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ALLOCATION OF DISTRIBUTION NETWORK LOSSES BY PRO RATA METHOD

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ABSTRACT

The deregulated power industries require meaningful loss allocation techniques to send correct economic signals to the electricity market by taking the location and characteristics of generations and loads into account. Recently, allocation of distribution network losses has become a major issue in the deregulated electricity market. The performance and cost issues of loss allocation are going to be at forefront of the discussions due to recent deregulation and competition in the electricity market. This paper presents a pro rata (PR) method based approach to allocate fair losses in radial distribution network (RDN) with distributed generation (DG). PR method is a practical method for loss allocation which has been adopted by electricity regulatory commission of Brazil, Spain and England. This paper overcomes the drawbacks of PR method by proposed approach for fair allocation of losses among DGs and consumers. To test the effectiveness of proposed PR method, it has been tested on 9-node RDN and obtained numerical results have been compared with those by conventional PR, and MW-mile methods.

I. INTRODUCTION

Due to deregulation and restructuring of electricity market, electrical network operator is facing new challenges to determine the cost associated with generation and distribution segment of the network. In this framework, the services provided by distribution network have charges which occupied a large section of total cost of the network. Out of the service charges, losses of the distribution network have large share. Therefore, the allocation of the distribution network losses among generators and consumers is playing an increasingly important role. In order to send correct economic signals to network operators, effective loss allocation techniques are required. Because of the non-linear relationship between losses and power flows, it is difficult to perform efficient loss allocation among generators and consumers.

Along with the restructuring of distribution network, another equally important development is the growing penetration of DGs which are small scale generators connected to distribution network. The power flows in some distribution network branches have been modified, and sometimes, may revert due to presence of DG. Thus, efficient loss allocation technique is required for fair allocation of losses by identifying the location and characteristics of DGs and consumers [1,2].

For fair allocation of losses in transmission network and RDN, number of techniques has been published in the literature. Among available techniques: PR method [3] is the simplest one in which the total losses are allocated to DG and loads based on the active power generation and consumption, respectively. In marginal loss allocation [4], losses are assigned to DGs and consumers using incremental transmission loss coefficients. In proportional sharing procedure [5], losses are allocated to the DGs and consumers by using the results of a converged power flow plus a linear proportional sharing principle. Conejo et al. [6] presented a new procedure for allocating transmission losses to DGs and loads based on the networks Z-bus matrix. Conejo et al. [7] also presented a comparison of four different practical algorithms for transmission loss allocation. Fang and Ngan [8] proposed a succinct method for allocation of network losses taking the influence of both active and reactive power injected into grids into account. Costa and Matos [9] addressed the allocation of losses in RDNs with DG by considering quadratic loss allocation technique. Daniel et al. [10] presented an approach for transmission loss allocation using a modified Y_{bus}. Carpaneto et al. [11] proposed a branch current decomposition method for loss allocation in RDNs with DG. Carpaneto et al. [12] also presented a detailed characterization of different loss

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allocation techniques for RDNs with DG. Savier and Das [13] presented allocation of power losses to consumers connected to RDN before and after network reconfiguration in a deregulated environment. Parastar et al. [14] presented an approach for transmission loss allocation. In this method, first, a relationship between the bus current injections and the generator or load currents is determined using a power invariant matrix and then Z-bus matrix is modified, which allows real power loss of the network to be expressed in terms of generator or load currents.

This paper presents a PR method based new approach for loss allocation in RDN. Conventional PR method allocates the losses based on power generation and consumption of DGs and consumers, respectively by avoiding the network power flow. Major drawback of conventional PR method is that it allocates the same losses to DGs/consumers which have same power injection/consumption at different location. Furthermore, it allocates higher losses to DGs and consumers which inject and consume, respectively, large power in the network and vice versa. The proposed PR method is a branch oriented approach and considers the network power flow. The proposed method overcomes these drawbacks related to the conventional PR method effectively.

Rest of the paper is organized as follows: to explain the procedure of proposed loss allocation method, nomenclature to express the terms in mathematical expression is explained in section II, the paper elucidates mathematical expression in section III, computation algorithm in section IV, results in section V and finally, conclusions in section VI.

II. NOMENCLATURE

P_x and Q_x are real and reactive power, respectively, at receiving end of branch x;
P_x^L and Q_x^L are real and reactive power, respectively, of load connected at node x;
P_x^G and Q_x^G are real and reactive power, respectively, of DG connected at node x;
LP_x and LQ_x are real and reactive power loss, respectively, in the branch x;
α_x is set of nodes ahead of branch x;
β_x is set of branches ahead of branch x;
$\Delta LP_{y,x}^L$ and $\Delta LP_{y,x}^G$ are allocated real power loss of branch x to load and DG, respectively, to node y;
ΔTLP_x^L and ΔTLP_x^G are total allocated real power loss to load and DG, respectively, connected at node x;
TLP is total real power loss of the network;
γ_x is total number of branches lying between node x to root node;
t_n is total number of nodes in the network;
$t_n(b)$ is total number of nodes ahead of branch b.

III. METHDOLOGY

To perform the loss allocation by proposed method, the node numbering scheme and network power flow algorithms are adopted from [15]. The real and reactive powers available at the receiving end of the branch x (neglecting shunt conductance and susceptance) are given as:

$$P_x + jQ_x = \left\{ \sum_{a\in\alpha_x} \left(P_a^L - P_a^G\right) + \sum_{b\in\beta_x} LP_b \right\} + j\left\{ \sum_{a\in\alpha_x} \left(Q_a^L - Q_a^G\right) + \sum_{b\in\beta_x} LQ_b \right\} \quad (1)$$

The real power loss in any branch x is allocated to load connected at node y ahead of it and can be expressed as:

$$\Delta LP_{y,x}^L = real\left\{ \left(LP_x + jLQ_x\right) \frac{P_y^L + jQ_y^L}{\sum_{a\in\alpha_x}\left(P_a^L + jQ_a^L\right) - \sum_{a\in\alpha_x}\left(P_a^G + jQ_a^G\right)} \right\} \quad (2)$$

The real power loss in any branch x is allocated to DG connected at node y ahead of it and can be expressed as:

$$\Delta LP_{y,x}^G = real\left\{ \left(LP_x + jLQ_x\right) \frac{-P_y^G - jQ_y^G}{\sum_{a\in\alpha_x}\left(P_a^L + jQ_a^L\right) - \sum_{a\in\alpha_x}\left(P_a^G + jQ_a^G\right)} \right\} \quad (3)$$

Total allocated real power loss to load and DG at node y is because of branches lying between root node and it and can be expressed as:

$$\Delta TLP_y^L = \sum_{c=1}^{\gamma_y} \Delta LP_{y,c}^L \quad \text{and} \quad \Delta TLP_y^G = \sum_{c=1}^{\gamma_y} \Delta LP_{y,c}^G \quad (4)$$

Total real losses in network should be equal to the sum of all branch real losses or sum of total allocated real losses to load and DG connected in the network can be expressed as:

$$TLP = \sum_{b=1}^{tn-1} LP_b = \sum_{b=1}^{tn-1} \sum_{a=1}^{tn(b)} \left(\Delta LP_{a,b}^L + \Delta LP_{a,b}^G\right) \quad (5)$$

IV. COMPUTATIONAL STEPS

For allocating the network losses by proposed method in RDN, algorithm follows the steps as below:

Step I: Read the data of network under consideration, execute the power flow of network, and compute the branch power loss in the network;

Step II: Allocate the individual branch losses to load and DG using Eqs. (2) and (3), respectively;

Step III: Calculate the total allocated losses of load and DG connected in the network using Eq. (4);

Step IV: Determine the total network losses which should be equal to the sum of total allocated losses of loads and DGs as given in Eq. (5).

V. RESULTS AND DISCUSSIONS

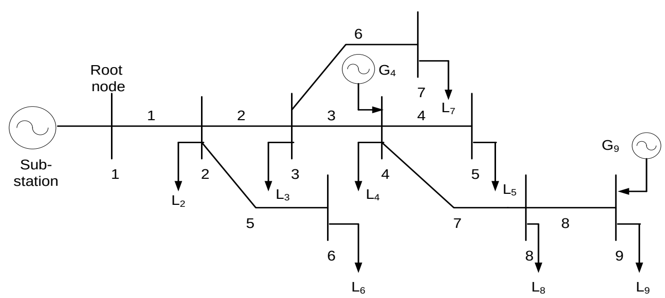

Fig. 1 Single line diagram of 9-bus radial distribution network

The proposed method has been tested on a 9-bus RDN. Single line diagram of the test network is shown in Fig. 1. Relevant data for the test network have been taken from [16]. The modification of reactive load at node 7 has been changed to 7.2 kVAr. The test network has a total load of (747.6+j560.4) kVA. Two DGs are connected on node 4 and 9, each injecting (38+j23) kVA.

Table 1. Allocated losses (in kW) by different methods

	Network load		Network DG		Proposed method		Power based conventional PR method		Current based conventional PR method		MW-mile method	
Bus no.	Active	Reactive	Active	Reactive	Load	DG	Load	DG	Load	DG	Load	DG
1	0	0	0	0	0	0	0	0	0	0	0	0
2	162	96	0	0	2.424	0	4.431	0	3.82	0	1.525	0
3	150	138	0	0	3.416	0	4.261	0	4.719	0	2.945	0
4	12	7.2	38	23	0.295	-0.936	0.329	-1.041	0.287	-0.915	0.339	-1.075
5	30	18	0	0	0.741	0	0.821	0	0.719	0	1.131	0
6	45.6	33.6	0	0	0.703	0	1.268	0	1.23	0	0.875	0
7	12	7.2	0	0	0.27	0	0.329	0	0.287	0	0.339	0
8	180	140.4	0	0	6.611	0	5.032	0	5.113	0	6.944	0
9	156	120	38	23	6.835	-1.616	4.355	-1.041	4.408	-0.924	7.512	-1.792
Total	747.6	560.4	76	46	21.296	-2.552	20.825	-2.082	20.582	-1.839	21.61	-2.867

Table 1 shows the allocated losses by different methods. In Table 1, positive allocated losses indicate penalty to consumer responsible for increasing the network losses, and negative allocated losses indicate reward to DG for reducing the network losses. Total network real losses of the test network are 18.744 kW. Proposed method assigns 21.296 kW and -2.552 kW of losses to loads and DGs, respectively, as shown in Table 1.

Also from Table 1, it is seen that both power based and current based conventional PR methods assign losses to participants depending upon their consumption/injection while proposed method assigns losses to network participants based on their power consumption/injection as well as their contribution in the feeder loss.

In order to show the effectiveness of proposed method to distinguish between two loads/DGs of similar power ratings but of different locations, the differences of loss allocated to such nodes are computed. For this purpose, loads at nodes 4 and 7 are selected while DGs at nodes 4 and 9 are selected.

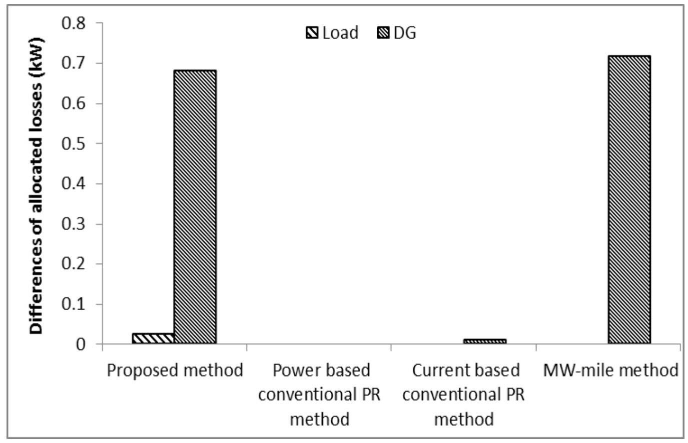

Fig 2. Differences of allocated losses of load at node 4 and 7, and DG at node 4 and 9

Fig. 2 shows the differences of allocated losses to load at node 4 and 7, and to DG at node 4 and 9. Fig. 2 clearly indicates that proposed method has capability to distinguish the same rating of network participants placed at different location than other methods. MW-mile method follows the proposed method but it has depended on physical distances of participant from the root node. If participants are having the same ratings with equal distance, MW-mile method assigns the same losses to both. Consumers connected at node 4 and 7 have same consumption with equal distance from root node, MW-mile method assigns same losses and therefore, difference between their allocated losses is zero as shown in Fig. 2. On the other hand, the proposed method assigns losses based on not only location but also contribution of participants in the total network losses.

VI. CONCLUSIONS

This paper presents a PR method based approach for allocation of network losses to load and DG connected to RDN. The proposed method is a circuit based branch oriented approach. Therefore, the proposed method allocates the branch losses while other methods allocate the total network losses. The proposed method has capability to distinguish the same rating of network participants placed at different locations. The proposed method allocates the losses to participants based on their location and contribution in feeder losses. All methods provide penalty to consumers and reward to DGs. All of the four methods do not require normalization to collect the total network losses.

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In today's world we strive to reduce carbon emissions and work towards energy efficiency and sustainable development. Sustainable development can only be achieved by efficient resource utilisation, generation and use of renewable energy and improving user awareness towards low carbon life style. The "International Seminar on Renewable Energy and Sustainable Development-RESD2015" highlighted progress that has been made around the globe towards energy efficiency, renewable energy, sustainability, resource utilisation and associate management and assessment methods. The presentations showed the depth and breadth of research across different research areas ranging from diverse background associating nearly 16 countries worldwide. It showed the real contributions and work going around the globe towards sustainable development. The conference has been a great success and we thank all our participants, organisers and committee members for their valuable contributions.

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