SOME PROBLEMS OF POWER QUALITY IN THE CZECH DISTRIBUTION NETWORKS

V. Vyskočil, Z. Špaček, J. Hůrková
EGÚ Power Institute Brno, 76a, Hudcova, 612 48 Brno (Czech Republic)
Tel: + 420 5 41 32 12 01 Fax: + 420 5 74 91 33 E-mail: vvyskocil@sky.cz

K. Procházka
EGC EnerGoConsult ČB, 52, Čechova, 370 01 České Budějovice (Czech Republic)
Tel: + 420 38 700 28 31 Fax: + 420 38 731 28 96 E-mail: kprochazka@egc.ipex.cz

P. Santarius
Technical University Ostrava, 15, 17. listopadu, 708 33 Ostrava (Czech Republic)
Tel: + 420 69699 42 79 Fax: + 420 69 691 95 97 E-mail: pavel.santarius@vsb.cz

J. Barták, K. Cvačka
West-Bohemian Power Utility Plzeň, 71, Sladkovského, 301 44 Plzeň (Czech Republic)
Tel: + 420 19 700 23 54 Fax: + 420 19 700 20 03 E-mail: CvackaK@zce.cz

M. Schneider, Z. Hejpetr
Prague Power Utility, 19, Na hroudě, 100 05 Praha 10 (Czech Republic)
Tel: + 420 2 42 55 43 Fax: + 420 2 66 79 63 19 E-mail: schnei01@pre.cz

P. Vašenka
North-Moravian Power Utility, 152, 28. října, 709 02 Ostrava (Czech Republic)
Tel: + 420 69 667 33 99 Fax: + 420 69 661 23 88 E-mail:vasenka@sme.cz

SUMMARY

The paper gives a survey of the power quality in public distribution networks in the Czech Republic and indicates the trends of individual parameters. At present the voltage unbalance, fliker, voltage distortion and harmonic voltages appear as problems of regional character. The power quality is evaluated mainly according to European Standard EN 50160 and UNIPEDE Guides. Some questions arising in connection with the implementation of criteria in EN 50160 or of other PQ criteria are discussed.

INTRODUCTION

Power utilities and many other institutions in the Czech Republic make efforts to supply consumers with electricity of a corresponding quality. Due to the galvanic or electromagnetic coupling between the distribution networks and the consumers' appliances and installations, the individual elements of this system influence each other. New appliances and technologies are being increasingly used and their contribution to worsening the quality of electricity is considerable. This trend follows from the progress of technology. In the Czech Republic it is even strengthened by opening the possibilities of importing modern technologies, as well as by structural changes of the whole economy. That is why we are devoting foremost attention to these problems since 1994. The aim of the work is to obtain a general view of the level and the main problems of power quality in public distribution networks, namely of electricity supplied to consumers.
The paper summarises some information and indicates problem areas resulting from the analysis of power quality parameters in about two hundred points of distribution systems of the majority of the Czech power utilities. It also examines some questions arising during the implementation of standards or other power quality criteria.
The 110 kV distribution networks and the MV networks (i. e. the 22 kV and 35 kV networks) were chosen for the first phase of investigation. The points of measurements were selected so as to represent typical situations.
The points marked by I (input) in the following chapters are the feeding points of the network of the respective voltage (for 110 kV networks these are 400/110 kV or 220/110 kV substations and power stations; for MV networks these are mainly substations 110/22 kV or 110/35 kV).
The points marked by O (output) are those where the network of the respective voltage delivers the power (for 110 kV networks these are usually 110/22 kV or 110/35 kV substations or points where large consumers supplied from 110 kV are connected; for MV networks these are usually the points where medium consumers supplied from MV are connected or MV/LV substations).
The measurement and data evaluation methods were chosen in such a way that the results might by evaluated according to various criteria [4], preferably according to the European standard EN 50160 [1] and UNIPEDE Guides [2,3].

1. VOLTAGE UNBALANCE

The measurement of voltage unbalance is carried out by using DRANETZ 8000, BK 500 and other analyzers. The measurement is performed and evaluated at chosen points of the network in the intervals of 10 minutes during one week. After estimation of the voltage unbalance $\boldsymbol{k}$ complying with the standard EN 50160 it is checked whether the unbalance $\boldsymbol{k}$ is not higher than 2 % for 95% of the period of measurement (p = 95), i. e. whether $\boldsymbol{k_{95}} \leq 2$.

The values of unbalance $\boldsymbol{k_{95}}$ (for p = 95 %) and $\boldsymbol{k_{100}}$ (for p = 100 %) at points I and at points O in MV networks are

given in Fig. 1a. The values of k are given in a decreasing order according to the magnitude of k_{95}.
Analogically, Fig. 1b shows the values of k measured at points I and at points O in 110 kV networks.

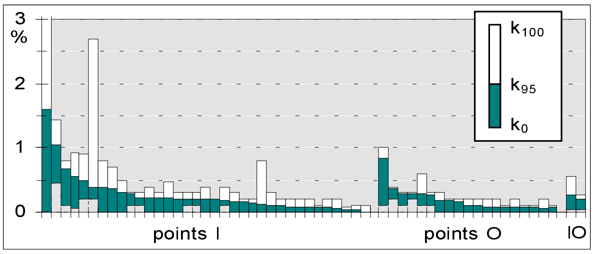

Fig. 1a: Unbalance k in MV networks

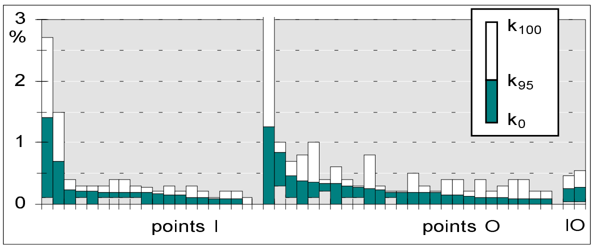

Fig. 1b: Unbalance k in 110 kV networks

Table 1: Average unbalance k_p in distribution networks

k_p	MV networks		110 kV networks	
	points I	points O	points I	points O
k_{95} (%)	*0.28*	*0.20*	*0.26*	*0.27*
k_{100} (%)	*0.56*	*0.27*	*0.46*	*0.54*

Table 1 presents the average values of unbalance k_{95} *and* k_{100}, which will not be exceeded in points I and O of MV and 110 kV networks for 95 % or 100 % of the week.

The unbalance in MV and in 110 kV networks is low. The magnitude of unbalance k_{95} always satisfies the criteria of EN 50160 in spite of the fact that in individual cases (see diagrams) the unbalance k_{95} amounts up to 1.6 % (22 kV) or 1.4 % (110 kV). These exceptional cases concern the points of the network situated in the vicinity of supplying the AC single-phase railway traction or, maybe, also when combined with a small short-circuit power or a non-standard scheme of the network.

However, the unbalance is even higher - up to 3.6 % or 3.3 % respectively for the rest 5 % of the week interval but these values are being tolerated by EN 50160. We do not consider the evaluation of unbalance according to EN 50160 sufficient in those cases when a generator or another equipment protected against unbalanced operation may be switched-off. Modern generators in power plants and in heating power plants are also equipped (complying with the requirements of their manufactures) with protection devices monitoring the level of current unbalance in which both the threshold for signalling and the threshold for tripping are being set.

E. g., the lower limit for adjusting protection devices of a certain type is 6 % for signalling and 8 % for tripping. These generators are connected to the 22 kV distribution network (which should be considered as a common supply node) via the unit transformers. The magnitude of the negative-sequence component of the current is then dependent on the negative-sequence component of the voltage in the 22 kV network:

$$I_2 = \frac{U_2}{Z_{2g} + Z_{2T}}$$

For the considered parameters of the generator Z_{2g} = X”$_d$ = 14 % and Z_{2T} = 10.5 % we obtain

$$I_2 = 4.08\ U_2$$

If we take as justified the above - mentioned requirement of the current unbalance for signalling and for tripping starting from 6 % (8 %) of I_n which, however, should not be brought about by the influence of the negative-sequence component existing in the utility’s network, then the maximum magnitude of U_2 need not exceed the limit

for signalling U_2 [%] ≤ 1.47

and for tripping U_2 [%] ≤ 1.96

These values should not be exceeded either at a limited operation of the distribution network, i. e. at minimum values of the short-circuit power.

2. FLICKER SEVERITY

We usually use flickermeters PANENSA MEFP for the measurement of flicker. The measurement of flicker P_{st} at chosen points of the network is carried out in the three phases during one week and flicker P_{lt} for two-hour intervals is being assessed. It is checked in compliance with EN 50160 and UNIPEDE Guides whether the condition $P_{lt} \leq 1$ is satisfied for p = 95 % of the week or for other values of p in other cases [4, 5, 7]
The values of flicker $P_{lt95,}$ P_{lt99} and P_{lt100} which will not be exceeded for p = 95 %, 99 % or 100 % of the week at points I and at points O of MV networks are shown in Fig. 2a. The values of flicker P_{lt} are given in a decreasing order.
Analogically, the values of flicker P_{lt} in the 110 kV network are shown in Fig. 2b.
The table 2a indicates the average values of fliker $P_{lt95,}$ P_{lt99} and P_{lt100t}, which will not be exceeded in 50% of points I and O in MV and 110 kV networks.
The table 2b shows various conditions for evaluating the magnitude of flicker P_{lt} and the percentage of measuring points which had not satisfied these conditions.

Table 2a: Average values of flicker P_{lt} in MV and 110 kV networks

P_{lt}	MV networks		110 kV networks	
	points I	points O	points I	points O
P_{lt95}	*0.41*	*0.84*	*0.44*	*0.49*
P_{lt99}	*0.63*	*1.08*	*0.64*	*0.69*
P_{lt100}	*0.77*	*1.25*	*0.78*	*0.86*

Table 2b: Conditions for flicker P_{lt} and percentage of points in MV and 110 kV networks where the flicker P_{lt} does not satisfy them

Conditions	MV network		110 kV network	
	points I (%)	points O (%)	points I (%)	points O %)
$P_{lt95} \leq 1$	0	29	2	9
$P_{lt99} \leq 1$	21	38	17	14
$P_{lt95} \leq 0.8$	3	38	17	9
$P_{lt95} \leq 1.5$	3	13	0	0
$P_{lt99} \leq 1.5$	7	29	0	0

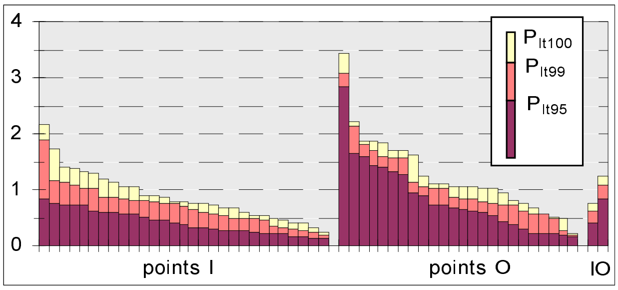

Fig. 2a: Values of flicker P_{lt95}, P_{lt99} and P_{lt100} in MV networks

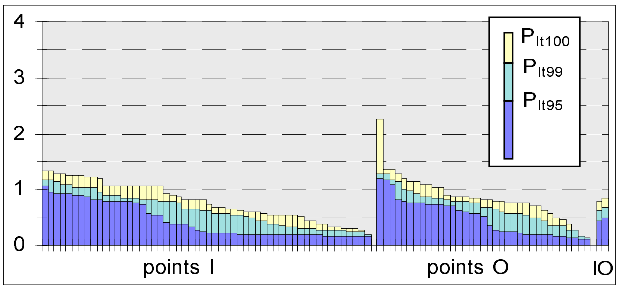

Fig. 2b: Values of flicker P_{lt95}, P_{lt99} and P_{lt100} in 110 kV networks

The magnitudes of flicker are relatively high in MV networks, especially at many points O, where 29 % of points do not satisfy the requirements EN 50160.

In 110 kV networks the magnitude of fliker at points O is lower than in the MV networks. In spite of this, fliker in 110 kV networks is considered high as at some points its magnitude exceeds the values permitted by EN 50160 for supplies from public MV and LV networks. By transmission into MV and LV networks a component of flicker is being generated which, together with flicker caused by fluctuating consumption supplied by MV or LV networks, may result in a final height of flicker exceeding the values given in EN 50160.

In general the values of flicker at points O are higher than at points I, especially in MV networks. The reason is the voltage fluctuation by fluctuating power taken by some consumers, mainly from MV networks but also from 110 kV ones.
It is evident that the high values of voltage fluctuation and flicker represent a quite frequent regional problem in our distribution networks. The considerations about making the conditions more exigent compared with EN 50160 do not correspond with the present situation.

The problems of flicker deserve attention also from the methodological point of view (i. e. gliding interval for the evaluation of P_{lt}) [5, 6].

3. SHAPE DISTORTION AND HARMONIC VOLTAGES

Analyzers DRANETZ (model 658 and 8000), BK 500 and others are used for measuring the total harmonic distortion factor (THD) and individual harmonic voltages (HA). The measurement is carried out and evaluated in the intervals of 10 minutes during one week. It is checked in compliance with EN 50160 and UNIPEDE Guides [1,2,3] whether the determined heights of THD and of individual harmonic voltages are not exceeded for p = 95 % of the week or for other values of p in other cases.
The table 3a indicates the average values of THD and of harmonic voltages HA for p = 95 % and p = 100 % in MV and 110 kV networks, which will not be exceeded in 50% of points I and O.

Table 3a: Average values of THD and of harmonic voltages

	MV network				110 kV network			
	points I		**points O**		**points I**		**points O**	
p	100	**95**	100	**95**	100	**95**	100	**95**
THD	2.00	**1.43**	2.50	**2.10**	1.30	**1.10**	1.60	**1.09**
3. HA	1.10	**0.64**	1.10	**0.90**	0.80	**0.65**	0.80	**0.60**
5. HA	1.60	**0.82**	2.00	**1.62**	1.10	**0.70**	1.20	**0.74**
7. HA	0.70	**0.41**	0.80	**0.61**	0.50	**0.30**	0.60	**0.32**

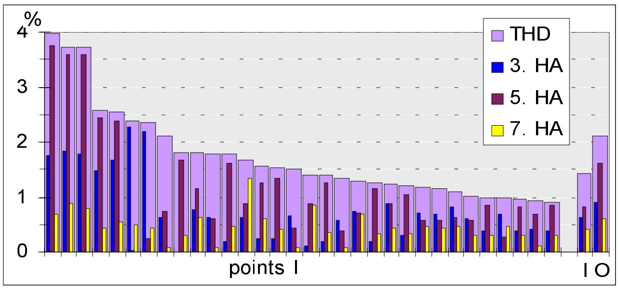

Fig. 3a: THD and HA - MV networks; points I

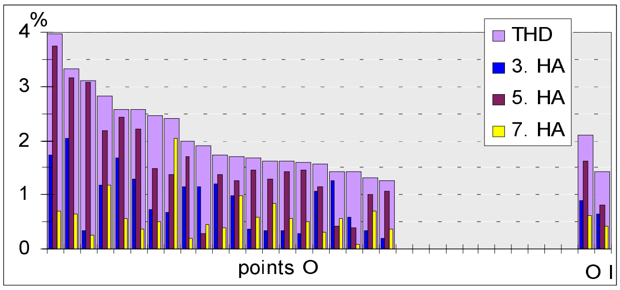

Fig. 3b: THD and HA - MV networks; points O

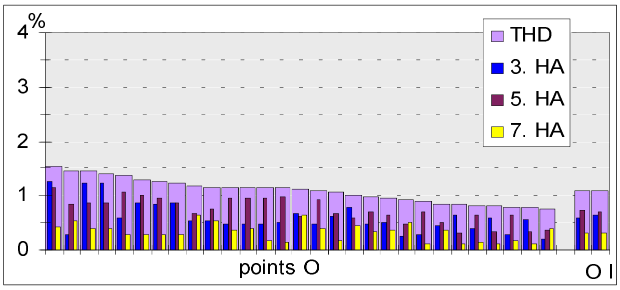

Fig. 3c: THD and HA - 110 kV networks; points O

Some graphs indicating THD and the content of the 3rd, 5th and 7th voltage harmonic for p = 95 % in the distribution networks are shown in the preceding figures:

MV networks - values for points I (Fig.3a)
- values for points O (Fig.3b)
110 kV networks - values for points O(Fig.3c)

The average values of the harmonic content and of THD are low in MV distribution networks. The 5th harmonic has mostly the highest absolute content followed by the 3rd and the 7th harmonics. The magnitude and the time pattern of the 5th harmonic are also decisive for those of THD. The 3rd or the 7th harmonics have the highest content only exceptionally, namely in the vicinity of some industrial loads.

However, the situation in individual points of network is not so favourable any more, although the assessed values are lower than those which - according to EN 50160 - need not be exceeded for 95 % of the week (8 % for THD, 5 %, 6 % and 5 % for the 3rd, 5th and 7th harmonic respectively). The content of the 5th harmonic (reaching up to 63 % of the permitted height) approaches the permitted values at most followed by the content of the 3rd harmonic (up to 46 %), of the 7th harmonic (up to 41 %) and by THD (up to 50 % of the permitted height). At present, 50 % of the permitted value for the content of the 5th harmonic are already exceeded at 17 points in the MV networks. Due to changes in the structure of electricity consumption in favour of the consumption of distorted current (electronic appliances, controlled drives and traction, technologies with rectifiers, modern light sources, etc.), this reserve decreases rapidly.

The analysis of THD and of voltage harmonics (HA) carried out at points of MV networks reveal that the values measured at supply terminals of various objects in MV networks in the Capital of Prague belong to the highest ones.

Table 3b: THD and HA at selected objects in Prague

p	**THD**		**3. HA**		**5. HA**		**7. HA**	
	100	**95**	100	**95**	100	**95**	100	**95**
1. Underground PJ	*4.30*	**3.73**	*2.30*	**1.84**	*4.10*	**3.60**	*1.10*	**0.87**
2. Administrative complex M	*3.80*	**3.32**	*2.40*	**2.05**	*3.30*	**3.16**	*0.80*	**0.65**
3. Commercial centre I	*3.50*	**2.83**	*1.30*	**1.17**	*2.80*	**2.42**	*0.70*	**0.55**
4. Street electric transport Z	*3.00*	**2.58**	*1.90*	**1.68**	*2.80*	**2.42**	*0.70*	**0.55**
5. Commercial centre K	*2.80*	**2.57**	*1.50*	**1.30**	*2.40*	**2.21**	*0.50*	**0.37**
6. Administrative complex CH	*2.20*	**1.98**	*1.30*	**1.14**	*2.00*	**1.70**	*0.30*	**0.37**

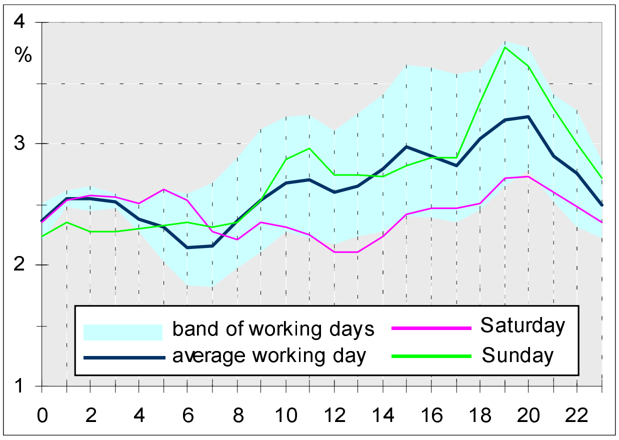

Fig. 3d: Supplying the underground (1) - THD on the average working day, on Saturday and Sunday

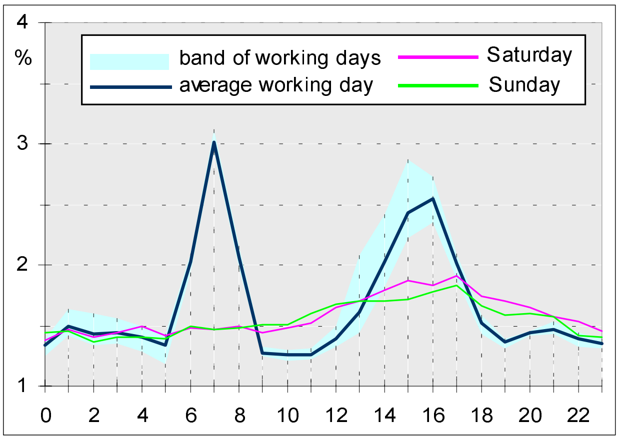

Fig. 3e: Supplying a commercial (3) - THD on the average working day, on Saturday and Sunday

Table 3b presents the results of measurements of THD and HA at six selected objects in Prague supplied from MV, for p = 95 % (EN 50160) and for p = 100 % respectively. The objects supplying the municipal electric transport (1, 4), administrative complexes (2, 6) and commercial centres (3, 5) were selected.

The time patterns of THD at points supplying the objects Nrs 1) and 3) on the average working day, on Saturday and Sunday are shown in Figs 3d and 3e.

The time patterns of THD and of harmonic content are different at individual points of the network. One or two more or less expressed maxima occur during the day and the time of their occurrence differs, too.
At a certain point of the network the time patterns of THD on individual working days are very similar. It may become evident from the band marked around the time pattern for an average working day which indicates the space marked off by the time pattern for individual days from Monday to Friday. On the contrary, the time patterns for Saturday and for Sunday differ one from another, as well as from those for working days.

At present the shape distortion and the harmonic content in MV networks do not exceed the values set by EN 50160. THD and HA in 110 kV networks are correspondingly high. But in spite of this, the problem of shape distortion and of harmonics exists in our 110 kV and MV networks and – under superposition with the distortion caused by local consumption in LV and MV networks - the 5th harmonic and THD may exceed the permitted values already now or in the near future. This may be expected especially in LV networks with a high concentration of the consumption of distorted current, e. g. in large towns such as Prague.
A numerical expression of the time patterns of THD and of the harmonic voltages would facilitate the elaboration of easy-to-take-in descriptions of the time diagram, the quantification and further systemisation.

4. MONITORING THE QUALITY OF SUPPLIED ELECTRICITY IN A REGIONAL POWER UTILITY

The utilisation of many new appliances has increased in LV networks in the last period which considerably contributes to worsening the quality of supplied electricity (e. g. semiconductor-based switched feeding sources of TV receivers, welding machines, copiers). This trend is confirmed by publications from other countries and by the results of measurements performed in the Czech Republic. That is why the North-Moravian Power Utility Ostrava prepared a program of a complex monitoring of the quality of supplied power which has been successively implemented since 1996.
In the years 1995-1996 the specialists of the Faculty of Electrical Engineering and Informatics of the Technical University Ostrava co-operating with the North-Moravian Power Utility carried out more than 80 measurements of harmonics in the LV distribution networks of this regional utility. The measurements revealed that only some statistically significant voltage harmonics (usually the 3rd, 5th, 7th, 9th and 11th harmonic) occur in the LV networks and that - mainly in case of the 5th harmonic - values are attained in some nodes of the network approaching the compatible level of 6 %.

Basing on the results of these measurements and with the aim to obtain a sufficient quantity of numerical data on the levels of individual indicators still before the standard ČSN EN 50160 comes into force, the power utility started, from the beginning of 1997, a program of monitoring the voltage quality at various points of the utility's supply area.

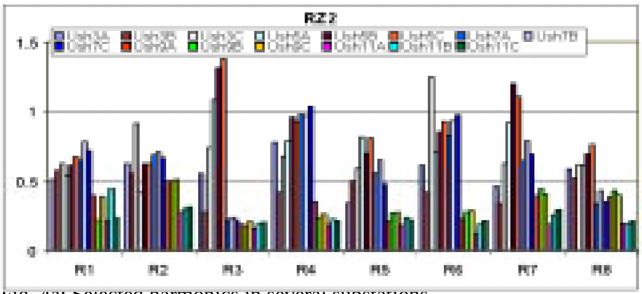

Fig. 4a: Selected harmonics in several substations

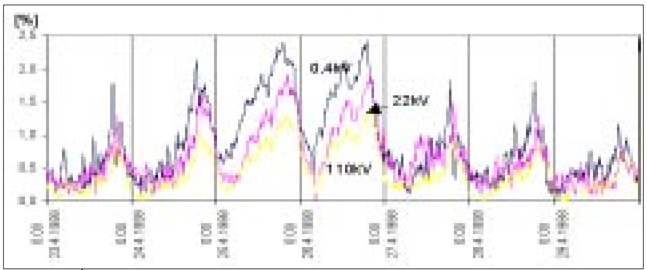

Fig. 4b: 5th harmonic at all network voltage levels

The voltage quality monitoring has been concentrated mainly on monitoring the level of harmonics and of fast voltage variations. A weekly measurement of voltages was performed at each voltage level in the supply area of each 110/22 kV substation, i. e. in the 110 kV substation, in the 22 kV substation (supplied from this 110 kV substation) and at the low voltage terminals of transformer supplied from the respective 22 kV substation. In every measuring points in the LV network we always selected a transformer substation supplying a mixed small consumption (i. e. family houses and housing areas) with a negligible business consumption. The results of the hitherto measurements are presented in Fig. 4a and Fig. 4b.

The results obtained till now show that the 5th harmonic is the most pronounced in LV networks which is evidently connected mainly with the operation of TV sets. Its values exceed (especially on weekend days) 50 % of the compatible level being 6 %.

Analogical time patterns are also observed for the 5th harmonics in MV and HV networks, despite of the influence of dominant industrial consumers which may manifest itself here.

Other harmonic voltages are mostly deep below the compatible level.

5. CONCLUSIONS

1. The introductory systematic works concerning the quality of electricity supplied by public networks in the Czech Republic were focused mainly on surveying the situation in MV and 110 kV networks.
2. The parameters monitored included voltage variations, voltage unbalance, voltage fluctuation, flicker, voltage distortion and harmonics. The treatment was carried out according to EN 50160 or to other criteria. Unbalance, flicker, voltage distortion and harmonic voltages appear to be regional problem areas.
3. The voltage unbalance in MV and 110 kV networks is low and satisfies EN 50160 in spite of the fact that in individual cases the unbalance during 95% of a week amounts up to 1.6 %. These exceptional cases concern the points in the vicinity of supplying the AC single-phase railway traction or, maybe, also when combined with a small short-circuit power or during non-normal service conditions of the network.
4. However, the unbalance is even higher - up to 3.6 % for 5 % of the week, but these values are being tolerated by EN 50160. The evaluation of unbalance according to EN 50160 is considered unsufficient in those cases when the generators or another equipment protected against unbalanced operation may be switched-off.
5. The magnitudes of flicker P_{lt} are relatively high in MV networks and they are not satisfying at many points of the network. In 110 kV networks the values of flicker P_{lt} are lower, in spite of this they are considered high. These magnitudes of fliker generate - by transmission into MV and LV networks - a component of the flicker which, together with flicker originating from the consumption supplied by MV or LV networks, may result in a final height of flicker exceeding the values permitted by EN 50160.
6. The values of flicker on supply terminals (O) are higher than at points (I) in which the network of the given voltage is supplied. The cause is a fluctuating power taken by some consumers.
7. High values of voltage fluctuation and flicker represent a quite frequent regional problem in Czech networks. The considerations about making the conditions more exigent compared with EN 50160 ($P_{lt95} < 1$; or p >95) do not correspond with the present situation.
8. The problems of flicker deserve attention from the methodological point of view and in connection with implementation of Standards (i. e. gliding interval for the evaluation of P_{lt}).
9. At present the total harmonic distortion and the harmonic voltages in MV and LV networks do not exceed the values set by EN 50160. The values in 110 kV networks are correspondingly high..
10. The 5th harmonic has mostly the highest content in 110 kV, MV and LV networks. It is followed by the 3rd and the 7th harmonics. The 5th harmonic is mostly decisive for the magnitude and time pattern of THD. Other harmonics are mostly deep below the compatible level.
11. The content of the 5th harmonic (reaching up to 63 % of the permitted height) approaches the permitted values at most and 50 % of the permitted value for the content of the 5th harmonic are already exceeded at 17 points in the MV networks. Due to changes in the structure of consumption in favour of the consumption of distorted current this reserve decreases rapidly.
12. The problem of voltage harmonic distortion and of harmonics exists in Czech distribution networks and - under superposition with the distortion caused by local consumption in LV networks - the 5th harmonic and THD may exceed the values given in EN 50160 already now or in the near future.
13. The values of THD and of harmonic voltages measured on supply terminals of objects in MV networks in the Capital of Prague belong to the highest ones (municipal electric transport, administrative and commercial centres, density of consumption).
14. The time patterns of THD and of harmonic voltages are different at individual points of the network. One or two maxima occur during the day and the time of their occurrence differs, too. At a certain point the time patterns of THD on individual working days are very similar. On the contrary, the time patterns for Saturday and for Sunday differ one from another, as well as from those for working days.
15. A numerical expression of the characteristics of THD and of the harmonic content would facilitate the elaboration of easy-to-take-in descriptions of the time diagram, the quantification and further systemisation.

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