Electric Power Systems Research 143 (2017) 303–311

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Novel approach for loss allocation of distribution networks with DGs

Kushal Manohar Jagtap [a,*], Dheeraj Kumar Khatod [b]

[a] Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, Uttarakhand 247667, India
[b] Electrical Engineering Department, Indian Institute of Technology, Roorkee, Uttarakhand 247667, India

ARTICLE INFO

Article history:
Received 30 April 2016
Received in revised form 8 September 2016
Accepted 13 October 2016
Available online 24 October 2016

Keywords:
Distributed generation
Loss allocation
Power flow
Radial distribution network

ABSTRACT

Due to liberalization of electricity market and competition among generating companies, the allocation of distribution network losses has become a challenging task. This paper presents a new method for loss allocation in radial distribution network (RDN) with distributed generation (DG) in context of restructured power system. The proposed method is a circuit based branch-oriented approach and employs a current summation algorithm for loss allocation. It establishes a direct relation between injected current at node and power loss in the branch. Real and reactive components of the current through a branch are decomposed into sum of real and reactive components of DG and load currents connected ahead of it. Cross-terms representing the mutual relation among network participants are allocated by adopting the logarithmic scheme of allocation. In order to show the effectiveness of the proposed method, it has been tested on three different load levels of 33-node RDN, and the obtained results are compared with those by other methods.

1. Introduction

Nowadays electric power industries throughout the world are experiencing major restructuring processes and are adapting the deregulated market operation. The restructuring of vertically integrated power system leads to unbundling of the generation, transmission and distribution segments into various autonomous business units [1,2]. Under such deregulated environment, generators would be in competition with each other to serve more than one utility distributor. Generation is assigned by auction or trade-contract instead of economic dispatching orders. Unlike the generation, transmission and distribution segments, however, are immune to competition and are generally considered as natural monopoly [2,3]. Like transmission network, distribution network is also a service provider which charges the consumers for its services without any economic and technical logic.

A large share of service charges is occupied by the power loss. Also, the changed interaction between suppliers and consumers has led to increase attention towards the economic aspects of the electricity supply management. In the past, loss allocation problem was addressed only to transmission networks, but with the increased penetration of distributed generation (DG) and introduction of competition among suppliers, this problem becomes very interesting for distribution networks as well [4]. DG has significant technical and economic impact on radial distribution network (RDN) as it alters the power flows in the network from unidirectional to bidirectional and thus affects network losses [4–6]. Performing efficient loss allocation is a hard challenge, because of the non-linear relationship between losses and power flows [3,4,6,7].

System losses are non-separable and quadratic function of node current injections, therefore this makes it impossible to express the total system losses as sum of terms uniquely attributable to generation or load. Therefore, in order to obtain the effective loss allocation, some attributes are recalled in Refs. [2,4,7]. In this regard, the methodology of loss allocation should:

1) be accurate, consistent, in equity, economically efficient, simple/easy to understand and implement;
2) send correct economic signal of active and reactive power of DG and load;
3) utilize only on-site metered network data;
4) provide minimum spatial cross subsidies; and
5) provide appropriate reward/penalty to DGs and consumers.

There are many methods in the existing literature dealing with the problem of loss allocation. Pro rata (PR) method [3,8] is the simplest one in which the total losses are allocated to DGs and loads based on the apparent power generation and consumption, respectively. MW-mile method [9] measures the length of a node from

* Corresponding author.
E-mail address: jagtapkushal@gmail.com (K.M. Jagtap).

http://dx.doi.org/10.1016/j.epsr.2016.10.032
0378-7796/

root node, and multiplies it with the rating of consumer and/or DG connected at the node under consideration to allocate the losses. Marginal loss coefficient (MLC) method [2,10] is widely used for loss allocation in the transmission network and considers the network power flows. It allocates the losses to different DGs and loads based on the MLCs derived from Newton–Raphson method and their power ratings. It results over recovery of the total network losses, and therefore requires method of normalization. To avoid the over recovery of losses, tracing methodology in Ref. [11] is used. Based on the proportional sharing principle, it states that power flows in the incoming lines at a node are distributed among the outgoing lines proportionally corresponding to their power flows. Due to the linear power distribution, entire losses are allocated to either DGs or loads by using upstream or downstream looking algorithm, respectively [12]. To avoid sole distribution of losses to DGs or loads, Conejo et al. [13] presented a new procedure for allocation of transmission losses to DGs and loads based on the networks Z-bus matrix. If shunt elements of the overhead lines are neglected, Z-bus matrix cannot be obtained for the system. Thus, this method is not applicable to RDN having negligible shunt elements of lines in most of the cases.

Conejo et al. [12] presented a detailed comparison of four alternative algorithms such as PR method, MLC method, unsubsidized MLC method, and proportional sharing method for allocation of transmission losses. Abdelkader [14] presented a method for transmission loss allocation which traces the complex power, and assigns power flow and losses of each line to every load in the network based on physical power flow through a network. Elmitwally et al. [15] presented an analytical approach for allocation of transmission losses based on circuit law and the orthogonal projection. It decomposes branch current into two components, and it is expressed as power transfer and voltage difference. Exposito et al. [16] addressed the non-trivial issues of power loss allocation among participants of the DC transmission network. They suggested several alternatives to split the cross-terms so as to determine the relative contribution of each participant.

Carpaneto et al. [17] proposed a branch current decomposition method for loss allocation (BCDLA) in RDNs with DG. In this method, the DG is rewarded or penalized according to the power consumption by consumer i.e., DG is rewarded during high load period while it is penalized during low load period even though during this period it assists to reduce the network losses compared to situation without DG. Carpaneto et al. [6] presented a detailed characterization of different loss allocation techniques for RDNs with DG. Jagtap and Khatod [7] presented a current summation algorithm based method for loss allocation and dealt the cross-terms of network participants by using a logarithmic scheme of allocation. They found logarithmic scheme of allocation producing more applicable results with different load models. Savier and Das [3] presented an approach to allocate losses to consumers in RDNs using voltage drop and current based power loss formula. By extending this formulation, Savier and Das [18] presented allocation of power losses to consumers before and after network reconfiguration. Further, Savier and Das [19] allocated energy losses by using formulation in Ref. [3]. In Refs. [3,18,19], the methods of loss allocation consider only passive RDNs. Atanasovski and Taleski [4] proposed a power summation method for loss allocation (PSMLA) in RDNs with DG. This method is a branch-oriented approach and distributes the cross-terms by employing the quadratic scheme of allocation.

Jahromi et al. [20] assigned network losses strategically by defining conditions at a node. They assigned losses in three steps. In the first step, it assigned losses to generators on those nodes where DG capacity was more than that of load; in the second step, it assigned losses to loads on those nodes where load capacity was more than that of DG; and in the third and final step, remaining losses were allocated by normalization. Costa and Matos [21] proposed a method which traces the real and imaginary parts of branch currents and has two steps. In first step, the losses in the distribution network are allocated to the consumers in the absence of DG. In second step, the variation in the losses resulting from the influence of DG is allocated to DGs only. Jagtap and Khatod [22] presented a method for loss allocation by developing the relation between injected apparent power and ratio of the sending and receiving node voltages. The allocation of losses using a power summation based approach offers complexity in treatment of losses in downstream branches fed by an upstream branch. Method in Ref. [22] dealt this problem by employing a backward sweep network reduction technique and hence reduced the additional steps of normalization.

From literature, it is observed that among existing techniques for loss allocation in RDN with DG, PR method allocates the same losses to network participants who have equal power generation/consumption connected at different locations. PSMLA method performs better as far as spatial cross subsidies are concerned. However, this method is unable to differentiate the consumers of same power rating but located at different nodes. BCDLA method overcomes this drawback of PSMLA method, however, it results poor spatial cross subsidies. Hence, there is still a scope to develop a new method for loss allocation in RDN with DG, which is able to distinguish the consumers of same power rating as well as results moderate spatial cross subsidies simultaneously.

In this paper, a simple and efficient method for allocation of losses in RDNs with DG is presented. The proposed method is a circuit based branch-oriented approach and employs a current summation algorithm. In this method, power loss in a branch is expressed in term of real and reactive components of current in the various nodes ahead of the branch under consideration. Since loads consume the same power in situations before and after integration of DG, in order to fairly allocate the losses and to minimize the spatial cross subsidies, the proposed method gives same treatment to loads in both the situations.

Further, this paper employs a logarithmic scheme of allocation [16] to split the cross-terms of real and reactive components of current. The logarithmic scheme of allocation produces fair loss allocation and maintains the consistency of loss allocation with different types of consumers and load levels [7]. In Ref. [16], the loss allocation has been considered for transmission network, and DC power flow technique has been used for the same neglecting the reactive power flow. However, in this paper, AC power flow model has been used and considers reactive power flow for loss allocation in RDN. To test the effectiveness of the proposed method, it has been tested on a 33-node RDN with three different load levels. The results obtained by it are compared with those by method [7], PSMLA, and BCDLA methods.

Rest of the paper is organized in three sections. Section 2 elaborates the mathematical formulation of proposed method for loss allocation; Section 3 presents the results of application of the proposed method on a 33-node RDN; and finally, Section 4 draws the conclusions derived.

2. Formulation of the proposed method

In traditional RDN, consumers have only one source of generation i.e., root node/substation, to meet their power demand, and therefore current in a branch of the network is sum of currents of consumers connected at various nodes ahead of it as shown in Fig. 1. This can be expressed mathematically as:

$$IB_x^a + \mathrm{j}\, IB_x^r = \sum_{k \in A_x} \left(IL_k^a + \mathrm{j}\, IL_k^r \right) \tag{1}$$

where