New Method for Allocation of Losses in Distribution Systems with Dispersed Generation

Metodija B. Atanasovski[1] and Vesna P. Borozan[2]

Abstract – **This paper presents a new method for allocation of losses in distribution networks with dispersed generation (DG). The method establishes direct relationship between losses in each branch of the network and injected active and reactive power in the nodes on which path to the power supply point (PSP) the branch is placed. It is assumed that the power flows in each branch of the distribution network are constant and equal to the sum of injected active and reactive power in each node on which path to the PSP, the branch is placed. DG in this method is treated as negative power injection. Application of the proposed method on real distribution network will be presented.**

Keywords – **Allocation of losses, dispersed generation, distribution systems.**

I. INTRODUCTION

Electricity supply industries worldwide are undergoing major structural changes with the basic objective of introducing competition and choice in electricity supply. An important feature of the market-based structure of electricity industry is the separation of the generation, transmission, distribution and supply segments of the power systems into autonomous business units. Prices in the generation and supply segments are determined through market mechanisms, whereas those in the natural monopoly segments of transmission and distribution are regulated. An essential condition for developing of competition is open access on a nondiscriminatory basis, to transmission and distribution networks. The central issue in open access concept is setting an adequate price for transmission and distribution services and clear identification and allocation of costs for these services to their users, avoiding or minimizing any possibilities for temporal or spatial cross-subsidies. Main operative cost of any transmission or distribution network are electric energy losses and the issue of their appropriate allocation to network users is of great importance for networks efficiency in market conditions.

In parallel with the structural changes described, another not less important development is the growing penetration of DG into power distribution systems. The Working Group 37-23 of CIGRE has summarized in literature [1] some of the reasons for an increasing share of DG in different countries. The presence of DG in distribution systems alters radically the way these networks should be considered from both technical and commercial aspects. This is because DG changes distribution networks from passive networks, with unidirectional power flows from higher to lower voltage levels, into active ones with multidirectional power flows.

This paper is primarily concerned with the allocation of variable network losses in distribution network with DG. According to structural changes mentioned above and introducing DG into distribution networks, the problem of allocation of losses become very important problem. In literature [2], requirements for ideal loss allocation method are summarized as follows: 1) *Economic efficiency:* Losses must be allocated in a way to reflect the true cost that each user imposes on the network; 2) *Accuracy, consistency and equity:* Loss allocation method must be accurate and equitable i.e. must avoid or minimize cross subsidies between users and between different time of use; 3) *Utilization of metered data:* From a practical standpoint it is desirable to base allocation of losses on actual metered data; 4) *Simplicity of implementtation:* For any proposed method to find favor it is important that the method is easy to understand and implement.

A large number of different methods for loss allocation have been published. Most of them are dedicated to transmission networks. In literature [3] and [4] authors introduce a basic assumption of proportionality that they use to determine the proportion of active power flow in a transmission line contributed by each generator. This limits the applicability of these methods to distribution networks, because when reactive power is not considered in the allocation process, cross subsidies will emerge. Also this methods neglect the crossed terms, which due to the fact that the power losses of specific branch are quadratic function, must be carefully allocated and can not be neglected. Another approach for allocating losses is the substitution method, which has been used in England and Wales. There are number of problems associated with this method, which are summarized in literature [2]. In order to overcome the problems with the substitution method, authors in [2] present marginal loss coefficients (MLC) method. By definition MLC measure the change in total active power losses due to a marginal change in consumption/generation of active and reactive power at each node in the network. In [5] authors present a method that applies the same concept as in [2] but from a different point of view. The proposed method determines the prices at different nodes in the distribution networks using nodal factors. In addition the proposed method is compared with classical distribution network pricing scheme which is used in most regulatory concepts in the world.

The proposed method in this paper is branch-oriented as [3] and [4] and tries to resolve the referred difficulties mentioned above. Method establishes direct relationship between losses in each branch of the network and injected

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active and reactive power in the nodes on which path to the power supply point (PSP) the branch is placed. PSP is the reference bus where the transmission network connects to the distribution network. DG in this method is treated as negative power injection. It is assumed that the power flows in each branch of the distribution network are constant and equal to the sum of injected active and reactive power in each node on which path to the PSP, the branch is placed. The network is considered lossless. Crossed terms are carefully allocated using the quadratic method for allocation of crossed terms proposed in literature [6]. Application of the proposed method on real distribution network is presented. Results are discussed according to the requirements for ideal loss allocation method.

II. PROPOSED METHOD

Let us consider distribution system with DG of Fig. 1. In order to simplify the problem, we first make the following assumptions:

- An AC power flow solution is available from on-line state estimation or off-line system analysis. The network is in steady state operation. There is only one path between each node of the distribution network and PSP, consisted of known set of branches.
- Appropriate indexing of network nodes and branches is done. Every branch of the network has its beginning and ending node. Beginning node is the node which contains less branches on his path to the PSP. The index of beginning node of one branch is smaller than the index of its ending node. Index of the branch is equal with the index of its ending node.
- Node voltage and injected active and reactive power in the network are known after power flow solution. A DG has the priority to provide power to the load on the same node. DG is treated as negative power injection. For the purposes of the method the following definition of injected active and reactive power in each node i, has been applied:

$$\begin{aligned} P_i &= P_{i(consumers)} - P_{i(DG)} \\ Q_i &= Q_{i(consumers)} - Q_{i(DG)} \end{aligned} \tag{1}$$

- Active and reactive power flow in each branch of the network is constant and is equal to the sum of injected active and reactive powers to each node of the network on which path to the PSP the branch is placed. The network is considered “lossless”.

According to these assumptions, active power losses on each branch of the network with index k, are calculated with following formula:

$$\Delta P_k = R_k \cdot \frac{\left[\left(\sum_{i=k}^{Z} P_i\right)^2 + \left(\sum_{i=k}^{Z} Q_i\right)^2\right]}{U_k^2} \tag{2}$$

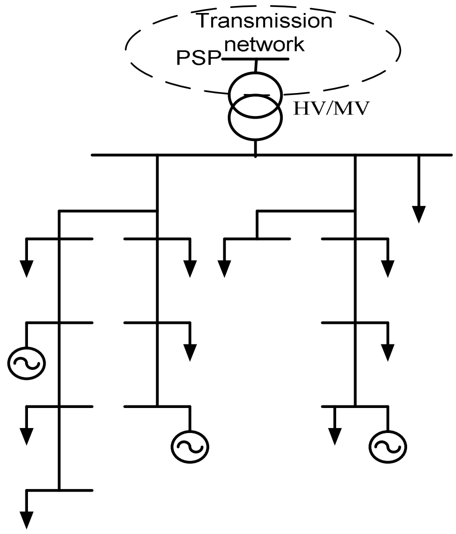

Fig. 1. Radial distribution network with DG

where:
R_k -is the resistance of the branch with index k;
U_k -is voltage magnitude of ending node of the branch with index k;
$\sum_{i=k}^{Z} P_i$ -is a sum of injected active power in the nodes on which path to PSP the branch k is placed;
$\sum_{i=k}^{Z} Q_i$ -is a sum of injected reactive power in the nodes on which path to PSP the branch k is placed;
Z –is a number of nodes on which path to PSP the branch k is placed.

The equation (2) can be developed in a form which shows that injected power in node i have impact in the following terms:

$$\Delta P_k^i = R_k \cdot \frac{\left[P_i^2 + 2 \cdot P_i \cdot \left(\sum_{\substack{j=k \\ j\neq i}}^{Z} P_j\right) + Q_i^2 + 2 \cdot Q_i \cdot \left(\sum_{\substack{j=k \\ j\neq i}}^{Z} Q_j\right)\right]}{U_k^2} \tag{3}$$

These terms have two different origins. Some are due to injected active and reactive power in node i, P_i^2 and Q_i^2. Other two terms are result of simultaneous influence of injected active and reactive power in node i and injected active and reactive power in other nodes on which path to PSP branch k is placed. These terms are called crossed terms and must be carefully allocated [6]. As referred in [6], these crossed terms can be allocated in a proportional, quadratic and geometric way. According to a quadratic relationship between losses and power, quadratic way of allocation of crossed terms has been adopted here. For better understanding of allocation of crossed terms the simplest case of single line will be considered, in which two transactions P_i and P_j create power flow respectively [6]:

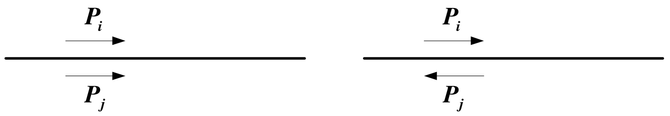

Fig. 2. Allocation of crossed terms

Two cases are considered in Fig. 2, when transactions have same and opposite directions. For both cases, the following approximate expression can be obtained:

$$\Delta P \cong \left(P_i \pm P_j\right)R = \left(P_i^2 + P_j^2 \pm 2P_iP_j\right)R \tag{4}$$

Allocation of losses between transactions is:

$$\Delta P^i = \left(P_i^2 \pm \beta_i P_i P_j\right)R \text{ ;} \qquad \Delta P^j = \left(P_j^2 \pm \beta_j P_i P_j\right)R \tag{5}$$

Mandatory balance of power can be simply written as:

$$\beta_i + \beta_j = 2 \tag{6}$$

Since power losses grow quadratic with power flows, it is also reasonable to impose the following constraint:

$$\frac{\beta_i}{P_i^2} = \frac{\beta_j}{P_j^2} \tag{7}$$

which, combined with (6), yields:

$$\beta_i = 2\frac{P_i^2}{P_i^2 + P_j^2}; \qquad \beta_j = 2\frac{P_j^2}{P_i^2 + P_j^2} \tag{8}$$

The same considerations can be applied for reactive power flows, which are not applied in [7], because dc power flow technique is used. Using the quadratic allocation of crossed terms (8), we can obtain losses of the branch k, allocated to node i:

$$\Delta P_k^i = R_k \cdot \frac{\left[P_i^2 + 2 \cdot P_i \cdot \left(\sum_{\substack{j=k \\ j \neq i}}^{Z} P_j \frac{P_i^2}{P_i^2 + P_j^2}\right) + Q_i^2 + 2 \cdot Q_i \cdot \left(\sum_{\substack{j=k \\ j \neq i}}^{Z} Q_j \frac{Q_i^2}{Q_i^2 + Q_j^2}\right)\right]}{U_k^2} \tag{9}$$

Total value of losses allocated to node with index i, will be a sum of losses allocated to it in each branch of the network placed on its path to the PSP, obtained with equation (9), as follows:

$$\Delta P^i = \sum_{k \in \alpha} \Delta P_k^i \tag{10}$$

where α is set of branches placed on the path of node i to PSP.

The assumptions and approximations made in the computation of proposed method give rise to very small differences between the losses calculated from application of the method and those calculated with power flow:

$$\Delta P \cong \sum_{i=1}^{n} \Delta P^i \tag{11}$$

where n is the total number of nodes of the network. These small differences are result of the neglecting generated reactive power from distribution lines because of the existence of their shunt capacitances b, with the proposed method. Distribution lines compensate part of the reactive power that flows through them and because of these, the sum of allocated losses with the proposed method is greater than the losses calculated with power flow. With this distribution network directly subsidize consumers, compensating part of the reactive power demanded by them. There is no need for fundamental reconciliation, but these small differences can be easily resolved by introducing constant multiplier reconciliation factor k_0. This factor is calculated as follows:

$$k_0 = \frac{\Delta P}{\sum_{i=1}^{n} \Delta P^i} \tag{12}$$

Finally total system active power losses allocated to nodes is:

$$\Delta P = \sum_{i=1}^{n} k_0 \cdot \Delta P^i \tag{13}$$

III. APPLICATION OF THE PROPOSED METHOD

Let us consider real radial 10 kV distribution network of Fig. 3, which is a part of the distribution network of Distribution Company-Bitola. There are different types of loads in the nodes of this network and to provide realistic load variations, several customer types are included in the analysis, using typical daily load profiles. Application of the proposed method is performed on hourly basis for two extreme cases: typical winter working day and summer Sunday. As input data for allocation of losses with the proposed method, power flow calculations are used. DG is working with constant output and constant power factor during the considered typical days.

Results for allocation of losses on hourly basis with the proposed method are given in Fig. 4 and Fig. 5. Fig. 4 shows the allocation of losses profiles in kW for network nodes, calculated with the proposed method for typical winter working day. Consumers located at nodes with positive allocation of losses will be charged for losses. Conversely, those consumers at nodes with negative allocation of losses will be rewarded. It is clear that between the hours 7:00 and 24:00 and between the hours 0:00 and 1:00 (19 hours in total), the DG at nodes HEC Filternica and TS Pumpi Vodovod are rewarded for there contribution to system loss reduction (signified by negative allocation of losses for this node during this period). However during early hours of the day between the hours 2:00 ans 6:00, when load is low, DG HEC Filternica contributes to increasing losses and therefore it is duly charged (signified by positive allocation of losses for this node during this period). During the same period DG in node TS Pumpi Vodovod is rewarded for its contribution to system loss reduction, because it directly supplies the load in the same node.

To illustrate spatial distribution of loss allocation with the proposed method, two time periods (operating points) were chosen, 2nd and 12th hour in a winter working day. Each node has different loss allocation, which can be positive or negative. At 2:00 the load is relatively low and therefore the DG at node HEC Filternica for example, increases total system losses and the allocation of losses is positive. At 12:00 hour, an opposite situation is presented. The load is relatively high and the DG at same node contributes to reducing the total system losses.

Fig. 5 shows the allocation of losses profiles in kW for network nodes, calculated with the proposed method for typical summer Sunday. It is clear that between the hours 0:00 and 24:00 (24 hours in total), the DG at node HEC Filternica is rewarded for its contribution to system loss reduction.

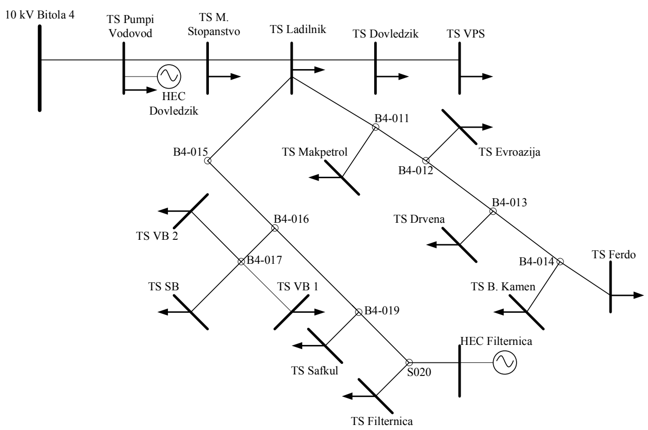

Fig. 3. Case studied 10 kV distribution network

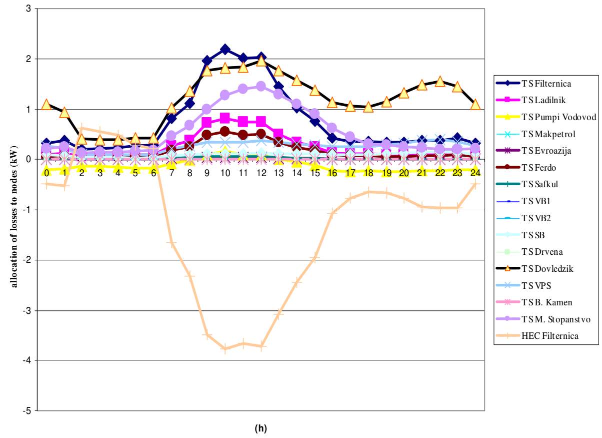

Fig. 4. Allocation of losses profiles for nodes for typical winter working day

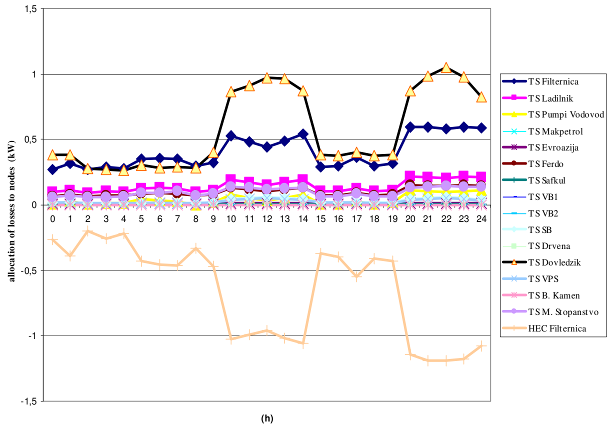

Fig. 5. Allocation of losses profiles for nodes for typical summer Sunday

IV. Conclusion

In this paper new method for allocation of losses in distribution systems with dispersed generation has been proposed. It has been demonstrated that the allocation of losses with this method is location specific and vary in time. Furthermore, allocation of losses with the proposed method can be positive or negative depending on the user particular impact on losses at any given time. The presented method is simple and easy for implementation and understanding. It can use all metered data in the network.

Application of proposed method has been illustrated on real distribution network. The results obtained clearly demonstrate that allocation of losses with this method change with time of day and from one location to another. The most appropriate approach for implementation of method is on hourly bases.

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