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Alternative Solutions in Distribution Network due to Increasing Consumption and Peak Generation

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Abstract: This paper deals with a real-life problem. In an existing distribution network, that already operates near to its limit load capability at peak loads, an industrial costumer requested an increase of connected power. On the other hand, in the same distribution network operating at low load, distributed generation units cause an increase in voltage that exceeds the prescribed limits. Thus, this paper focuses on the analysis of different approaches, that can be used to solve the described problems. For the given network configuration, the Backwards Forward Sweep load flow calculations are applied inside Differential Evolution based optimizations for different load and generation scenarios. To keep the voltage profile inside prescribed limits and to prevent current overload of individual lines, the network reconfiguration and reactive power generation in the transformer substation and in the distributed generation units is analysed. The obtained results show, that the reactive power generation can be applied to increase the maximal load power whilst a proper voltage profile, at minimal load and maximal distributed generation, is achieved by network reconfiguration.

Keywords: Load flow, Optimization, Voltage profile, Distribution network

1 Introduction

Normally, distribution networks operate according to established and relatively conservative rules of operation, which enable proper network operation in all operating conditions. Normally, the total allowed voltage profile changes in 20 kV networks are in the range of ±3 % to provide a proper voltage profile also in 0.4 kV networks. However, in some cases, when new distribution lines cannot be built immediately, also operation with the voltage profile changes that exceed the ±3 % in 20 kV networks can be tolerated.

This paper deals with a real-life distribution network with distributed generation, operating close to its upper loading limit, where industrial consumers want to increase the installed power. Different solutions that can be applied to solve this problem are discussed in the paper. They are evaluated using load flow calculations [1], were the impact of distributed generation units on the voltage profile in the network must be considered [2].

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2 Distribution Network

The discussed distribution network is powered by a single 31.5 MVA 110/20 kV transformer equipped with an on load tap changer (OLTC). It is placed in the substation Ravne. A 1 Mvar capacitor bank, that can provide reactive power, is placed in the substation Mežica. The transformer supplies over 2500 consumers connected to 53 20/0,4 kV transformers and two bigger industrial consumers. Figure 1 shows a simplified one-line diagram of the distribution network, where substations with switching capabilities and two bigger consumers, Žerjav and Topla, are connected. Each of the two bigger consumers is powered by different feeder. The biggest distributed generation units are two hydropower plants with the total power of 4 MVA connected to the distribution network at Žerjav. They are equipped with synchronous generators able to generate variable reactive power.

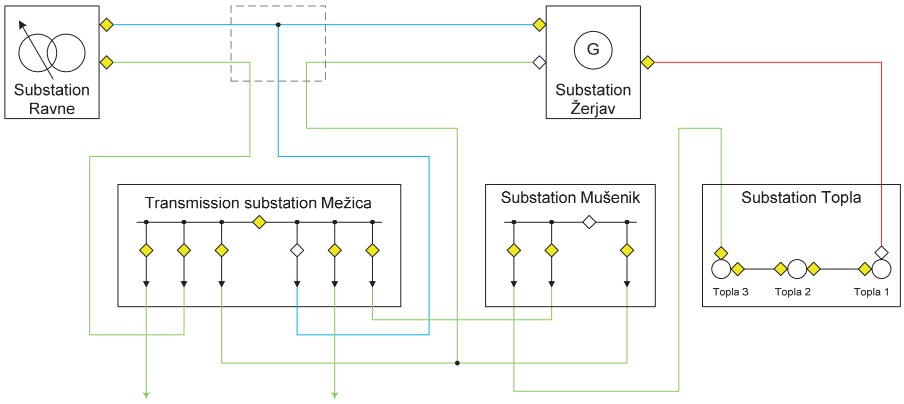

Figure 1: Simplified one-line diagram of the discussed distribution network

The discussed distribution network is considered as symmetrical. Therefore, a single-phase modelling approach is used. More detailed descriptions of the network, applied model, load and generation profiles are given in [3].

3 Approach and Solutions to Problems in Distribution Network

The two industrial consumers require the increase of installed power from 6,5 MW to 9 MW at Žerjav and from 6 MW to 6.5 MW at Topla. Since the network already operates near the maximal allowed voltage drop, the increase of installed power cannot be granted if conventional method of distribution network design and operation are applied. A proper solution of this problem is to build a new transmission line directly to Žerjav. Normally it takes several years to get right of way and to fulfil all legal requirements. The question is what can be done in the meantime. In order to evaluate all possible solutions, a stochastic search algorithm called Differential Evolution [4] is employed together with Backward Forward Sweep load flow algorithm for radial network [5] and modified Backward Forward Sweep for weakly meshed network [6]. The optimization tool, obtained in this way, is used to determine that increased maximal power of industrial users, where the voltage profile in the discussed distribution network is inside prescribed limits. The analysis is performed with and without 1 Mvar capacitor battery in the transformer substation Mežica, where maximal values of the measured network load profiles and radial network configuration are considered. It is checked

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what is the impact of closed loop operation on the voltage profile. Finally, for the maximal 3.6 MW active power generation of the two hydropower plants connected to the network in Žerjav, different options, including network reconfiguration, are checked to provide a proper voltage profile in the network, considering minimal network loads.

3.1 Calculation of Maximal Acceptable Power of Industrial Consumers

To determine the maximal power of the industrial consumer, where the network voltage profile is steel inside given voltage limits, the worst-case scenario is checked. The distributed generation units are omitted whilst the maximal point from the measured yearly load profile is considered. The limits were set to ±3 %, ±5 % and ±8 % of the nominal 20 kV voltage. Thus, the bus voltage of the transformer with OLTC in substation Ravne (swing voltage) is considered with 20.6, 21.0 and 21.3 kV. The optimization is applied to find the maximal power of the consumer, where the voltage profile in the entire network is under prescribed limits and none of the lines shows current overload. The obtained results are shown in Table 1. The power marked with * means that the line current and not the voltage is the limiting factor in the given case. Calculation in ±3% voltage zone is not possible due to too low swing voltage.

Table 1: Maximal power results without considered distributed generation

VOLTAGE ZONE	SWING VOLTAGE [KV]	POWER ŽERJAV [MVA]	POWER TOPLA [MVA]
±3%	20.6	/	/
±5%	21.0	7.46	3.56
±8%	21.3	10.57*	7.22

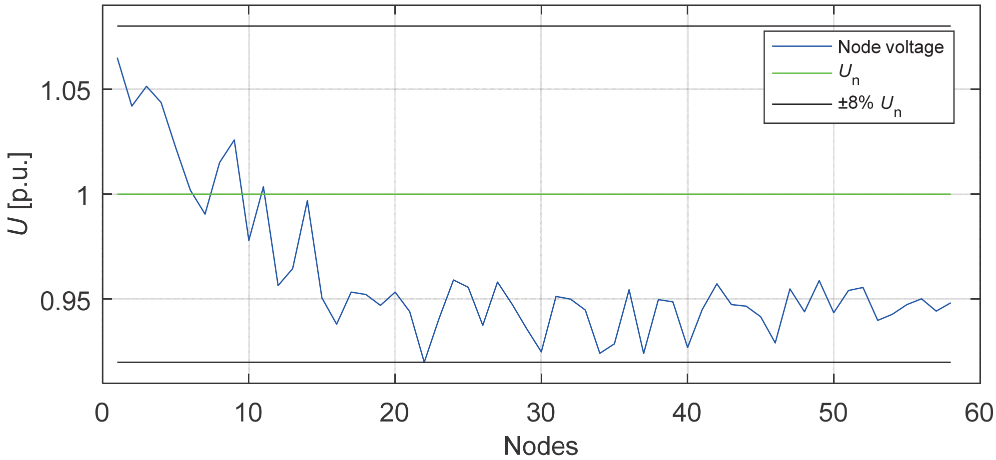

Figure 2: Voltage profile at the maximal power from Table 1 and the voltage limit of ±8%

Figure 2 shows the network voltage limit as a function of the node number for the voltage limit of ±8 % and the maximal power of industrial consumer shown in Table 1. Žerjav is presented with the node 23 and the three transformers at Topla are presented with the nodes 30, 34 and 37.

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In the next calculation, the distribution generation in Žerjav is not omitted. Based on measured generation profiles, the minimal generated power of 0.5 MVA with different factors cosφ is considered. Since the two industrial consumers are supplied by different feeders, only power in Žerjav is presented. The obtained results are shown in Table 2.

Table 2: Maximal power that can be connected in Žerjav considering distributed generation at different cosφ

VOLTAGE ZONE	**SWING VOLTAGE [KV]**	**POWER ŽERJAV [MVA]**			
		cosφ = 0.95	cosφ = 0.9	cosφ = 0.8	cosφ = 0.6
±3%	20.6	/	/	/	/
±5%	21.0	7.96	7.98	8.00	7.99
±8%	21.3	11.07*	11.06*	11.05*	10.99*

To increase the power of the consumer that are connected in Topla, the 1 Mvar capacitor bank in the substation Mežica is considered in the analysis. The obtained results are shown in Table 3.

Table 3: Maximal power that can be connected in Topla considering 1Mvar capacitor bank in Mežica

VOLTAGE ZONE	**SWING VOLTAGE [KV]**	**POWER TOPLA [MVA]**	
		Without capacitor bank	With capacitor bank
±3%	20,6	/	/
±5%	21	3.56	4.27
±8%	21.3	7.22	7.69

3.2 Closed Loop Operation

Operation in the closed loop is considered only to check if such an operation can improve the voltage profile. The problems related to the protection system configuration and setting are not discussed in this work. The loop is closed through Žerjav and Mežica (Figure 1). All distribution network consumers are assumed to operate at maximal power as in chapter 3.1, whilst the power of the consumers is set to 9 MVA in Žerjav and 6.5 MVA in Topla. Figure 3 shows the comparison of voltage profiles in the case of operation with radial feeders and feeders in the closed loop arrangement. The results presented in Figure 3 show that the closed loop operation cannot substantially improve the voltage profile at maximal load.

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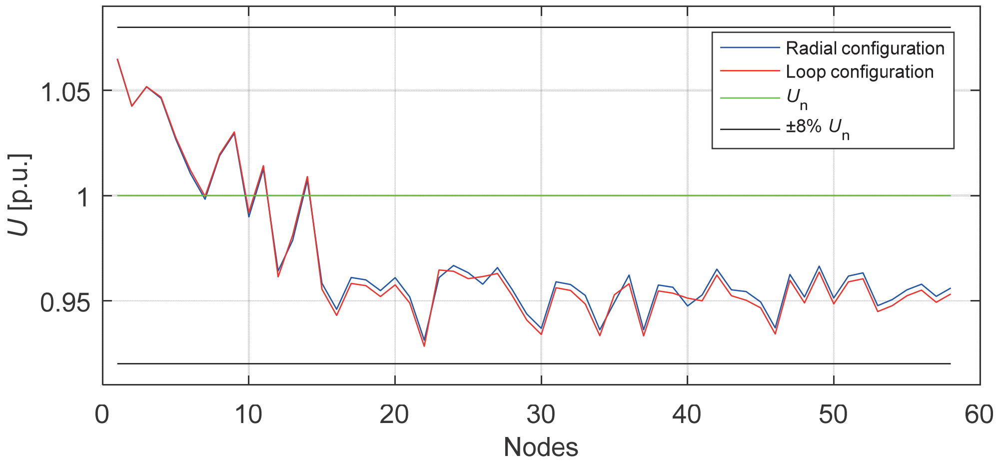

Figure 3: Comparison of voltage profile considering radial feeders and feeders in closed loop arrangement

3.3 Increased Voltage in the Network due to Distributed generation

Problems with to high voltage occur mostly at nightly hours at peak generation of the two hydropower plants connected to the network in Žerjav. To solve problems with too high voltages, the network reconfiguration during nightly hours and the reactive power generation of the two hydropower plants are applied. The network reconfiguration should be performed automatically when the voltage exceeds its upper limit. Otherwise the network operates in normal configuration with feeders in radial arrangement. normally. An example of the voltage profile in the distribution network at peak generation of 3.6 MW in Žerjav is shown on Figure 4.

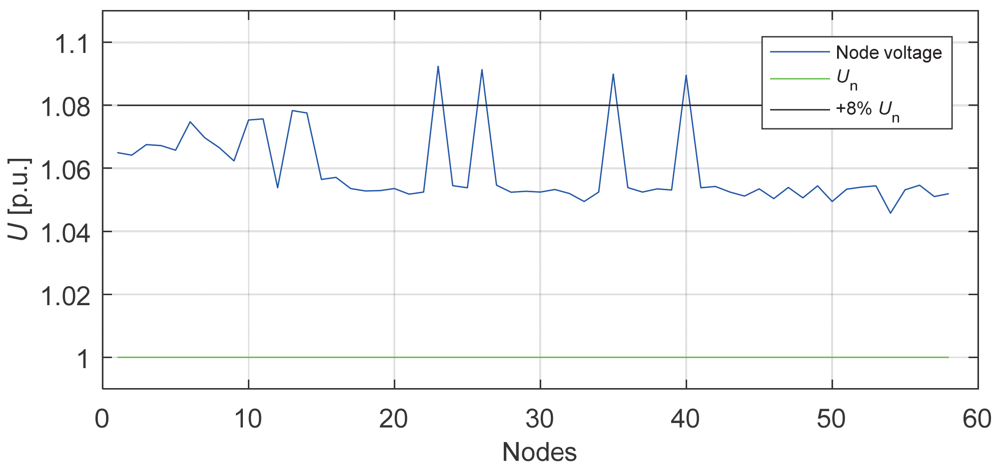

Figure 4: Voltage profile at peak distributed generation

The three reconfigurations of the distribution network can be performed:

a) switch Topla from Mušenik to Žerjav,
b) switch Žerjav from Ravne to Mežica and
c) switch Žerjav from Ravne to Topla.

In the analysis, cosφ of the two hydropower plants is reduced to increase the generated reactive power, which decreases the voltage profile and increases the network losses. The

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calculations are performed for cosφ of 0.99, which is the normal value, and for cosφ = 0.8. Figure 5 to Figure 7 show the voltage profiles for different network reconfigurations and different values of cosφ. The corresponding networks losses, including losses of transformers, are presented in Table 4.

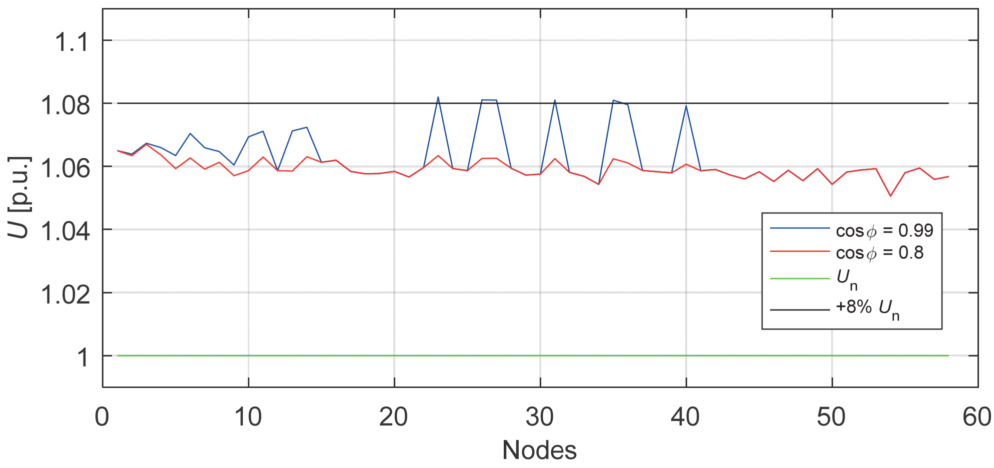

Figure 5: Voltage profile for the reconfiguration a)

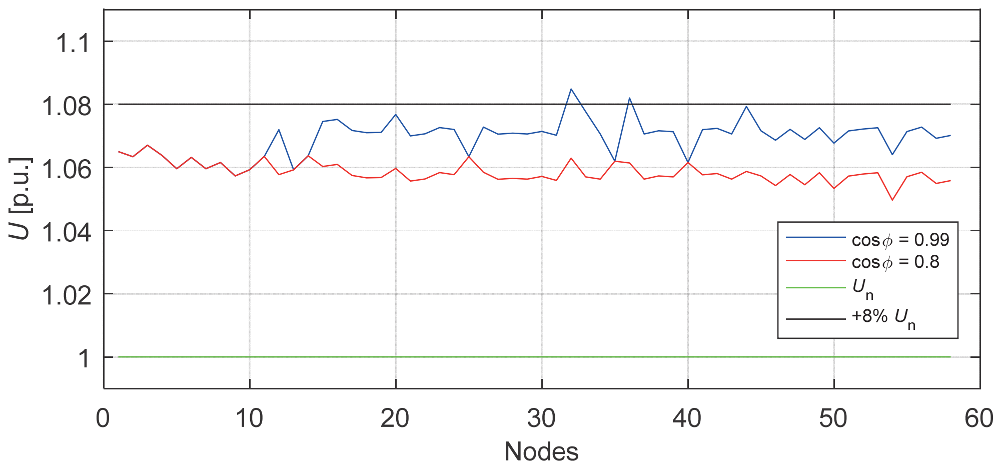

Figure 6: Voltage profile for the reconfiguration b)

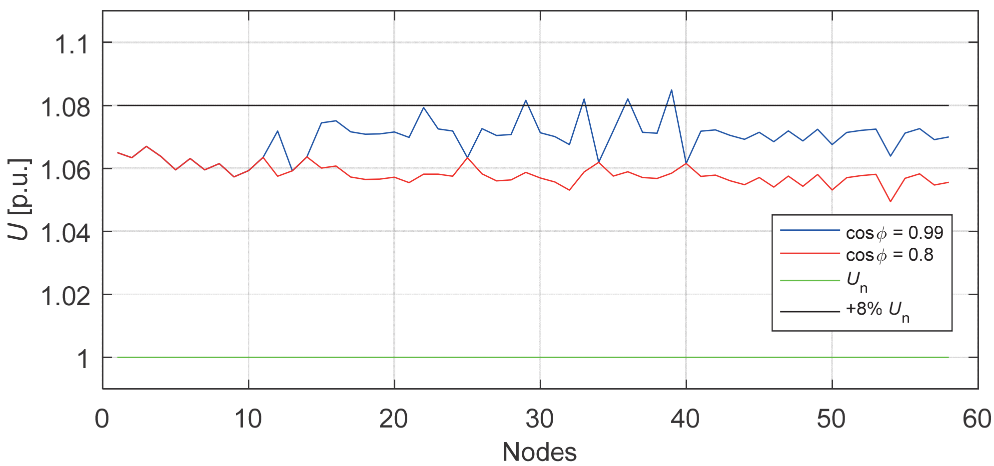

Figure 7: Voltage profile for the reconfiguration c)

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Table 4: Network losses for different network reconfigurations and cosφ

RECONFIGURATION	NETWORK LOSSES [kW]	
	cosφ = 0.99	cosφ = 0.8
a)	76.1	92.2
b)	83.5	105.5
c)	86.8	114.7

4 Conclusions

The aim of this work is to evaluate possible solutions that can be used to increase the power of two industrial consumers in a distribution network already operating at the upper limit of its maximal loading. To perform the evaluation, Differential Evolution based optimizations are combined with the Backward Forward Sweep load flow methods, adapted for radial and weakly mashed networks. The discussed network is considered as symmetric; therefor only single-phase calculations are performed.

The described tools are applied to check the current situation in the distribution network, to check the possibility for the power increase of two industrial consumers, and to check how the closed loop arrangement of feeders and reactive power generation influence the voltage profile in the discussed network.

The results presented in the paper show that the power of two industrial consumers can be increased if the voltage drop of 8 % can be tolerated in the discussed 20 kV distribution network, having in mind that some lines can operate near to their upper current limit. In critical line sections. 20/0,4 kV transformers could be equipped with OLTCs in order or provide proper voltage profiles in the low voltage 0.4 kV networks even in the cases when the 20 kV voltage changes in the range of ± 8 %.

In the given case, the operation of radial feeders in closed loop arrangement does not contribute to the voltage profile improvements. However, the network losses can be reduced for 0.1 % in comparison to the operation with radial feeders.

The increase in voltage profile at low load and maximal generation of distributed generation units is resolved by network reconfiguration and reactive power generation. Three possible network reconfigurations are checked. The results obtained by all three reconfigurations are similar. They differ mainly in the location of the switches that should be applied and in the corresponding network losses. It is shown that the reactive power generation in distributed generation units can help to reduce the network voltage profile, however, on the costs of increased network losses.

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