to node \( k \), which is calculated utilizing the loss allocated to all nodes that receive active power from this node. \( L_k^p \) is composed of \( L_{P,1}^p \) and \( L_{P,2}^p \), whose formulation are presented in the following sections. \( L_{Loss,1,4}^p \) is set to zero for all of the active sink nodes, that is, the nodes whose active load is more than their active generation. This is because the active engendered power of all DGs connected to these nodes is consumed locally by the loads connected to these nodes. Consequently, the DGs connected to these nodes should not be allocated any active loss.

The procedure to calculate \( L_k^p \) is as follows.

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1) Step 1: Assign zero \( L^{p}_{k} \) to each of the active sink nodes, as well as the node connecting the transmission and distribution systems.

2) Step 2: Loop over all the nodes whose \( L^{p}_{k} \) is not obtained yet: \( \text{HL}^{p}_{k} \) of all nodes that receive active power from this node is antecedently calculated, then obtain for this node utilizing .

3) Step 3: If there is a node whose \( L^{p}_{k} \) is not obtained yet, go back to Step 2); otherwise, stop the procedure.

1) Loss Allocated to the DGs Due to active Flows:
A kindred proof to the one aforetime expounded could demonstrate that this method can calculate for all nodes.
Surmise DG \( G_{j} \) with power output of \( P_{DG} \) is connected to node \( k \).

The loss allocated to this DG, due to active flows, can be calculated utilizing \( L^{p}_{k} \) as

\[
L^{p}_{G_{j}} = L^{p}_{k} \left( \sum_{j \in G_{k}} (P_{DG} + \Sigma_{F_{k} \neq G_{k}} P_{DG} + \Sigma_{F_{k} \neq G_{k}} P_{DG}) \right)
\]

Where \( G_{k} \) represents the set of DGs connected to node.

2) Loss Allocated to the DGs Due to Reactive Flows:
The loss allocated to node \( k \) due to reactive flows is calculated as (16), shown at the bottom of the page. The loss allocated to DG \( G_{j} \) due to reactive flows might be obtained as

\[
L^{q}_{G_{j}} = L^{q}_{k} \left( Q_{DG} \right)
\]

3) Total Loss Allocated to DGs:
The total loss allocated to DG \( G_{j} \) is obtained by integrating (8) and (9) as

\[
L_{G_{j}} = L^{p}_{G_{j}} + L^{q}_{G_{j}}
\]

C. Normalization for Calculating the Final LA Formula:
In this step, normalization is executed, so that the total amount of maxima paid by loads and DGs is identically tantamount to the total loss cost. The normalization factor is obtained as

\[
NF = \frac{P_{\text{loss}}}{\Sigma L_{D_{i}} + \Sigma L_{G_{j}}}
\]

Hence, the loss allocated to load \( D_{i} \) and the loss allocated to DG \( G_{j} \) is normalized as

\[
L_{D_{i}}^{\text{normalized}} = L_{D_{i}} NF \quad L_{G_{j}}^{\text{normalized}} = L_{G_{j}} NF
\]

Equation (12) is the final formulation for calculating the loss allocated to load \( D_{i} \), and DG \( G_{j} \). As the figure shows, calculating the loss allocated to loads is executed parallel to calculating the loss allocated to DGs, which considerably decreases the computation time for sizably voluminous systems.

IV. CASE STUDY
In this section, the power-flow results as well as the distribution lines' resistance and total charging capacitance, taking 1 MVA and 20 kV as the base power and voltage. Node 1 is victual by a 63/20-kV transformer. Nonzero shunt parameter of lines makes it possible to utilize the Z-bus LA method, since the Y-bus matrix is not singular in this case. The loads' and DGs' data and the results of the proposed LA method as well as Z-bus, BCDM method are provided. The DGs are located at nodes shown in the figure. The DGs are considered as negative loads for power-flow calculations.

The DGs placement in the Genetic Algorithm Loss Allocation based on objective function and algorithm of the method. It is automatically read the placement, DGs size increase and voltage profile.

Fig. 4: Source node Voltage profile of 69-bus distributed system

Fig. 5: Sink node Voltage profile of 69-bus distributed system (Over Loads)
This paper presents a novel LA method for radial distribution systems, in which the loss allocated to each node is dependent on the loss allocated to its adjacent nodes and the loss of the lines connected to the node. The proposed method has the following properties, which are explained in to be the desirable properties of every LA method. This paper has discussed the optimal placement of DG’s in 69-bus RDS system considering the dynamic loaded conditions or load levels and provided. The considerable improvement of voltage profile and the reduction of real and reactive power losses in the system by using Loss Allocation method. An innovative approach for management of DG power is represented. The proposed method deals with optimal selection of nodes for the placement and size of the DG by using GA. The load flow problem has been solved by forward/backward load flow methodology. The rating and location has been optimized using Genetic Algorithm. In GA, coding is developed to carry out the allocation problem, which is identification of location and rating by one dimensional array. The effectiveness of the approach is demonstrated on the IEEE 69-node reliability test system.

V. CONCLUSION

This paper presents a novel LA method for radial distribution systems, in which the loss allocated to each node is dependent on the loss allocated to its adjacent nodes and the loss of the lines connected to the node. The proposed method has the following properties, which are explained in to be the desirable properties of every LA method. This paper has discussed the optimal placement of DG’s in 69-bus RDS system considering the dynamic loaded conditions or load levels and provided. The considerable improvement of voltage profile and the reduction of real and reactive power losses in the system by using Loss Allocation method. An innovative approach for management of DG power is represented. The proposed method deals with optimal selection of nodes for the placement and size of the DG by using GA. The load flow problem has been solved by forward/backward load flow methodology. The rating and location has been optimized using Genetic Algorithm. In GA, coding is developed to carry out the allocation problem, which is identification of location and rating by one dimensional array. The effectiveness of the approach is demonstrated on the IEEE 69-node reliability test system.

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