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Voltage Level Increase in Low Voltage Networks through Reactive Power Compensation Using Capacitors

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Abstract

The voltage level matter, in power distribution networks, has a great importance due to the effect which an improper voltage may have over the electrical users. A higher voltage level may determine a shortened equipment life, while a low voltage level cause the increasing of the current network which leads to equipment failure. The voltage variation limits in distribution networks are imposed by standards in force. Performance Standard of Electrical Distribution Network stipulates the following: "In the delimitation point, in normal working condition, the effective mean value of delivered voltage within 10 minutes in 95% during any period of a week should not have a deviation greater then ±10% of contract voltage for MV and HV respectively ±10% of nominal voltage for LV. "Voltage decrease outside the limit of -10% is one of the most common deviations in distribution networks, causing penalties charged to the distribution operators. Thus, voltage increasing, for them where this is necessary, is an important concern for the distribution operators. This work aims to treat the increasing voltage level solution in low voltage networks using capacitors to compensate reactive power flow.

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Keywords: voltage drops; power losses; capacitors; distribution network; compensate reactive power flow.

1. Introduction

The issue of voltage level in electrical distribution networks is highly important, given the consequences that an inadequate voltage might have upon the electrical users. Therefore, while a higher voltage level can lead to

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decreasing the lifetime of equipment, a lower one causes current increase through the network, inducing equipment damage, electrocution, arson or even loss of human life.

Voltage variation limits in electrical distribution networks are required by the applicable standards. According to the Performance Standard for Electricity Distribution Systems, at the delimitation point, in normal operating conditions, the average root-mean-square of a 10 minutes' voltage for 95% of a week mustn't exceed a deviation of ± 10% of the voltage contracted for medium voltage (MV) and high voltage (HV), respectively, ± 10% of nominal voltage for low voltage (LV).[1]

Voltage decrease beyond the limit of -10% is one of the most common matters encountered in low voltage electrical distribution networks, ending up in penalties which the distribution operator must support.

Given these reasons, voltage adjustment in networks where needed is one of the most important concerns of the energy distribution operators.

The present study approaches the theme of voltage level increase in low voltage networks, using capacitor banks in order to compensate the reactive power flow.

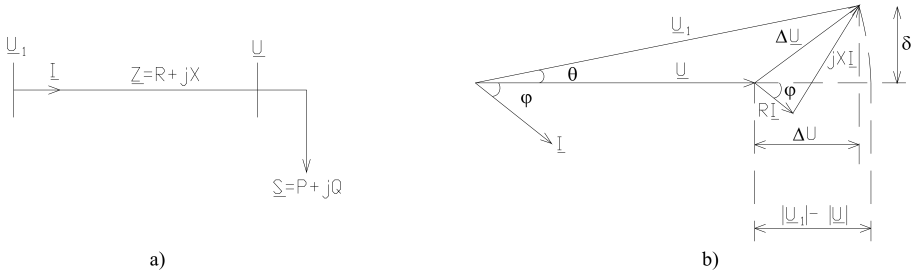
As follows, we will analyze the influence of capacitor bank functioning on voltage, through different regimes. Voltage level will be monitored both in the substation to which the capacitor bank is connected and at the end of the line where problems were reported.

2. Voltage adjustment in electrical networks

Voltage represents a quality parameter of electricity and its variation must not exceed certain limits, established by the existing standards, depending on the nominal voltage of the network.

Unlike frequency, which has the same value in all mesh points, voltage level fluctuates a lot through the network, depending on the active and the reactive power flows and on the network parameters.

In Fig. 1. is shown a radial electric line, which supplies a user concentrated at the extremity and the vectorial diagram of voltage and of voltage drop that occur on the mentioned line. [3]



a) b)

Fig. 1. a) Radial electric line, supplying a user concentrated at the extremity; b) Vectorial diagram of voltage and of voltage drop that occur on the considered line.

$$\Delta\underline{U} = \underline{U_1} - U = \underline{Z}\cdot\underline{I} = (R + jX)\underline{I} = \frac{(R + jX)\cdot(P - jQ)}{U} = \tag{1}$$

$$= \frac{P\cdot R + Q\cdot X}{U} + j\frac{P\cdot X - Q\cdot R}{U} = \Delta U + j\delta U$$

where: ΔU – the longitudinal component of voltage drop;
δU – the widthwise component of voltage drop.

Considering that the direct-axis impedance of most components which form electrical networks is characterized by low values of resistance, compared to positive reactance (R << X), the following relations can be used to approximate voltage drop values (2):

$$\Delta U = \frac{QX}{U}$$

$$\delta U = \frac{PX}{U} \tag{2}$$

$$\theta = arcsin\frac{PX}{U_n^2}$$

Taking into account these aspects, we can affirm that the voltage level in network nodes is mostly given by reactive power flows, while phase alteration is determined by active power flows.
From here, we can also deduct the main voltage control means in electrical networks:

- changes of reactive power flows;
- changes of network parameters: R, X;
- insertion of additional voltages. [2]

Changes in reactive power flows imply the existence of means available to produce or to absorb reactive power. Among these, there are: synchronous generators and motors, synchronous compensators, derivation capacitor banks, coil shunts and FACTS devices (Flexible Alternating Current Transmission Systems). [3]

Changes of network parameters can be achieved by connecting or disconnecting circuits or by compensating the reactive inductance of the network. [2]

The introduction of an additional voltage in the network can be accomplished by adding a control device connected in series with the network elements, which may be a voltage transformer or some other means of voltage injection (voltage booster)

3. The adjustment of voltage in low-voltage electrical distribution network, which supplies household users by compensating reactive power flows, using capacitors banks.

The present study has emerged consequently to the lack of such measurements within SDEE Mures, aiming the finding of a reliable temporary method, both in technical terms, and in economical ones, in order to improve voltage level until the outset of works planned for this purpose.

The capacitor bank was built in 4 functioning steps, each of 50 kVAr: step I – 5 kVAr, step II – 10 kVAr, step III – 15 kVAr and step IV – 20 kVAr. Capacitor step command was realized automatically using a Varlog controller.

The first method was to install a capacitor bank in a substation, where problems were reported, related to voltage level at circuit extremities.

Voltage monitoring was conducted both in the substation where the capacitor bank was set and at the ending of the circuit having problems. This task implied 4 stages:

- normal functioning, without the capacitor bank;
- functioning with the capacitor bank coupled to automatic mode, given a required power factor;
- functioning with the capacitor bank at a sub-compensation scheme (cosφadjusted < 0,92);
- functioning with the capacitor bank at an overcompensation scheme ($\cos\varphi_{adjusted}$ within capacitive field).

Measurements were carried out using 2 MAVOWATT 30 Power Vista analyzers and the obtained data was processed using Dran View 6 software.

Network characteristics are presented as follows: air circuit starting from PTA 330 (160 kVA), having an approximate length of 1550 m, composed of two parts. The first one, of approximately 900 m, made of O1-A1 multiple conductors having 35 mm^2 cross sections, while the last part is made of TYIR twisted conductors with 70 mm^2 cross sections and an approximate length of 650 m.

Measurements were performed in both extremities of the network, during a week for each functioning regime of the capacitor bank, with the analyzers set only for voltage acquisition purpose.

For a better relevance of measurements, minimal voltage results were analyzed for each 10 minute interval of the considered periods.

In Table 1 are presented the average minimum voltage values for each operating mode of the capacitor, as well as for the voltage drop in the circuit considered.

Table 1. Average minimum voltage values and voltage drops.

Capacitor operating mode	PTA measurements			End of network measurements			Voltage drop ΔU_{PT-CR}		
	U_{Rmin}	U_{Smin}	U_{Tmin}	U_{Rmin}	U_{Smin}	U_{Tmin}	U_{Rmin}	U_{Smin}	U_{Tmin}
	[V]	[V]	[V]	[V]	[V]	[V]	[V]	[V]	[V]
Without capacitor	226.949	233.537	228.954	208.824	197.072	221.471	18.125	36.465	7.483
Capacitor operated automatically	226.625	233.334	228.435	209.684	204.859	218.118	16.941	28.475	10.317
Capacitor blocked in step I	226.516	233.353	228.527	210.842	200.001	219.684	15.674	33.352	8.843
Capacitor overcompensation	226.997	233.593	229.206	206.997	193.899	222.972	20	39.694	6.234

As can be seen, no comparison can be made between the results obtained by this method. This is because the voltage values vary depending on the electric charge and the type of electric charge in the analyzed circuit. The electric loads transited in the circuit are not cyclic, to allow us to compare data acquired in different timeframes. For this reason, we resorted to comparing minimum values of the voltages obtained at the transformer and at the end of the network separately for each operating mode of the capacitor, as well as to the comparison between the two voltage values.

The graphical representation of the voltage values thus leads to plausible results of the influence of the compensation of reactive power, as can be seen from the Fig. 2 to Fig. 5:

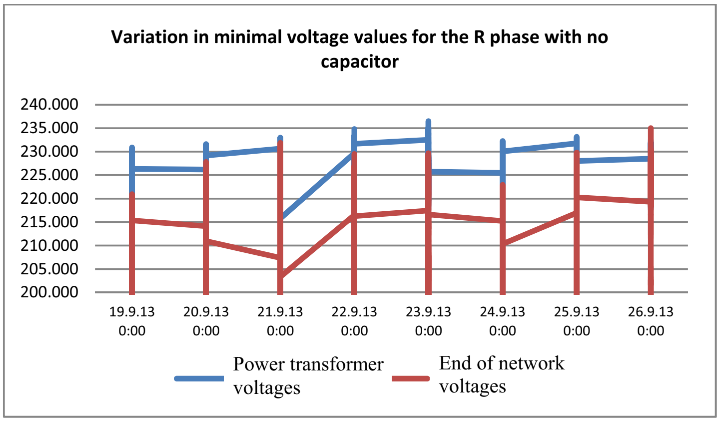


Fig. 2. Variation in minimal voltage values for the R phase with no capacitor

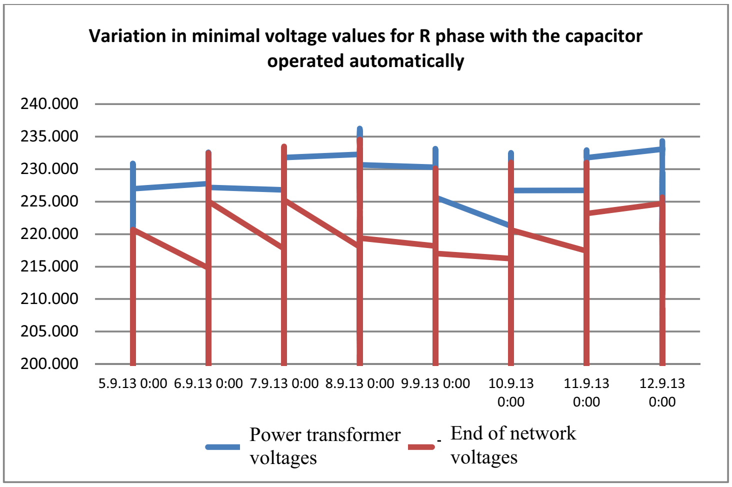


Fig. 3. Variations in minimal voltage values for the R phase with the capacitor operated automatically

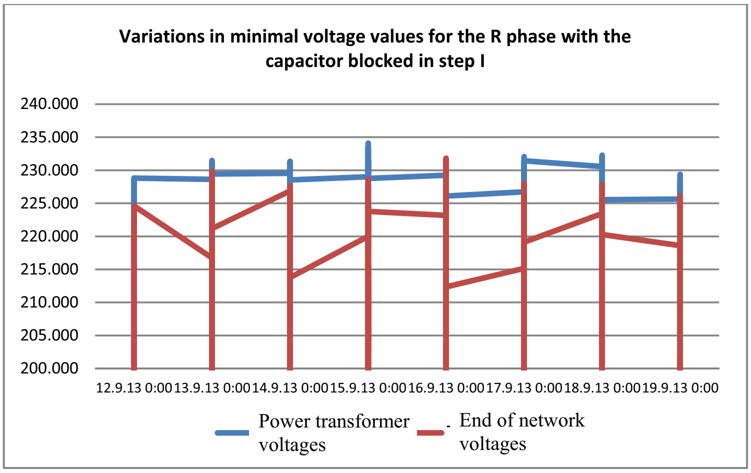


Fig. 4.Variations in minimal voltage values for the R phase with the capacitor blocked in step I

a) Variation in minimal voltage values for the R phase with no capacitor;
b) Variations in minimal voltage values for the R phase with the capacitor operated automatically;
c) Variations in minimal voltage values for the R phase with the capacitor blocked in step I;
d) Variations in minimal voltage values for the R phase with capacitor overcompensation.

As can be seen in these figures, the case in which the difference between the voltage values at the beginning of the network and those at the end of the network (voltage drops) has minimal values is that in which the capacitor operates automatically, with control over the introduction and removal of capacitor steps.

The least favorable case is that in Figure 2, in which the network operates normally, without the intervention of the capacitor.

In the case in which the network operates with the capacitor blocked in step I (5 kVAr), there is a noticeable improvement in the voltage drop or the results obtained in the case previously described do not occur, while in the case of capacitor overcompensation, the results are even less favorable; the voltage drop increases, due to the circulation of reactive power injected by the capacitor.

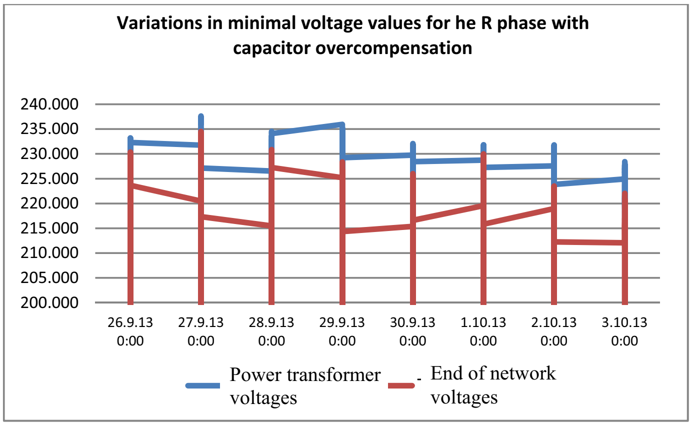


Fig. 5. Variations in minimal voltage values for the R phase with capacitor overcompensation

Consequently, it can be said that the influence of reactive power compensation on voltage drops is a beneficial one. However, the measure is not always enough, as it brings an improvement of only a few volts, so voltage values will not be brought back to the admitted voltage threshold of ± 10% of the nominal voltage values.

In the case shown, the "voltage gain", calculated by the average minimum voltage values, without capacitor and automatically operated capacitor, was of 1.184 V for the R phase, 7.99 V for the S phase and - 2,834 V for the T phase. The fact that a worsening of voltage values was recorded for the T phase shows that reactive power is low in this phase and reactive power injected led to overcompensation and thus, to increased voltage drop.

4. Conclusions

Based on the results obtained and on analyzes performed, some interesting conclusions can be drawn, referring to the influence and the efficiency of reactive power compensation in low-voltage electrical networks, using capacitor banks.

The influence of reactive power flow compensation upon voltage drops is a positive one, taking into account some aspects, though:

- efficiency in economical terms, but technically limited results;
- the result isn't the same for each phase, taking into account the fact that actually the network operates in an unbalanced way, if considering electric charge;

In case the capacitor bank is regarded as a viable solution, the following aspects have to be taken into account:

- the correct dimensioning of the capacitor bank, so that it can compensate the reactive power flow, up to a reasonable power factor ($0,92<\cos\varphi\leq1$);
- steps must be chosen in a way that would allow the finest adjustment of the power factor, in order not to obtain as a result $\cos\varphi< 0,92$ (under-compensation) or passing into the capacitive area of reactive power (overcompensation). The influences related to these operating modes aren't the most appropriate, as specified during the analyze of cases 2 and 3 from Figures 3 and 4;
- the capacitor bank should allow automatic operation, if there is a required power factor ($0,92<\cos\varphi\leq1$), in order to avoid the appearance of the operating conditions shown above;
- the ideal case would mean choosing an automatic capacitor bank, that would allow mono phase reactive power compensating (separately for each phase). The disadvantage of this option is that it is leading to increasing costs.

A future survey possibility could imply setting up the capacitor bank not at the beginning of the line, as in the presented case, but in a point chosen after calculations based on reactive power flow and which would lead to completely different results.

As general conclusions, we can affirm that the use of capacitor banks in order to improve voltage level in low-voltage electrical networks is a viable solution in economical terms (the three phased version), but returning limited results considering voltage level increment, a reason why it isn't adequate for this purpose. However, there might occur some situations in which this solution is beneficial, as long as the remarks presented above are taken into account.

At the moment, there are also other options for improving the voltage level, which are not based on this operating principle, but have noticeable results. We refer here to voltage boosters, which, according to measurements and analyzes performed, are recommended both from economical and technical standpoints.

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