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Loss Allocation & Power Flows in Distribution System

Y. M. ISMAIL[1], V. GANESH[2]
Pulivendula, Andhrapradesh, India.

Abstract: In order to minimize power losses caused by high current and improve the voltage profile in the distribution network, the location of Distributed Generator (DG) plays an important role. Distributed Generator Location Considering Active and Reactive Power Flows in Radial Distribution System for Distribution Loss Allocation work presents a new approach to reduce losses in distribution system by considering active and reactive power flows of the system. The power flows of balanced radial distribution system are determined by LA (Loss Allocation) method that can be applied to radial medium voltage distribution systems with DGs. The method starts by assigning zero power losses to a specific group of nodes. Then, the power loss allocated to other nodes is calculated based on the power loss of the lines connecting the zero assigned nodes. Since this method results in over-recovery of total loss, normalization is executed at the end to compensate. The method is simple and is based on the results of power flow. The proposed method does not allocate negative losses to the loads and DGs. The method includes calculating the losses due to active and reactive flows allocated to loads and DGs. Finally Normalization is done so that the losses allocated to the loads and DGs add up to the total active loss. In the first section power flows of the system is analyzed. In the section –II location of DG is considered for active and reactive power flows and in the section-III the proposed method is implemented on 69 bus systems including the test system comprises 17 nodes, 12 loads, 3 DGs, and 16 distribution lines and results are shown in MAT LAB.

Keywords: Distributed Generation, Loss Allocation, Radial Distribution Systems.

I. INTRODUCTION

The Increase in deployment of distributed generation (DG) and the shift of distribution loads from customer mode to prosumers have altered distribution systems from passive to active mode. As a result, some of the transmission networks issues have been generalized to distribution systems as well. One of these issues is loss allocation (LA), which specifies the fraction of total distribution loss that each load or DG is responsible for. Although there are many transmission LA methods in the literature, distribution LA is still a new topic and most of the distribution system operators still do not have a standard policy. Most of the methods implemented for distribution LA, have been mainly proposed for transmission LA, which are listed below.

- Allocates the distribution loss to DGs and loads based on their active power levels, neglecting their location, which is not fair;
- Marginal method, which calculates the marginal loss coefficients (i.e., the changes in total loss due to a change in active/reactive node injection), based on the results of power flow; these coefficients are then used to obtain the share of DGs and loads in total loss; the results of this method needs reconciliation in order to compensate for over recovery of loss.
- direct loss coefficients method, presented in , which finds a direct relation between the losses and nodal injections; both this method and marginal method are based on the results of Newton–Raphson power flow and, hence, have the flaws of application of this type of power flow in specific distribution systems where the number of nodes is large, the lines' resistance is negligible to their reactance, or consists of very long or very short lines.
- Substitution method, where the responsibility of a participant is calculated by subtracting the total loss when the participant is not attached to the system from the loss when it is attached; this method is proved to give unfair results.

Circuit-based methods, which contain a group of methods as follows.

- Z-bus method , 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 also negligible .
- The method based on a modified bus admittance Matrix.
- Succinct method , 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.
- Branch current decomposition method (BCDM), in which the loss allocated to each node is calculated based on the current of its upward branches (i.e., the branches that connect the node to the root node).

Tracing methods, which are based on attributing the branch power flows to the nodes injection powers; although a considerable amount of transmission LA literature is dedicated to these methods, the terminology seems to disappear in distribution LA; this is due to the fact that in radial distribution systems, each branch current can be easily written in terms of the current of its downward nodes;

meanwhile, the BCDM, categorized as circuit- based methods, is a version of tracing methods used for distribution LA; the method presented by Costa and Matos in is another version of tracing methods, which implemented the quadratic LA technique; the power summation algorithm proposed in is a tracing method, in which the active and reactive power of the receiving end of each branch are decomposed to the nodal injection of the system nodes and the losses of downstream branches that are connected to the branch Reference and present a comparative study of distribution LA methods. The following points should be considered in distribution LA:

- 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.
- 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.
- The methods used for transmission LA could be used 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 . This point is really important, as the slack node current in distribution systems is usually large and it allocates a high proportion of total losses to itself, using the transmission LA methods.
- It is implicitly assumed 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 starts by assigning zero power losses to a specific group of nodes. Then, the power loss allocated to other nodes is calculated based on the power loss of the lines connecting the zero assigned nodes and these nodes. Since this method results in over-recovery 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: the next section explains the bases of the method, which is proceeded by the formulation of the method presented in Section III. In Section IV, the proposed method and five other methods are applied to a rural distribution feeder in order to compare the results. Finally, the last section presents the concluding remarks

II. PROPOSED METHOD ASSUMPTIONS AND BASES

The distribution loss allocated to the node connecting the distribution and transmission network is set to zero.Consider the node depicted in Fig. 1. ($PG1$+$PG2$+……) >($PD1$ +$PD22$ +…..) the proposed method allocates zero losses to all loads connected to this node, since it means that the loads are locally fed by the DGs and, hence, do not result in any power loss.

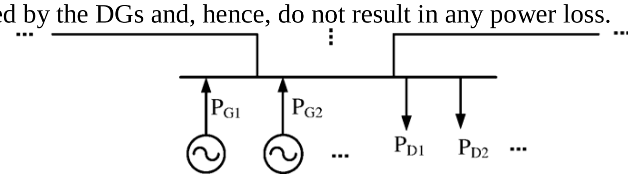

Fig.1. Sample node of a distribution system.

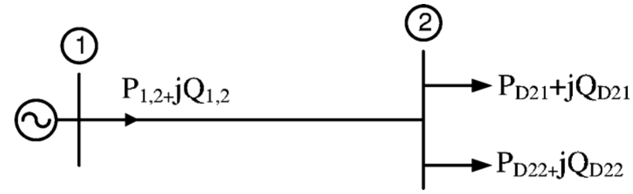

Fig. 2. Sample feeder.

In case ($PG1$+$PG2$+……) < ($PD1$+$PD22$+…..)

- The method allocates zero losses to the DGs connected to the node.
- The proposed method does not allocate negative losses to the loads and DGs.
- The distribution system is assumed to be a radial system, in which the loads and DGs have private owners.
- Consider the circuit depicted in Fig. 2, which shows two nodes of a system.

III. PROPOSED METHOD

The method is composed of three steps as follows.

1. Calculating The Loss Allocated To The Loads:
Loss due to active flows:

- specifying the active source nodes, which are the nodes whose active generation exceeds their active demand;
- assigning zero active loss to the active source nodes;
- calculating the loss assigned to nodes other than the source nodes, due to active flows;
- calculating the loss allocated to the loads due to active flows.

Loss due to reactive flows:

- Specifying the reactive source nodes, which are the nodes whose reactive generation exceeds their reactive demand;
- Assigning zero loss to the reactive source nodes;
- calculating the loss allocated to other nodes due to reactive flows;
- calculating the loss allocated to the loads due to reactive flows.

Total Loss: by summing up the loss allocated to loads due to active and reactive flows.

2. Calculating The Loss Allocated To The DGs:
Loss due to active flows:

- determining the active sink nodes, which are the nodes whose active demand exceeds their active generation;
- assigning zero loss to the active sink nodes;
- calculating the loss assigned to other nodes due to active flows;
- calculating the loss allocated to the DGs due to active flows.

Loss Due To Reactive Flows:

- determining the reactive sink nodes, which are the nodes whose reactive demand exceeds their reactive generation;
- assigning zero loss to the reactive sink nodes;

- calculating the loss assigned to other nodes due to reactive flows;
- calculating the loss allocated to the DGs due to reactive flows.

Total Loss: by summing up the loss allocated to DGs due to active and reactive flows.

3. Normalization so that the losses allocated to the loads and DGs add 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 based on the loss allocated to its adjacent nodes.

IV. CASE STUDY

In this section, the proposed LA method is implemented on a sample rural distribution system, whose single-line diagram is shown in Fig. 3. This system comprises 17 nodes, 12 loads, 3 DGs, and 16 distribution lines. Table I presents the power-flow results as well as the distribution lines ‘resistance MVA and 20 kV as the base power and voltage. Node 1 is fed by a 63/20-kV transformer. Nonzero shunt parameter of lines makes it possible to use 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 pro rata, marginal, Z-bus, BCDM, and succinct method are provided in Table II. As Table II shows, three DGs are located at nodes 15–17. The DGs are considered as negative loads for power-flow calculations.

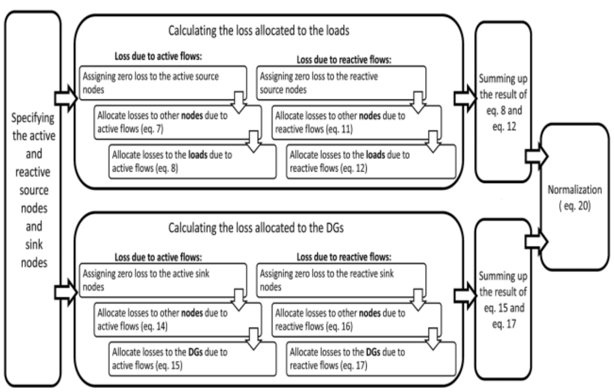

Fig. 3. Steps of the proposed LA method.

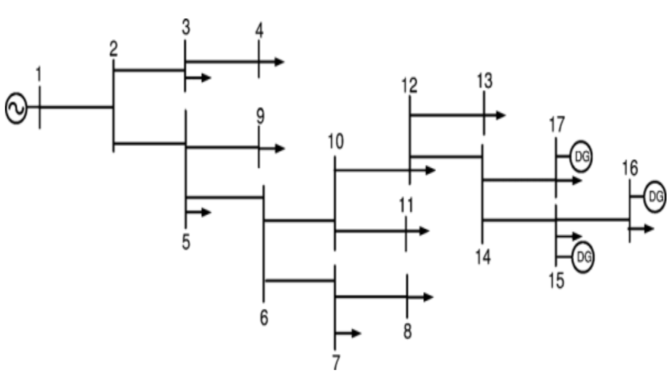

Fig.4. Test distribution feeder.

The proposed method has been applied to a larger system comprising 69 nodes, The following comments could be mentioned about different LA methods as follows.

- The loss allocated to each node due to active flows is the summation of two terms: 1) a fraction of the loss allocated to the nodes that send active power to the node, and 2) the loss of the lines connecting the node to the nodes that send active power to it. As a result, one can conclude that the loads located at the end of long feeders usually allocate high losses. This can be seen in Table II, as the load connected to node 11 is allocated to high losses. In contrast, the loads located in places near high generation points, such as node 5, are allocated low proportions of loss. In other words, one of the advantages of the proposed method is considering system topology in LA. This is fair compared to the results of the pro rata method, which ignores users’ location for LA. For instance, please note that the loss allocated to nodes 5 and 11 is not much different in the pro rata method, due to ignoring system topology.
- The results of the proposed method not only depend on the users’ location, but the method also considers the users ‘demand/generation. This can be seen as the loss allocated to node 8 is large.
- The marginal method involves calculating the Jacobian matrix, which is an extra calculation burden needed for this LA method. Likewise, the Z-bus method is based on calculating the Z-bus matrix, which is time consuming for huge distribution systems. In contrast, the proposed method does not need any further calculation except the results of power flow.
- The methods, such as Z-bus and succinct, which were originally derived for transmission LA, allocate a fraction of total loss to the slack bus. Since the loss allocated to the slack bus should be zero in distribution LA, the results of such methods need to be modified, in order to distribute the loss allocated to the slack bus among other nodes.

TABLE I: Distribution Lines Data

Branc h no	From node	To node	R (pu)	X (PU)	From node injection (KW)	From node injecton (KVAR)	To node injection(KW)	To node injection (KVAR)
1	1	2	0.00250	0.00260	0.00	0.00	1094.01	682.94
2	2	5	0.00070	0.00070	140.00	80.00	894.00	569.94
3	2	3	0.00080	0.00080	89.00	50.00	200.00	113.00
4	3	4	0.00070	0.00070	111.00	63.00	111.00	63.00
5	5	9	0.00210	0.00220	89.00	50.00	89.00	50.00
6	5	6	0.00200	0.00210	0.000	0.000	665.00	439.93
7	6	10	0.00010	0.00010	0.000	0.000	186.00	167.93
8	6	7	0.00090	0.00090	141.000	80.000	479.00	272.00
9	7	8	0.00170	0.00170	338.000	192.000	338.00	192.00
10	10	11	0.00060	0.00060	152.000	86.000	152.00	86.00
11	10	12	0.00180	0.00180	266.000	151.000	34.00	81.93
12	12	13	0.00030	0.00030	10.000	5.000	10.00	5.00
13	12	14	0.00110	0.00110	0.000	0.000	-242.00	-74.07
14	14	15	0.00110	0.00110	-95.000	-29.290	-223.00	-85.15
15	14	17	0.00070	0.00070	-19.000	11.080	-19.00	11.08
16	15	16	0.00010	0.00010	128.000	-55.860	-128.00	-55.86

TABLE II: Load and DG Data LA Results

Generation node no	P (KW)	Q (kVAR)	pro rata method	Marginal method	z-bus method	BCD	succicent method	proposed method
3	89	50	0.16	0.34	0.22	0.33	0.22	0.09
4	111	63	0.2	0.49	0.29	0.43	0.29	0.18
5	140	80	0.25	0.56	0.43	0.62	0.44	0.26
7	141	80	0.25	0.52	0.78	0.96	0.79	0.86
8	338	192	0.6	2.08	2.12	2.56	2.15	3.39
9	89	50	0.16	0.49	0.3	0.41	0.3	0.16
11	152	86	0.27	0.37	0.77	0.97	0.79	1.23
12	266	151	0.48	-0.3	1.36	1.7	1.42	0.39
13	10	5	0.02	-0.03	0.05	0.06	0.05	0.01
15	205	116	0.37	-1.98	-0.25	1.05	-0.15	0
16	72	41	0.13	-0.8	-0.09	0.39	-0.06	0
17	241	137	0.43	-2.14	-0.51	0.72	-0.8	0
Subtotal			3.31	-0.41	5.47	10.2	6.05	6.57
15	300	145.29	1.31	2.79	0.36	-1.53	0.22	0.03
16	200	96.86	0.87	2.1	0.24	-1.08	0.17	0.02
17	260	125.92	1.13	2.15	0.55	-0.78	0.19	0
Subtotal			3.31	7.04	1.15	-3.4	0.58	0.05

TABLE III: LA Results for the 69 Nodal Systems

Load node no	P(KW)	Q(KVAR)	LA in KW	Load node no	P(KW)	Q(KVAR)	LA in KW
6	20.6	12.2	0.05	43	25	13.3	0.08
7	4.04	30	0.27	44	54	43.7	0.35
8	75	54	0.97	45	39	26	0.33
9	30	22	0.69	46	1.2	1	0.01
10	28	19	1.2	47	51	43.5	0.03
11	145	104	0	48	79	56.4	0.11
12	145	104	0.33	49	284.7	174.5	0.93
13	81	52	0.47	50	284.7	174.5	1.37
14	93	72	1.21	51	40.5	28.3	0.57
15	71	52	1.65	52	26.6	12.7	0.44
16	5.5	2	0.19	53	87.35	63.5	0
17	21	15	1.63	54	96.4	79	0.03
18	14	10.4	2.06	55	24	17.2	0.01
20	1	0.6	0.53	56	125	85.9	0.16
22	56	31.5	0	57	100	72	0.13
23	64	52.5	0.01	58	12	7.5	0
24	28	20	0.01	59	29.5	20	0.01
25	33.3	23.4	0.04	60	51.97	43.2	0.06
26	44	30	0.1	61	44	28	0.1
27	44	30	0.14	62	32	23	0.12
28	26	18.6	0	63	13.6	9.7	0.09
29	26	18	0.01	64	27	12	0.3
30	20.3	12.7	0.02	65	59	42	1.16
31	35	33	0	66	18	13	0
32	65	52	0.02	67	18	13	0
33	75	51	0.08	68	28	20	0.07
34	31	24.5	0.06	69	28	20	0.1
35	31	24	0.09	Generation node	P(KW)	Q(KVAR)	LA in KW
36	26	18.55	0.01				
37	26	18.55	0	11	500	220	0.77
38	35.6	22.4	0	22	100	44	0.01
39	105	87	0.01	31	200	88	0.05
40	93	72	0.01	38	1000	440	0.1
41	139.22	96.3	0.19	53	300	132	0.05
42	71	66	0.18	58	400	176	0.13

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:

- The method is consistent with the results of power flow.
- The losses allocated to the loads/DGs depend on the amount of energy they consume/produce.
- The location of each load and DG is a key factor in the amount of loss allocated to them.
- The method is easy to understand.
- The implementation of the method is straightforward and does not need complicated programming or extensive computational effort.

In order to allocate energy losses throughout a day, the method must be executed separately for each hour, which is time-consuming. Hence, the authors are working on a stochastic method, which could find equivalent loads based on their variation during a particular time span with an equal energy loss effect to replace the value of loads.

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