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Abstract. This paper presents the technical impacts of distributed generation in the distribution network in order to reduce the voltage drops. Input data, including the lengths, power factory, active and reactive load in each busbar of 10 kV distribution line is used to create the network model using a digital simulation and electrical network calculation. With the connection of distributed generators in the network, the need for investments in the distribution network infrastructure is reduced. When they are optimally located, the power losses and voltage drops within the distribution network are reduced and the reliability of the power supply stability is achieved. The model is used to analyze voltage drops in the last busbar of 10 kV line in the distribution network. The results show that, with the sufficient capacity of the installed distributed generator, the voltage drops in the last point of 10 kV line are reduced. It is seen that the distributed generation has a significant impact on reducing the voltage drops and are also successful in eliminating the bottlenecks, specifically to reduce the power losses and stabilize the electricity supply.

Keywords: Distributed generation, Distribution network, Power losses, Voltage drops.

1. Introduction

Numerous studies related to distributed generators (DG) can be found in the literature, as well as numerous definitions describing this type of production. Thus, DGs can be defined as electricity production in power plants of small dimensions and power, which are usually connected to the distribution network and not connected to the transmission network, and whose production is not coordinated with other conventional power plants [1].

DG are small electricity producers located near the consumption and load [1]. Their production capacities can range from several kW to several MW and are directly connected to the distribution radial network. The presence of the DG changes the power flow and load characteristics of the distribution network. It gradually becomes an active load network and it implies changes in the power flow [2].

To synchronize DG and distribution network voltages, the three main parameters are:

- Voltage magnitude - voltage values can vary up to 0.5 % from the nominal voltage.
- Voltage frequency - frequency values can vary up to 0.1 [Hz].
- Phase angle between voltages - can be up to 10^0.

The connection of the DG has affected in the voltage profile, power flow, losses, stability, short circuit currents and radial distribution network. The influence will depend on the number, type, location, and size of generators.

DG is supposed to support and improve the voltage of the distribution system, but the question that arises is to what extent this statement is correct, as it has been demonstrated that the penetration of DGs into the distribution system can cause voltage fluctuations. Moreover, specific DG technologies change their output power with time, as in the case of photovoltaics and wind generators. As a result, voltage fluctuations occur that worsen the quality of energy delivered to consumers [3].

DG helps to deliver backup power during the times of increased electricity demand, having also as a result the reduction of the distribution power losses [3].

On the other hand, the implementation of DG has had positive impact on the distribution network because they contribute to the compensation of reactive power for voltage control, frequency regulation and can act as backup resources, in the event of system failure, and primary resources.

DG is one of the possible options for mitigating the problems of load increase, line overload, quality of supplied electricity, system reliability and reduction of line losses [4]. DG generates power at the local level to meet the requirements of local consumption.

DG can provide benefits for both the consumer and the distribution system, especially in locations where conventional generation is not feasible or where there is no adequate infrastructure [5].

The anaother positive impacts of DG on the distribution network are: Free produced energy, environmental friendliness avoiding emissions, the possibility to supply places where power systems have not been built, easiness in use and low operating costs [6].

In addition to the advantages, the integration of DG into the power system has certain disadvantages, and the basic one is to increase the voltage at the connection point. Also have other negative impacts, such as the unexpected power flows, which are reflected in the quality of the voltage and system parameters respectively and the frequency of the system [7].

Negative tchnical impacts of DG connection to the distribution network can be sublimated through the following aspects [8]:

- High specific investment costs;

- Voltage profile instability due to bidirectional power flow;
- System frequency deviations;
- Higher harmonics; some DGs must be connected to the network via a DC/AC interface, which can contribute to the appearance of higher harmonics;

It has been proven that DG can minimize energy losses (active and reactive) of distribution networks due to their installation near load centers. Consequently, the specific location of a DG in a distribution network and the specific capacity of the DG resulting in minimal energy loss are generally identified as the optimal location.

This paper treats the technical impact of DG after its installation in the observed part of the distribution system. It has been analyzed what are the impacts of the installed DG on voltage drops and energy losses in 10 kV lines, based on Exact loss formula, according to Olle Ingemar Elgard.

The paper is structured as follows: Technical Impacts of Distributed Generators presented in section 2, Impact of DG in voltage drop presented in section 3 and Conclusions of this paper are summarized in section 5.

2. Technical impacts of DG in distribution network

The technical impact of DG connection on the distribution network is reflected through [9-11]:

- Improving of voltage stability;
- Improving the quality of energy;
- Increase the reliability and security of the system;
- Impact on protection coordination;
- Reduction of power losses.
- Reduction of voltage drops.

2.1 Voltage deviations and influence on voltage regulation

The effect of voltage increase is a key factor limiting the number of added DGs in the distribution network. If the capacity of DG units increases, then voltage regulation analysis is required [12].

DG integration does not have to be a problem when the DG is connected to a system that has low voltage problems.

3.2 Improving the quality of energy

The integration of DG can contribute to improving the quality of energy, through raising the voltage value and correcting the power factor. Conversely, the integration of DG, ie the occurrence of two-way power flows and complex control of reactive power can be problematic and lead to voltage fluctuations, ie. degradation of energy quality.

Different DGs have different characteristics, and therefore different levels of impact on energy quality. Thus e.g. a large wind generator connected to an insufficiently strong electricity grid can lead to significant problems in terms of energy quality [13]. Also, the power electronics that monitor the connection of DG to the network tends to generate higher harmonics, which again makes it a problem for the quality of energy.

In general, from the aspect of energy quality, DGs affect the occurrence of:

- voltage oscillations (fluctuations);
- voltage flicker (flicker);
- harmonic voltage distortions.

3.3 Reliaiblity and possible security of the system

Reliability issues relate to permanent interruptions in electricity supply.

DG systems can potentially provide the following options to increase the reliability of the power system:

- Increasing the total production capacity of the system;
- Increasing system reserves and
- Reducing the load on distribution network.

The higher the available reserve, the higher the reliability of the system. In this regard, DGs can be used as backup generators, which can be put into operation in the event of a system failure.

3.4 Coordination of protection

DG integration requires protection coordination that can sustain two-way power flows. The contribution of the DG strongly depends on the type of DG and the way the DG unit is connected to the distribution network [13].

During the operation of the DG parallel to the distribution network, it is necessary to install its protection, to protect it from daily events that occur in the distribution network such as: Power outage in the distribution network, short circuit currents and protection from voltage changes as well as frequency changes.

3.5 Reduction of power losses

One of the main impacts of DG is the impact on power losses in distribution lines and therefore it should be positioned so as to contribute to the reduction of power losses.

The goal of DGs is to decentralize and partially abandon the construction of large power plants where energy is transmitted over long distances, which leads to losses in the system. Since these are small production units that are connected to a medium voltage network or a low voltage network, during planning it should be ensured that the produced energy is used at the same or lower voltage levels. Otherwise, there would be an increase in network losses.

Calculations, analyzes, estimates and measures to reduce power losses represent a significant technical and economic task [4].

The exact loss formula is a nonlinear load-based equation to determine the optimal location and size of the DG unit in a radial network to improve the voltage profile and reduce power losses.

Losses in a network are dependent on the operating conditions of the system and are given by the formula known as the exact loss formula.

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} (P_i P_j + Q_i Q_j) + b_{ij} (Q_i P_j - P_i Q_j) \quad (1)$$

$$_{ij} = \frac{r_{ij}}{V_i V_j} \cos (\delta_i - \quad)_j \quad (2)$$

$$b_{ij} = \frac{_{ij}}{V_i V_j} \sin \; (\delta_i - \quad)_j \quad (3)$$

Where:
P - active power;
Q - reactive power,
V – voltage, and
r_{ij} - resistance between busbars i and j.

It has been proven that in the case of networks with increasing power losses, the installation of a DG unit will significantly affect the reduction of technical losses in the network.

3. Impact of DG in voltage drop

During the calculation of voltage drops in the distribution nework, it must be taken into account the ratio X/R, because in the distribution grid cannot be ignored the active resistance.

This way, we can model the distribution lines with the impedance $Z = R + jX$ and voltage drops are as in (4).

$$\Delta V = (R + jX) I = \frac{P_L R + Q_L X}{V_L} \quad (4)$$

Where:

$$I = \frac{P_L - jQ_L}{V_L} \quad (5)$$

Where:
ΔV - voltage drop;
$R + jX$ - line impedance;
P_L - active power;
Q_L - reactive power;
V_L– voltage amplitude, and
I - the rms value of the current flowing through the line.

Due to the small X/R ratios in the distribution networks and the radial structures of these networks, the influence of DG on the distribution network voltage is significant [14]. The above equations should be considered as one of the constraints of the optimization problem [15].

4. Simulation results

For the analysis is taken in consideration to work in parallel with network DG with S_{inst}= 918.95 kVA. It will be connected to the 10 kV line “Llukari” located in the Pristina distribution network. This10 kV line is supplied from Substation 110/10(20) kV, “Pristina 5” whose length is L=15.57 km. From this 10 kV line, 15 SS 10/0.4 kV are supplied with an installed capacity S_{inst}=5.14 MVA.

Load distribution diagram in case of DG connection in 10 kV line is presented in Fig.1.

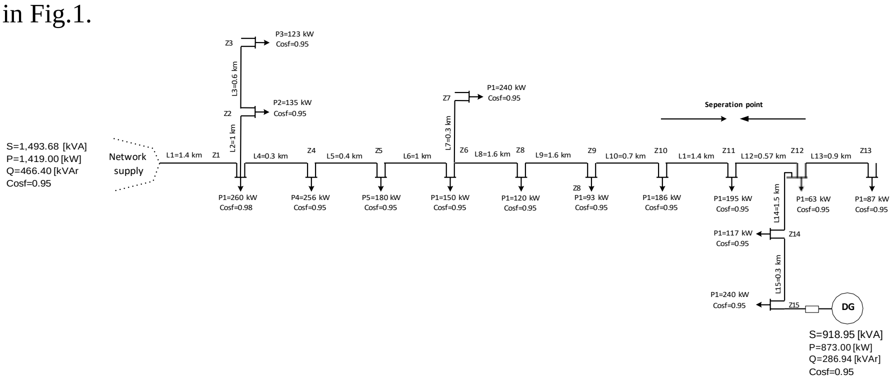


Fig.1 Single line diagram of line “Lukari”, supplying from two sources (system and DG)

In the Table 1 presented calculation of voltage drops in 10 kV line without DG.

Table 1. Calculation of voltage drops in 10 kV line in case without DG

Busbar nr.	P [kW]	Q [kVAr]	ΔU%=100/Un²*{ri *Pi*li+xi*Qi*li) [V]	ΔU%=100/Un²*(ri *Pi*li+xi*Qi*li) [%]	U_2 [V]	U_{2f} [V]
SS					10.50	6.06
Z1	513.00	168.61	262.62	2.50%	10.24	5.91
Z4	108.00	35.50	42.51	2.91%	10.19	5.89
Z5	180.00	59.16	53.24	3.41%	10.14	5.86
Z6	390.00	128.19	118.77	4.54%	10.02	5.79
Z8	120.00	39.44	140.32	5.88%	9.88	5.71
Z9	93.00	30.57	125.03	7.07%	9.76	5.63
Z10	186.00	61.14	49.51	7.54%	9.71	5.60
Z11	195.00	64.09	78.29	8.29%	9.63	5.56
Z12	150.00	49.30	23.02	8.51%	9.61	5.55
Z14	117.00	38.46	42.66	8.91%	9.56	5.52
Z15	240.00	78.88	5.74	8.97%	9.56	5.52
Total	**2,292**	**753.34**	**941.70**	**8.97%**	**9.56**	**5.52**

Voltage drop at the end of the 10 kV line, are presented in Fig.2.

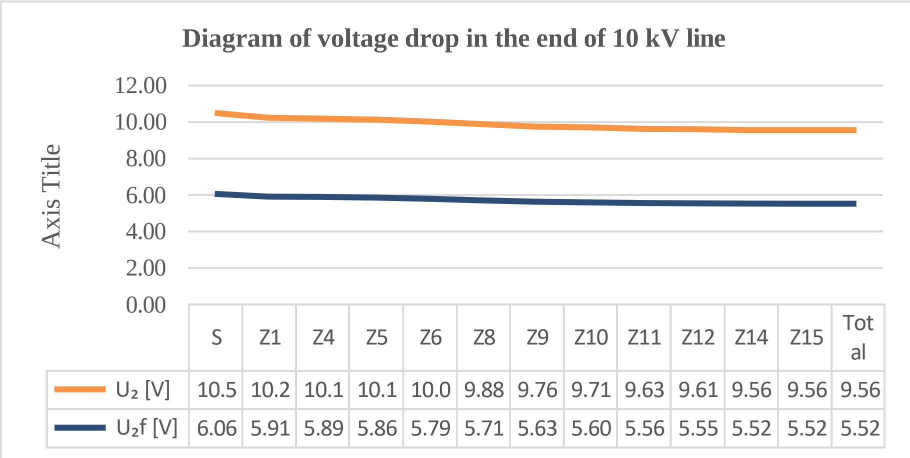


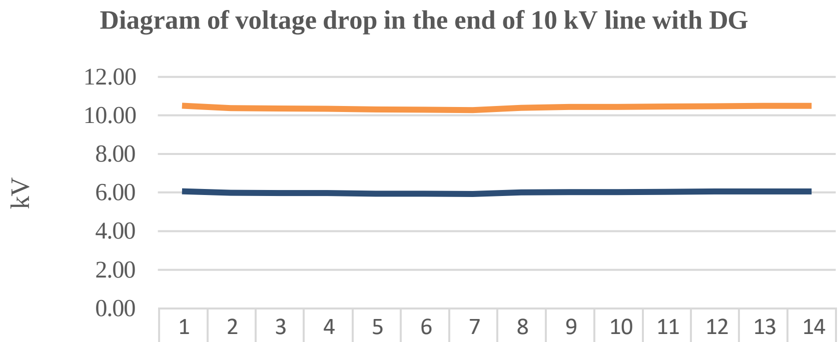
Fig.2 Voltage drops diagram at the end of the 10 kV line.

In the Table 2 presented calculation of voltage drops in 10 kV line with DG.

Table 2. Calculation of voltage drops in 10 kV line, suplied from substation and DG.

Busbar nr.	P [kW]	Q [kVAr]	$\Delta U\%=100/Un^2*\{ri*Pi*li+xi*Qi*li)$ [V]	$\Delta U\%=100/Un^2*\{ri*Pi*li+xi*Qi*li)$ [%]	U_2 [V]	U_{2f} [V]
S					10.50	6.06
Z1	513.00	168.61	123.67	1.18%	10.38	5.99
Z4	108.00	35.50	16.54	1.34%	10.36	5.98
Z5	180.00	59.16	19.45	1.52%	10.34	5.97
Z6	390.00	128.19	37.73	1.88%	10.30	5.95
Z8	120.00	39.44	22.64	2.10%	10.28	5.94
Z9	93.00	30.57	11.03	2.20%	10.27	5.93
Z10	21.00	6.90	0.89	1.03%	10.39	6.00
Z10	165.00	54.23	10.56	0.63%	10.43	6.02
Z11	195.00	64.09	7.99	0.53%	10.44	6.03
Z12	150.00	49.30	27.01	0.46%	10.45	6.03
Z14	117.00	38.46	6.92	0.20%	10.48	6.05
Z15	240.00	78.88	14.04	0.13%	10.49	6.05
Total	**2,292**	**753.35**	**174.80**	**0.13%**	**10.49**	**6.05**

Voltage drop at the end of the 10 kV line, supplied from substation and DG, are presented in Fig.2.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
U_2 [V]	10.5	10.3	10.3	10.3	10.3	10.2	10.2	10.3	10.4	10.4	10.4	10.4	10.4	10.4
U_2f [V]	6.06	5.99	5.98	5.97	5.95	5.94	5.93	6.00	6.02	6.03	6.03	6.05	6.05	6.05

Fig.3 Voltage drops diagram at the end of the 10 kV line, suplied from two sources, system and DG.

The results for voltage drop in the end of 10 kV line "Llukari" for both cases can be shown at the Fig.2 and Fig.3, respectively. The voltage drop in the case without DG in the end of the 10 kV line "Llukari"is: ΔU=8.97%. Voltage drop in the case with DG in the end of this 10 kV line is: ΔU=0.13 %.

5. Conclusions

From the simulated results obtained, some conclusions can be drawn in terms of operation and integration of DG and their impact in the distribution system. From this, it can be concluded that DG also have their role in improving the performance of the parameters of the integrated power system or even of isolated substations. Thus, they affect the security of supply of consumers as well as the quality of tensions and reduction of losses. From this paper, it is also possible to conclude that voltage drops are under the allowed maximum voltage drop range as is the IEC 61000 standard applied for distribution networks which is ±10% to ±15%. This is also shown in the results obtained, that the capacity of DG, its location and size of load play an important role for voltage drop as it is shown at Fig.3.

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