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Selected problems of the cooperation between distribution networks and the sources of dispersed generation

***Abstract**. The addition of a new source of active power to an electric power distribution network alters its operation conditions. The effect of such changes depends on the power of the additional source, its location in the network as well as its type. In the paper the influence of the active power source on the selected parameters of the operations of the distribution network – such as the active power losses and voltage levels – is presented. Also, the influence of the level of power of the additional source and the level of the network's load on the location of tie points is considered.*

Streszczenie.** Instalacja dodatkowego źródła mocy czynnej w elektroenergetycznej sieci rozdzielczej zmienia warunki jej pracy. Efekt zmian zależy od mocy dodatkowego źródła, miejsca jego lokalizacji w sieci oraz rodzaju przyłączanego źródła. W pracy analizuje się wpływ źródła mocy czynnej na wybrane parametry pracy sieci dystrybucyjnej takie jak straty mocy czynnej i poziomy napięć. Dokonano analizy wpływu mocy przyłączanego źródła i poziomu obciążenia sieci na lokalizację stałych punktów podziału sieci **(Wybrane problemy współpracy sieci dystrybucyjnych ze źródłami generacji rozproszonej).

Keywords: electric power distribution network, active power losses, dispersed generation, location of dispersed generators.
Słowa kluczowe: elektroenergetyczne sieci rozdzielcze, straty mocy czynnej, generacja rozproszona, lokalizacja generacji rozproszonej.

Introduction

The generation of electric power through small generators connected directly to the electric power distribution networks has played in recent years an increasing part in meeting the demand for electric power. The rated power of such generators, referred to as dispersed generation (DG), is significantly lower than the power of industrial generators. However, the number of DGs successively increases. The proper location of such generators could influence the working conditions of the electric power networks through decreasing the variation of voltage and power losses [1], [2], [3], [4], [5], [6], as well as through increasing the reliability of electric power delivery. In case of the networks with relatively small voltage variations, the construction of local DGs may constitute an alternative to the modernization of the existing network or new industrial investments. On the other hand, the presence of DGs in the network causes additional problems. They are privately owned, which makes it more difficult for the Distribution System Operator to manage the network's flow.

The choice of the location of a DG in a distribution network should be determined through the analysis of the working conditions of the network for various loads and levels of the generated power. An arbitrary choice of such a location and the power of the DG may cause the increase of the power losses in the network.

In [1] the problem of the accuracy of the analysis of DG's influence on the workings of the distribution networks using different computation methods is presented. In [3], the necessity to change the location of tie points in a medium voltage electric power network in relation to the level of the network's load and the generated power of the DG is analyzed. Various models and methods for solving the problem of the optimal location of power sources are used [5].

The present paper is a continuation of the considerations presented in [1], [2], [3] and [7]. The present analysis pertains to the operations of two medium voltage circuits. In the first circuit the changes of power losses and of the voltage levels for different locations of DG in a medium voltage network under various level of the reactive power compensation are considered; in the second circuit, for the predetermined locations of DGs, the problem of the optimal location of the tie points in relation to the level of power losses is considered.

Model of the network

The assessment of the influence of an additional DG on the electric power network should be carried out on the basis of the analysis of the computation of load flow [1]. Such computations realized for medium voltage distribution networks require the basic data pertaining to the structure of the network's connections as well as its level of load. The analysis of load flow for various relations between the network's load and the power generation at DGs may lead to the correct picture of the cooperation between the network and the new power source (DG).

In order to construct the network's model, the following assumptions were accepted:

- the parameters of the respective line sections of the primary trunk and the lateral branches of feeder are known,
- the additional power sources are connected to the selected nodes of the network,
- the additional power source is modelled as an extortion of active power,
- the rated power of medium voltage (MV) / low voltage (LV) transformer substations is known,
- the load of all the MV/LV transformer substations is characterized by a uniform power factor $\mathrm{tg}\varphi = 0.48$,
- the load of the network's nodes is calculated as a product of the level of the network's load and the power of the given transformer.

The level of the network's load is calculated as a quotient of the total power flowing into the circuit and the sum of the rated powers of all the MV/LV transformers of the circuit. This assumption is usually accepted in case of computing load flow in the medium voltage networks, since there are no continuous measurements of the parameters of the MV/LV transformer substations available.

The influence of the location of the additional power source on the power losses in a distribution medium voltage network

In [1] and [7] the preliminary analysis of the influence of the addition of a DG source on the operations of a medium voltage network was presented. In the present paper, further such results, obtained with the use of a software based on load flow analysis, will be described. The analysis was carried out for a radial distribution network. The length of all the network's sections is 87.882 km. To the network, there are 83 transformers connected, of total rated power 9752 kVA. The peak load of the feeder is 3683,4 kVA. The analyzed network together with the assumed location of the additional power sources, is presented in Fig. 1. The computations were carried out for the network without the additional DG, as well as with it, for 7 selected network's nodes. The simulations assumed the following values of the additional source generation: 0, 20, 40, 60, 80, 100 and 120% of the maximum network's load, with the receivers' load for the natural tgφ and, after the compensation, for tgφ = 0,4.

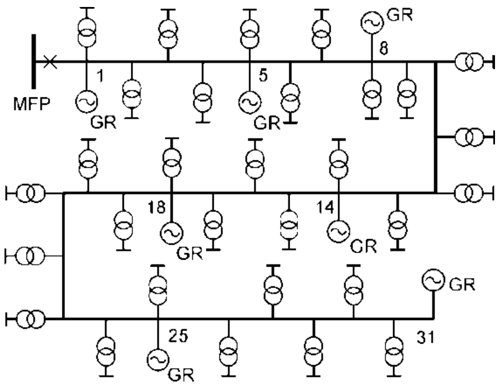

Fig. 1. The structure of the distribution medium voltage network together with the possible locations of the additional power sources (the figure does not reflect the network's branches)

In Fig. 2 the results of the computations of the voltage levels in the nodes of the network (for the natural tgφ) are presented. The chart includes only those nodes which were consecutively considered as the connection points of the new power source. It was assumed that the value of voltage at the main feeding point (MFP) is set at the level of 1.05 of the rated voltage of the network. The connection of a DG should improve the voltage conditions in the network. The increase of the voltage depends on the location and the power of the additional power source. Significant amount of newly generated power may lead to the excessive increase of voltage.

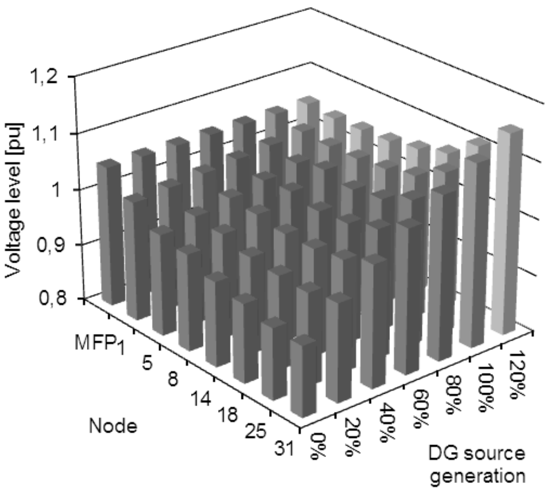

Fig. 2. The value of voltage in the network's nodes with the additional power source ($tg\varphi_{nat}$=0,48)

In Fig. 3 the active power losses in a medium voltage network with additional power sources connected at the selected points of the primary trunk of feeder for the natural tgφ are presented. In the figure, the power losses without the additional power source are also marked. The power losses (in a network with additional generation) depends on the location of the new source and its power.

The analysis suggests that the additional power source DG with the power not greater than the peak load of the feeder leads to the decrease of the power losses in the feeder. A DG with power greater than the peak load of the network may lead to the increase of the power losses in case its location is distant from the MFP.

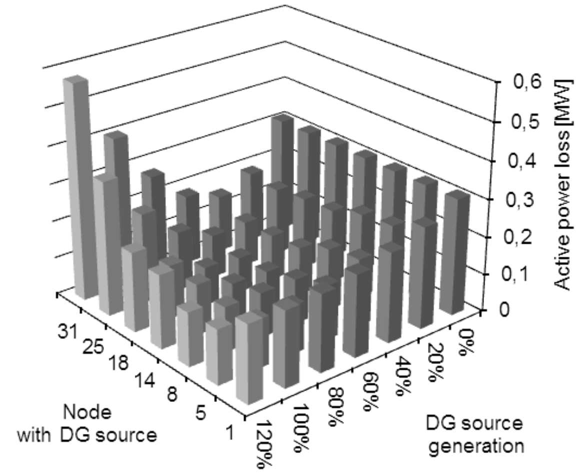

Fig. 3. Active power losses in a distribution network with the power source DG connected ($tg\varphi_{nat}$=0,48)

The best location of the new power source – in relation to power losses – is the node 18. With the generation at the level of 60% of the feeder demand, which is approx. 2,21 MW, the active power losses in the network are 94,14 kW. With the increase of the power of the DG source, the optimal location of the new source "moves" towards the nodes which are closer to the MFP. Because of voltage reasons, the connection of the DG source in such a case produces best outcomes at the final node of the network (node 31).

The computations of the influence of the location of DG on the level of losses in a distribution network for a circuit compensated to the level of tgφ=0,4 were also carried out. The results of the computations are presented in Fig. 4.

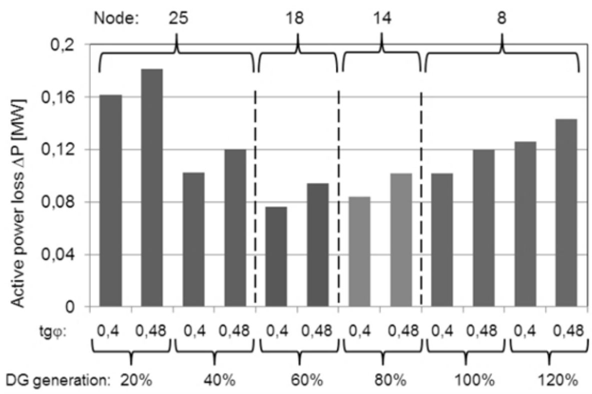

Fig 4. The minimal active power losses in a distribution network with the new power source DG connected and with compensation to tgφ = 0,4

The computations show that the compensation of reactive power does not alter the location of the connection of the additional power sources DG, given the criterion of minimizing active power losses. The minimal values of active power losses were obtained for the nodes: 8, 14, 18, 25 (Fig. 3 and 4).

The influence of the network's load and the generated power on the power losses in the medium voltage distribution network and the location of the tie points

Medium voltage distribution networks wok as open system. The networks are "split" at the locations convenient for the network's service, as well as resulting from the analysis of power demand. The basic criterion for the choice of such a location may be the value of the active power losses. The next example analyzed in the present paper serves to show the influence of the changes in the network's load and in the power generation on the optimal (i.e., leading the minimization of the active power losses) location of the tie points.

The network consists of four MV feeder supplied from the main feeding points (MFPs). The network is presented in Fig. 5. The Figure represents the primary trunk of feeder, but does not include lateral branches (which are, however, taken into account in computations). In the network, two locations of DG sources are identified. The number of MV/LV transformer substations, rated powers of the transformers S_{nt}, as well as peak load S_{max} and minimal load S_{min} are presented in Table 1.

The analysis assumes that:

- the minimal average load of the MV/LV transformer substations is 15%,
- the maximal average load of the MV/LV transformer substations is 50%,,
- at the selected points of the network two additional power sources are connected,
- the sources cannot supplied the MV feeders on their own,
- the analysis is carried out for two levels of power generation, 500 kW and 1000 kW (for each source), with tgφ=0 (cosφ=1).

Table 1. The parameters of the medium voltage network

Feeder	Number of stations	S_{nt} [kVA]	S_{min} [kVA]	S_{max} [kVA]
A	31	6336	880,74	2935,52
B	13	1955	234,50	781,58
C	37	5116	857,06	2856,59
D	31	5185	900,22	3000,45
	112	18592	2872,52	9574,14

It was assumed that before the addition of the new power source the network works with tie points located at a, d, g, j and l (Fig. 5). The selected tie point locations guarantee the lowest active power losses in the network. The addition of the new power sources changes the conditions of the network's operations. In consequence, the load flow changes, and hence the active power losses. The results of computations of the active power losses for the network without the additional power sources is presented in Table 2.

Table 2. Active power losses without new power sources

Feeder	Power losses [kW]					
	Generation at minimal load			Generation at peak load		
	0 kW	500 kW	1000 kW	0 kW	500 kW	1000 kW
A	4,85	2,72	11,41	56,09	34,67	25,39
B	0,19	0,19	0,19	2,16	2,16	2,16
C	3,96	3,96	3,96	45,72	45,72	45,72
D	4,52	3,24	11,86	51,86	34,89	28,77
	13,52	10,11	27,42	155,83	117,45	102,05

The level of power generation of the additional power sources should be adjusted to the network's load. If the generation is too high, the power losses increase. The presence of the additional power sources requires also the readjustment of the location of tie points. In Table 3 the optimal tie points given the criterion of minimizing the active power losses and in relation to various combinations of load and generation are presented. The optimal locations of tie points are presented in Table 4.

Table 3. Active power losses in optimal configurations

Feeder	Power losses [kW]			
	Generation at minimal load		Generation at peak load	
	500 kW	1000 kW	500 kW	1000 kW
A	3,451	9,413	34,674	33,281
B	0,194	0,067	2,165	2,165
C	0,747	0,186	45,721	20,316
D	2,622	6,953	33,413	32,881
	7,014	16,619	115,973	88,643

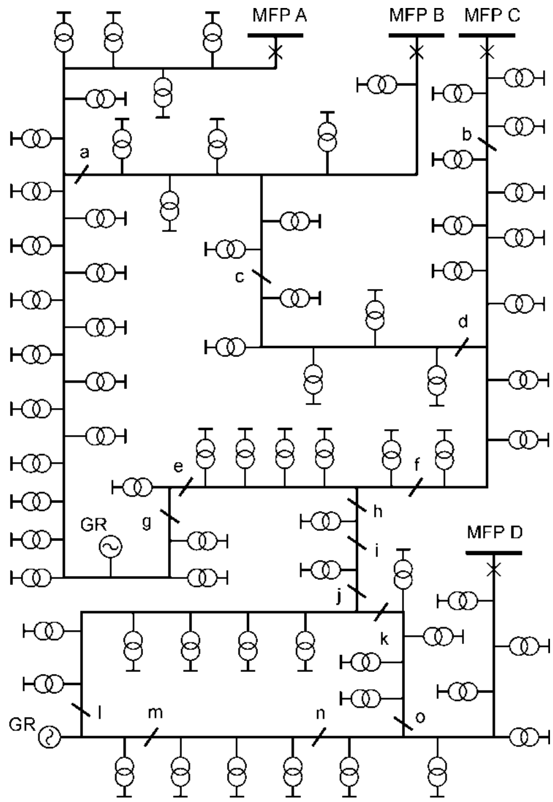

Fig. 5. A simplified scheme of the medium voltage network

The connection of a local power source influences the location of the network's tie points: they should be moved along the primary trunk of feeder depending on the changes in load and the power generated by the additional source.

Table 4. Locations of the optimal tie points in the network (according to Fig. 5)

Tie points locations			
Generation at minimal load		Generation at peak load	
500 kW	1000 kW	500 kW	1000 kW
a; d; f; h; k	a; b; c; h; o	a; d; g; j; m	a; d; e; i; n

In Fig. 6 the value of current at each line section of the primary trunk of feeders connecting the MFP A and the MFP C is presented. According to Fig. 5 the feeders supplied from the MFPs A and C are connected at two different points. Under the normal operation conditions those are the tie points. Fig. 6, reflecting the current flow in a close configuration of the network (closed connectors at

the tie open points), reveals the influence of the additional generation DG on the current flow in the network. In the figure the locations of the additional source (cf. also Fig. 5) are depicted together with the optimal locations of tie points at both minimal and peak loads.
In Fig. 7 the value of voltage at the primary trunks' nodes connecting the MFPs A and C for the new tie points is presented. The addition of a new power source improves the voltage condition of the network. The increase of voltage – the greatest at the node connected to the new power source – depends on its power and the level of the network's load.

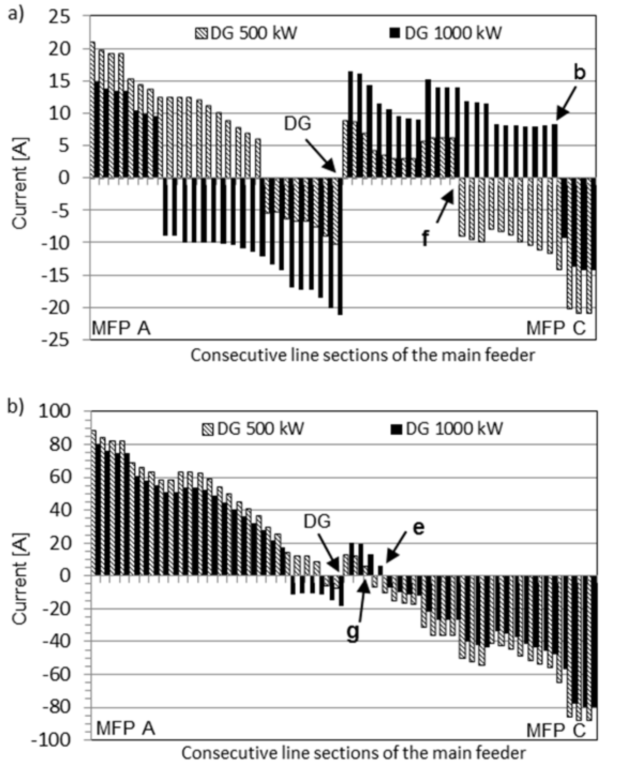

Fig. 6. The value of the current in the consecutive line sections of the primary trunk of feeders connecting MFP A and MFP C; a) minimal load, b) peak load

Conclusions
The computations reported above lead to the following conclusions:
- the location of the additional power source DG does influence the operations of the distribution network; the effect of those influences depends on the location of the additional source within the network, its power and the level of the network's load,
- the preliminary studies suggest that the reactive power compensation of the loads does not alter the connection points of the additional sources DG given the criterion of minimizing the active power losses;
- the variability of load in electric power networks as well as the changes in the dispersed generation causes the changes in load flow; in effect, it is very difficult to establish a configuration of the network with minimal active power losses; the influence of dispersed generation on the power losses in distribution networks reveals the need for more regular analysis of the power flow in the network and the identification of its optimal configuration;
- the analysis of the influence of additional power sources DG on the operations of electric power distribution networks should be furthered with the use of software dedicated to the computation of power flow.

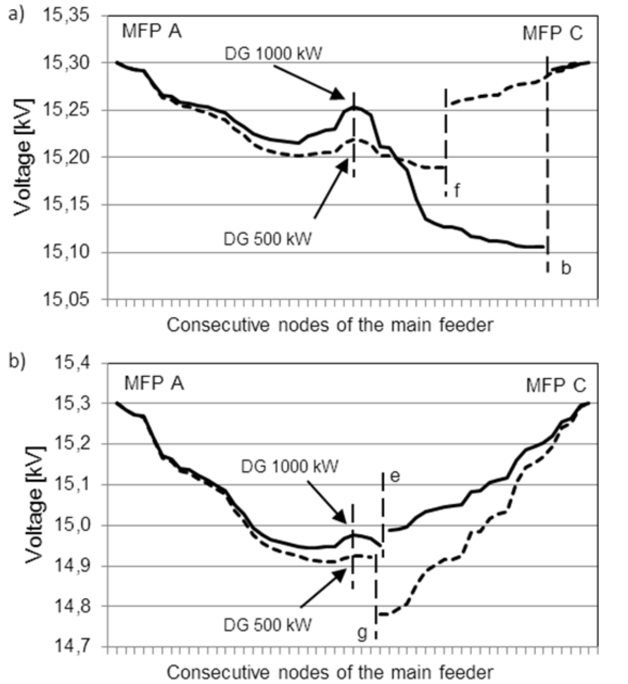

Fig. 7. The value of voltage in the consecutive nodes of the primary trunk of feeders between the MFP A and MFP C; a) minimal load, b) peak load

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