Real Case Study of Loss Allocation in Distribution Systems with RES

Metodija Atanasovski[1], Tomche Mijoski[2], Mitko Kostov[1], Blagoja Arapinoski[1]

Abstract –**This paper deals with variable energy losses in distribution networks and their allocation. Adequate, transparent and fair loss allocation is crucial for identification the user's responsibility for the losses cost in the network and affects future installations of renewable energy sources (RES) and loads and network development. There are three approaches for allocation of losses to users of distribution systems: average, marginal and actual. This paper uses actual approach for loss allocation in distribution systems. Namely, power summation method for loss allocation is implemented on real distribution network in North Macedonia. The calculation of loss allocation is performed for period of one calendar year using seasonal 24 hours typical load diagrams scaled according to the maximum registered load and seasonal daily generation curves of the RES according to the installed power. The results are presented and discussed. Useful conclusions are presented at the end.**

Keywords – **Renewable energy sources, Loss Allocation, Distribution systems.**

I. INTRODUCTION

Renewable Energy Sources (RES) have a dominant role in all new power plants in the countries in the European Union. The increased presence of RES in distribution systems as part of dispersed generation (DG), changes the overall concept of network operational and planning issues. Namely total distribution management technical and economic functions are affected from increased presence of RES. Nowadays, distribution system operators and planers are challenged with a great number of requests for network integration and connection of small hydro power plants (SHPP), photovoltaic units (PV) and biogas power plants. Power flows and network lines and transformers capacity on distribution feeders and substation are dramatically challenged and total distribution network is transformed into active one with increased flows and counter flows from and to transmission network.

The main economic operational cost of each distribution network are power and energy losses. Total losses in the distribution systems are consisted of two components: variable and fixed. Variable losses are load dependent and fixed losses are voltage dependent. This paper deals with variable losses and their allocation. Adequate, transparent and fair loss allocation is crucial for identification the network user's responsibility for the losses cost and affects future installations of RES and loads and network development. Ex ante losses allocation in the network is for planning purposes and ex post losses allocation is operational cost issue. There are three approaches for allocation of losses to users of distribution systems: average, marginal and actual. This paper uses actual approach for loss allocation in distribution systems.

This paper considers the power summation method for loss allocation (PSMLA) [1] implemented on real distribution network in North Macedonia. PSMLA is based on summation process starting from terminal branches by allocating losses in each branch to nodes supplied by it, and thus injected power at these nodes are corrected with allocated losses. Allocation of crossed terms of active and reactive power is calculated using quadratic distribution of crossed terms. DGs in the methodology are treated as negative active and reactive power injections, while loads are considered positive [1].

Real study case is distribution feeder supplied from power station 110/35/10 kV/kV/kV with one transformer 110/35/10 kV with rated power 20/14/14 MVA. The feeder is 10 kV and it is consisted of 83 nodes, 28 on voltage level 400 V, and the others on 10 kV. There are 28 transformers 10/0,4 kV/kV. The loads are households and light industry modeled with typical load profiles [2]. Five small hydro power plants are connected on the feeder and one PV power plant. The total installed power of the RES units is 2 MW. The calculation of loss allocation is performed for period of one calendar year using seasonal 24 hours typical load diagrams scaled according to the maximum registered load and seasonal daily generation curves of the RES according to the installed power. The results are analyzed and useful conclusions are presented in the third and fourth sections, respectively.

II. PSMLA METHOD

Methodology for allocation of losses begins at terminal branches, using the algorithm of the backward procedure of the power summation method [3]. It is well known that the power at ending node of terminal branches is equal to the injected power at its ending node. Following this principle, for any terminal branch m, power losses are calculated using the formula [1]:

$$\Delta P_m + \mathrm{j}\Delta Q_m = \frac{\underline{Z}_m}{U_m^2} \cdot \left(P_m^2 + Q_m^2 \right) = \Delta P_m^m + \mathrm{j}\Delta Q_m^m \qquad (1)$$

where ΔP_m^m and ΔQ_m^m are active and reactive losses of branch m, allocated to node m, $\underline{Z}_m$, is the impedance of branch m, P_m

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and Q_m are active and reactive power injected at the ending node of branch m, respectively and U_m is voltage magnitude of ending node m.

Next, the losses in branch m to injected power at node m are added. New (corrected) injected power at node m is calculated as:

$$P_m + \mathrm{j}Q_m = P_m + \Delta P_m^m + \mathrm{j}\left(Q_m + \Delta Q_m^m\right). \tag{2}$$

For any other non-terminal branch k, (1) can be written as it is shown in [1]:

$$\Delta P_k + \mathrm{j}\Delta Q_k = \frac{Z_k}{U_k^2} \cdot \left[\left(\sum_{j\in\alpha} P_j \right)^2 + \left(\sum_{j\in\alpha} Q_j \right)^2 \right], \tag{3}$$

where α is a set of nodes for which branch k is on the path from the node to the root, including node k; P_j and Q_j are corrected injected active and reactive power, for all nodes in α, respectively.

Active and reactive losses of branch k, allocated to node i from α, ΔP_k^i and ΔQ_k^i, can be obtained with the formula:

$$\Delta P_k^i + \mathrm{j}\Delta Q_k^i = \frac{Z_k}{U_k^2} \cdot H_i \tag{4}$$

where $H_i = \left(P_i^2 + Q_i^2 + P_i \cdot \sum_{\substack{j\in\alpha \\ j\neq i}} \beta_{ij}^P \cdot P_j + Q_i \cdot \sum_{\substack{j\in\alpha \\ j\neq i}} \beta_{ij}^Q \cdot Q_j \right)$,

$$\beta_{ij}^P = \frac{2\cdot P_i^2}{P_i^2 + P_j^2},\ \beta_{ji}^P = \frac{2\cdot P_j^2}{P_i^2 + P_j^2},$$

$$\beta_{ij}^Q = \frac{2\cdot Q_i^2}{Q_i^2 + Q_j^2} \text{ and } \beta_{ji}^Q = \frac{2\cdot Q_j^2}{Q_i^2 + Q_j^2}.$$

Injected active and reactive power at each bus i in α are corrected with the allocated losses in branch k allocated to node i:

$$P_i + \mathrm{j}Q_i = P_i + \Delta P_k^i + \mathrm{j}\left(Q_i + \Delta Q_k^i\right),\ i\in\alpha \tag{5}$$

The process ends when all branches terminal or non-terminal are analyzed using (1) or (4), respectively [1].

III. REAL STUDY CASE

The PSMLA method is tested on real distribution network depicted on Fig. 1. Time horizon of one year is analyzed and spatial and time variation of allocation of losses is investigated. Analyzed distribution feeder is supplied from power station 110/35/10 kV/kV/kV with one transformer 110/35/10 kV with rated power 20/14/14 MVA. The feeder is 10 kV and it is consisted of 83 nodes, 28 on voltage level 400 V, and the others on 10 kV. There are 28 transformers 10/0,4 kV/kV. The loads are households and light industry modeled with typical load profiles taken from literature [2]. Five SHPP are connected on the feeder and one PV unit. The total installed power of the RES units is 2 MW. The calculation of loss allocation will be performed for period of one calendar year using seasonal 24 hours typical load diagrams scaled according to the maximum registered load and seasonal daily generation curves of the RES according to the installed power. The SHPP are working with constant daily generation curve, scaled to the rated power according to the season (spring 0.92, summer 0.29, autumn 0.55 and winter 0.95). Power factor of all SHPP is 0.97 and PQ generator model is used for power flow calculations. PV unit is scaled with daily generation bell shape seasonal curves depicted on Fig. 2 and it is also modeled as PQ generator with power factor 1.0. Transmission network 110 kV is modeled as a slack bus, lines are modeled with π-equivalent and transformers are modeled with G-equivalent. The power flow calculation using power summation method and loss allocation with PSMLA method are performed for 24 hours for working days, Saturdays and Sundays for four seasons: spring, summer, autumn and winter. The households and light industry loads are modeled 24 hours typical load diagrams for each type of day and season. Two scenarios are considered: without and with DGs (RES). Fig. 3 illustrates the export/import of electrical energy per year to/from transmission network for the considered scenarios.

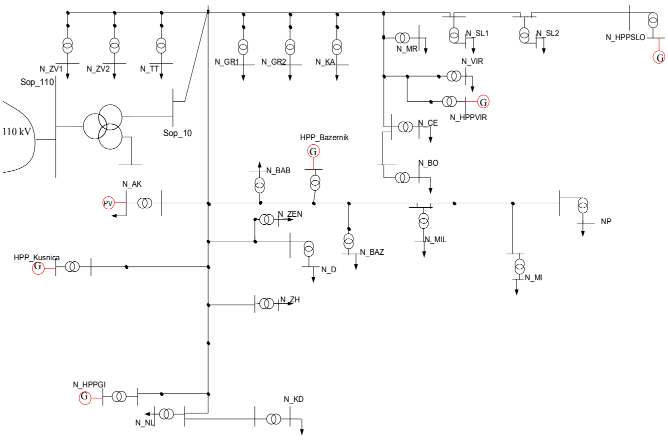

Figure 1. Real case study distribution network

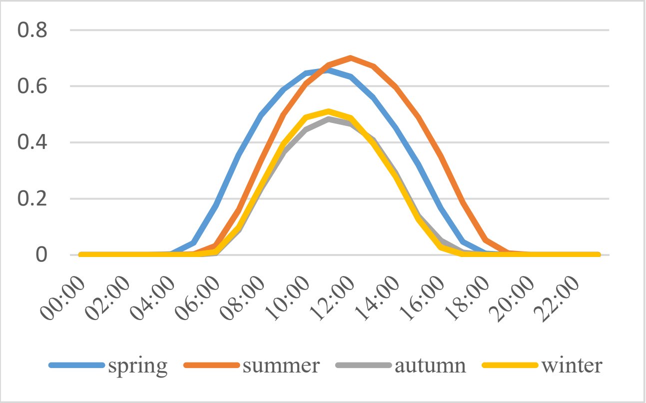

Figure 2. PV unit seasonal generation curves

Fig. 4 depicts the energy balance per year of the distribution feeder and Fig. 5 gives the total energy losses on the distribution feeder per year, both for two considered scenarios. Analyzing the results, presented on the Figs. 3-5, it is obvious that DG causes rapid change of the lines power flows in the network and in scenario with DG 1597 MWh energy is exported to the transmission network and counter flows are present. Total energy losses per year in the distribution network are 10 % higher in the scenario with DG, compared with scenario without DG.

Total RES energy generation per year is 12400 MWh and total load energy is 10492 MWh. It can be concluded that RES generation is sufficient to supply the total load on the distribution feeder and it exports surplus energy to the transmission network. The counter flows caused from surplus energy generated from RES, increase the losses in the network for 28 MWh per year compared with scenario without DG.

Fig. 6 illustrates the allocated energy losses per year in kWh to network nodes (RES (DGs) and loads) for the considered scenarios. Positive loss allocation means that network user will be penalized for increasing network losses and negative loss allocation means that network user will be rewarded for decreasing network losses. The only rewarded RES in the network are the SHPP called HPP Bazernik with allocated losses of -12.1 MWh per year and PV unit in node N_AK with loss allocation per year of -0.082 MWh. All other RES have positive loss allocation.

Total allocated losses per year to RES for scenario with DG is 110 MWh and to loads is 198 MWh. Total allocated losses to loads for the scenario without DG are 280 MWh. The 29 % decrease of total losses allocated to loads in scenario with DG compared to scenario without DG is mainly caused from improved voltage profile in the network. The improved voltage profile is a result of RES units operation, especially SHPP that are working with power factor 0.97.

Time change of allocation of losses to nodes calculated with the PSMLA is depicted on Fig. 7, Fig. 8, and Fig. 9.

Fig. 7 illustrates time variation of allocated losses to nodes for spring working day. HPP Bazernik and PV unit in node N_AK are the only rewarded RES power plants because their generation decreases energy losses in the network, while all other SHPP are penalized for increase of energy losses in the network.

Fig. 8 depicts temporal change of allocated losses to network users for summer Sunday. Practically for summer Sunday all RES generation units have negative loss allocation for 24 hours and they are rewarded for losses decrease in the network.

Fig. 9 presents variation of allocated losses to network users for autumn Saturday. RES power plants HPP Bazernik, NK_HPPKusnica and PV unit (node N_AK) are rewarded because their operational power in autumn decreases network losses. Winter season temporal variation of allocated losses to nodes is very similar as spring season, because SHPP are operated with almost equal generation power and power factor. According to the presented results, PSMLA method demonstrates temporal and spatial variation of allocated losses, generating economic efficient signals for reward and penalty to network users.

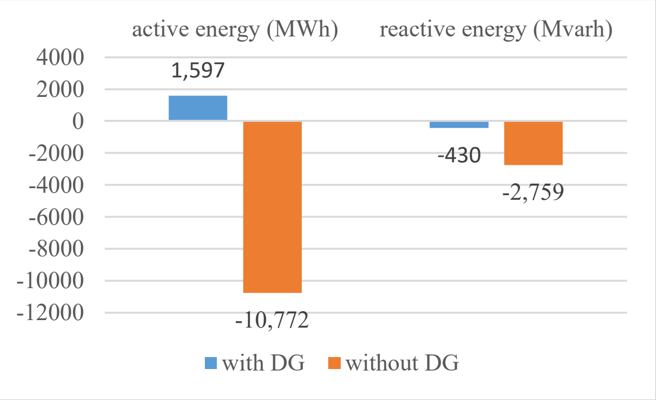

Figure 3. Exchange of active and reactive energy with the transmission network with and without DG (+export, -import)

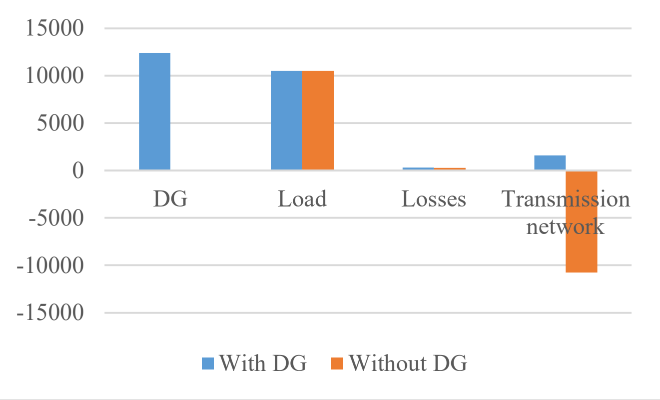

Figure 4. Active energy balance (MWh) per year for the two considered scenarios

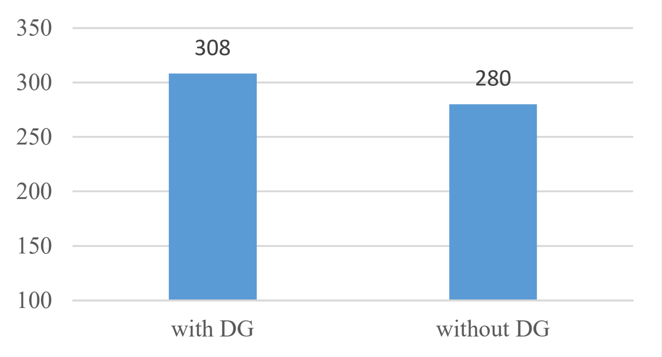

Figure 5. Total energy losses (MWh) per year for the considered scenarios

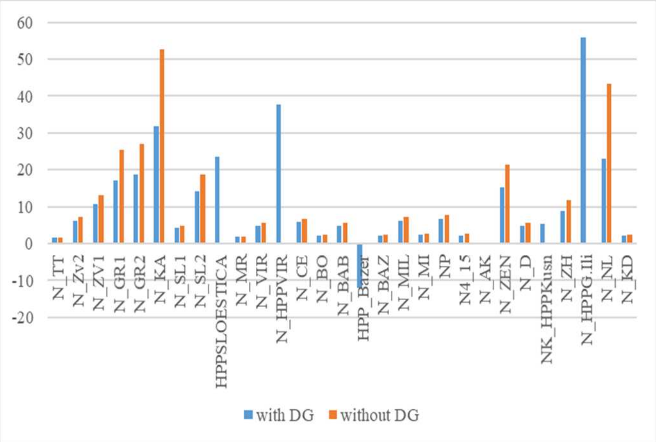

Figure 6. Allocated losses to nodes per year (MWh)

IV. CONCLUSION

Loss allocation problem becomes very important nowadays due to high prices of electricity in Europe and increased operational costs of network operators. This paper contribution is successful implementation of PSMLA on real distribution network in North Macedonia. PSMLA method is based on actual approach and it uses the backward/forward procedure to allocate network losses to RES as DG units and loads. Load flow results obtained with power summation method are used as input data for loss allocation. The presented results for one calendar year illustrate time and space variation of allocated losses. Two RES units in the network (one SHPP and PV unit) are well positioned in the network in the sense of reward for energy losses decrease in the network. Since total RES generation exceeds the total load in the network, all other SHPP are penalized per year for increasing network losses. According to power balance per year, counter flows of energy are present in the distribution network and electricity is exported to the transmission network.

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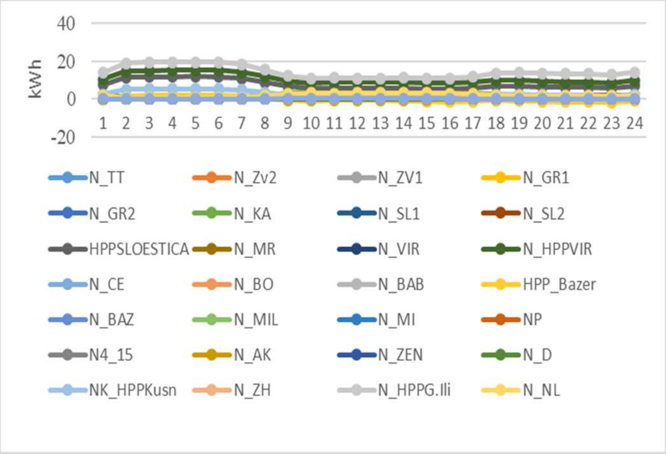

Figure 7. Variation of allocated losses (kWh) to nodes for working day in spring season

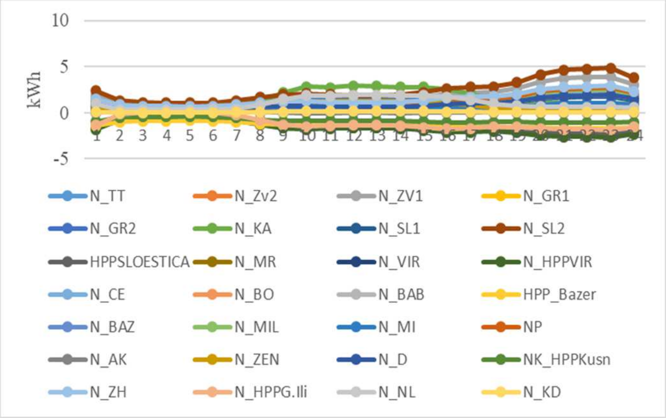

Figure 8. Variation of allocated losses (kWh) to nodes for Sunday in summer season

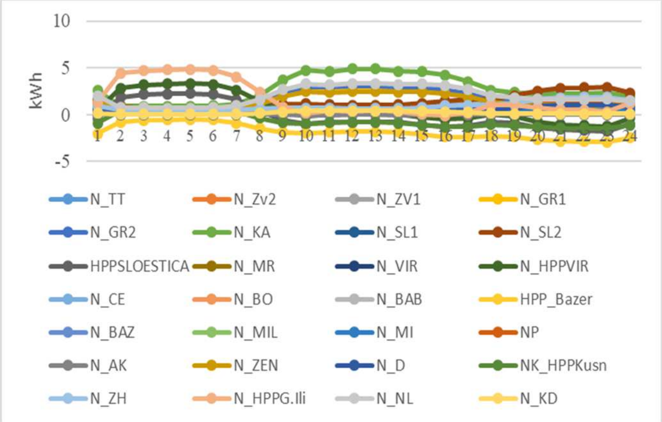

Figure 9. Variation of allocated losses (kWh) to nodes for Saturday in autumn season