NEW LIMITS FOR VOLTAGE QUALITY IN LV NETWORKS AND THE COSTS AND TIME NECESSARY FOR MEETING THEM

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ABSTRACT
The paper presents the results of a three-year measurement of voltage quality (VQ) carried out at a selected sample of 80 LV distribution networks in all regions of the Czech Republic, both from the point of view of the valid standard EN 50160:2007 [1] and with regard to its proposed changes [2] elaborated based on the requirements of ERGEG [3]. The paper also deals with possible consequences for DNOs relating to compensations to customers for VQ acc. to ERO Decree [4] and, with the costs for reconstruction of all LV networks, in which some parts do not fulfil the valid EN 50160 and its proposed changes.
The voltage quality in LV networks was monitored both in the MV/LV transformer station and in the middle (approximately) and at the end of the chosen feeder.

INTRODUCTION
The LV distribution system of the Czech Republic represents 140 thous. km of LV lines (47% of cables), 88 thous. distribution transformer stations (DTS) and nearly 6 mil. of supply points. The technical lifetime of this equipment is considered to be 35 – 45 years. Changes of requirements on the parameters of supplied electricity including their extension may involve the necessity to reconstruct networks which were designed complying with criteria and standards valid at the time of their construction, prior to the end of their life-time. The demand to increase the VQ in the whole LV distribution network should respect the present state of networks and the real needs of supplied customers. The responsibility for the VQ should be divided between customers with disturbing appliances and the DNO. The general increasing the quality even in old networks would lead to increasing the costs of distribution, which brings no benefit to most of customers, but they would be forced to pay it. The DNO, forced to invest into modernizing networks under the threat of sanctions for not meeting the standards according to [4], would be therefore criticized for high distribution costs.

For that reason, for evaluating the possible impacts [4], all major DNOs in the Czech Republic organized a measuring campaign in 80 LV networks in the year 2006. After analysing it was decided to continue the campaign in the following years with two stages of measurement in each year (summer and winter period). The same agglomerations were selected for measuring campaign in 2007 and 2008 as in 2006 so that it would be possible to monitor the development of the level of characteristic voltage quantities during the periods of measurement and their dispersions. Different agglomerations for measuring campaigns in 2008 were chosen – in agreement between DNO and the elaborator of evaluation – only in those cases when the networks of the respective agglomerations were reconstructed in the year 2006 or 2007. The importance of these measurements increased also in connection with the considered increasing the number of percentiles of 10 minute measuring intervals from 95% to 99%, in which the voltage must be within the given limits, because the measured data also enable to asses the impact of this change.

EXTENT OF MEASUREMENT – CHARACTER OF LV NETWORKS BEING EVALUATED
About 10 agglomerations – LV networks were selected in each of eight regions of the Czech Republic in which the VQ was measured at the beginning (DTS), in the middle and at the end the chosen feeder. The sample of the networks was chosen in such a way that it may be taken as representative for LV distribution networks. Cable networks, overhead networks as well as mixed networks supplying domestic sector and its combination with small consumption (38% - overhead networks, 39% cable networks and the remainder – mixed networks) were chosen in individual regions. Simultaneously with the VQ measurement (quantities of current were also measured when it was enabled by local conditions), the internal impedance as a characteristic quantity of the network being evaluated was measured, too. When it was enabled by conditions, the impedance of the network was measured at the beginning, in the middle and at the end of the chosen feeder too.

The following Fig. 1 to Fig. 3 show the division of the measured LV networks according to the following criteria:
- Age of the chosen feeder
- Length of the chosen feeder
- Internal impedance of the network at the points of measurement
EVALUATION OF REALIZED ELECTRICITY QUALITY MEASUREMENTS

The data obtained from VQ measurements were imported into the system for archiving and evaluating the electricity quality measurement DAM [5] and they were evaluated by this system in a uniform way.

<table>
<thead>
<tr>
<th>Exceeded limits</th>
<th>Pst</th>
<th>Plt</th>
<th>Uu</th>
<th>THD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EN 1999</strong></td>
<td>1</td>
<td>1</td>
<td>2%</td>
<td>8%</td>
</tr>
<tr>
<td><strong>DTS</strong></td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>middle</strong></td>
<td>19</td>
<td>9</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td><strong>end</strong></td>
<td>34</td>
<td>21</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td><strong>sum</strong></td>
<td>36</td>
<td>23</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td><strong>EN 2007</strong></td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>DTS</strong></td>
<td>13</td>
<td>9</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td><strong>middle</strong></td>
<td>29</td>
<td>21</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
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<td>31</td>
<td>23</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td><strong>sum</strong></td>
<td>32</td>
<td>23</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td><strong>prEN 2008</strong></td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>DTS</strong></td>
<td>13</td>
<td>9</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td><strong>middle</strong></td>
<td>30</td>
<td>21</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td><strong>end</strong></td>
<td>32</td>
<td>23</td>
<td>25</td>
<td>4</td>
</tr>
</tbody>
</table>

The evaluation concerns not only the binding parameters according to [4] but also other VQ parameters according to [1] (flicker, harmonics and voltage unbalance), i.e. those parameters for which the compensations for not meeting the limits of electricity quality according to Decree Nr. 540 have not been related so far.

The evaluation of the 3rd stage of measurement is presented as an example in the following tables. Data on the number of stations, out of their total number, which did not satisfy the limits for voltage deviations according to criteria of the initial standard EN 50160:1999 (marked as 1999), of its valid version (marked as 2007) and of its version now being prepared (marked as pr2008) are given in Table 1.

The numbers of networks not satisfying the voltage deviations, flicker, voltage unbalance and the total harmonic distortion of the voltage were evaluated at the same time and they are figured in Table 2. Exceeding of the permitted level of flicker dominates in all cases.
Assessment of networks according to voltage deviation

Fig. 4

The results of all stages of measurement are summarized in Fig 4 (for the evaluation of voltage deviations) and in Fig 5 (for the evaluation of all parameters monitored).

Assessment of networks for all voltage characteristics

Fig. 5

With regard to the dominant influence of flicker on the number of not satisfying networks, we have also evaluated the value of the internal impedance of the network as a probable cause of exceeding the limits set for the flicker. Fig. 6 shows the extent in which the reference impedance $Z_b = 0.4 – j0.25 \ \Omega$ is exceeded in the networks (in the middle and at the end of chosen feeders). According to [6], this reference impedance is the basis for the possibility of connecting appliances without negotiating it with DNO.

Dependence $Pst - Z$

Fig. 6

As it has been confirmed by many VQ measurements realized till now, the level of individual voltage quality parameters considerably varies between individual weeks of measurement.

So as to assess the extent of the relative variation of individual voltage quality parameters in agglomerations being evaluated, we have calculated the dispersions of individual characteristic quantities during three years of measurements. Two types of dispersions were chosen for assessing the value of the dispersion:

- Maximum dispersion – from four realized stages of electricity quality measurement
- Average dispersion – values given in the table are the average maximum dispersions related to the limit defined for the given characteristic quantity

Table 3

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Maximum dispersion [%]</th>
<th>Average dispersion [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_{\text{min}}(95)$ [V]</td>
<td>4.3</td>
<td>3.0</td>
</tr>
<tr>
<td>$U_{\text{max}}(95)$ [V]</td>
<td>1.7</td>
<td>1.3</td>
</tr>
<tr>
<td>$U_{\text{min}}(100)$ [V]</td>
<td>7.1</td>
<td>4.4</td>
</tr>
<tr>
<td>$U_{\text{max}}(100)$ [V]</td>
<td>2.1</td>
<td>1.6</td>
</tr>
<tr>
<td>$P_{st}$</td>
<td>67.4</td>
<td>37.8</td>
</tr>
<tr>
<td>$\mu_{\text{L}}$</td>
<td>82.3</td>
<td>46.4</td>
</tr>
<tr>
<td>$\mu_{\text{M}}$</td>
<td>26.7</td>
<td>15.8</td>
</tr>
<tr>
<td>THD$_u$ [%]</td>
<td>10.1</td>
<td>7.5</td>
</tr>
<tr>
<td>$Z$ [%]</td>
<td>14.5</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Fig. 7 shows the dependence of the magnitude of flicker in the networks measured on their internal impedance. It becomes evident that the limit for flicker may be exceeded even in networks with satisfying internal impedance while in networks with not satisfying internal impedance the limits for flicker need not be exceeded.

The calculation of dispersion was based on values for 95% of measuring intervals, only the calculation of the values of $U_{\text{min}}(100)$ [V] and $U_{\text{max}}(100)$ [V] was based on 100% of measured samples for weeks being evaluated. It may be seen from the given values that the greatest maximum and minimum dispersion exists in values of $P_{st}$ and $\mu_{\text{L}}$. However, a relatively high dispersion also exists in...
values of voltage unbalance, but in this case it isn’t critical.

COSTS OF IMPROVING THE VOLTAGE QUALITY

Better voltage quality in the distribution system can be practically achieved only by two ways:
• using of appliances with lower disturbing emissions
• increasing the short-circuit power in the distribution network

Due to a high number of LV networks which do not fulfill the requirements on electricity quality according to [1] and with regard to the structure of consumption it is not realistic to evaluate, in a wider extent, the measure in which the poor quality of electricity is responsibility of some customer and the extent in which it is caused by a high impedance of the network. With respect to high number of customers, a realistic way may thus be mostly decreasing the internal impedance of the network (increasing the short-circuit power).

The increasing of the short-circuit power in the distribution network means the refurbishment of some of its elements before the end of their lifetime and a considerable over-dimensioning of new elements with regard to power being transmitted. The over-dimensioning is considered only for achieving a low internal impedance at the point of delivery between DNO and the customer.

Direct investment costs for achieving the already valid tolerances for the voltage in the Czech LV networks may be estimated approximately to 400 mil. €. In the case of accepting more stringent limits 230 V ± 10% in percentile 99% these direct investment costs would be increased up to approximately 413 mil. €.

So that a full compliance with the EN 50160 standard, i.e. including the flicker may be obtained, these direct investment costs could be estimated in the amount of 800 mil. €.

NEED FOR A TOTAL-WIDE MEETING OF LIMITS OF ALL VOLTAGE CHARACTERISTICS

Special surveys concerning the satisfaction of customers with the quality of supplied electricity and their willingness to pay a higher price for better quality have not yet been organized in our country. Undoubtedly, a criterion of the need for improving the electricity quality parameters (satisfaction of customers) can be identified from the number of claims concerning the quality and their justification. In the case of two major distribution networks the claims concerning the quality make not more than 3% of the whole number of claims. Related to the number of customers it is less than 0.1%.

CONCLUSION

The voltage quality measurement in LV networks of the Czech Republic, carried out on a sample of 80 networks, revealed that about 10% of networks monitored do not satisfy the present limits for voltage level according to [2] and the acceptance of proposals according to [3] would result in increasing their number by up to 5% approximately. A much higher number of networks do not satisfy from the flicker point of view. The matter concerns up to about 50% of customers at the end of measured feeders.

The limits for harmonics and for voltage unbalance are not exceeded.

There is a wide dispersion of VQ parameters, above all in flicker comparing the four realized measurements stages.

The requirement for a rapid achieving of the compliance of LV networks with [1] and/or [2] (e.g. within a usually utmost term of implementing the standard within 3 years) is not realistic because it would lead, among others, to stopping investments and reconstructions of HV and MV distribution networks for several years as well as to capacity problems both on the side of the energy sector itself and on the side of external suppliers of projection and building services.

Especially with regard to a changing structure of appliances sensitive to flicker, to a small number of claims and to high costs we do not consider as justified to accelerate total-wide reconstructions of the networks without evaluating the appropriateness and justification of present limits for Pst and Plt.

The exceeding of the permitted limits was also stated at 15 to 23% of points where the internal impedance of the network was less then its reference value according to [6]. In the last year was the poor VQ rightfully claimed by less than 0.1% of customers (related to their total number).

REFERENCES