IS THE DANISH POWER QUALITY IN ACCORDANCE WITH INTERNATIONAL STANDARDS?

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INTRODUCTION

This paper describes some of the major results from the large Danish power quality survey, which included approximately 200 delivery points in the low voltage system. The results are based on nearly 700 data sets, each one of them representing one week of measurings. All the significant voltage parameters have been measured.

In addition to the ordinary statistical figures for each of the measured parameters, the paper looks on the seasonal and daily variations. The connection between the power quality and the short circuit impedance has also been investigated. Especially the results for harmonics and the flicker level have been surprising for the participating utilities.

THE POWER QUALITY IN DENMARK

Generally speaking the power quality situation in Denmark is and has been good, thanks to an extensive electrical system with a high level of maintenance and an unproblematic geography. However, for some years there have been some indicators, saying that this situation might be changing in the years to come. A change in the power quality level which is similar to what is expected in other countries in the industrialised world.

The reduction of the power quality is caused by an increasing number of non-linear loads in the industry and in household appliances and by installation of more dispersed generation. Add to this, that much of the same non-linear equipment is very sensitive to disturbances in the voltage. This means that customers are more focused on the power quality issue.

New standards, e.g. EN 50160 [1] and IEC 1000-3-2 [4] and new monitoring equipment have also brought power quality on the agenda among electrical utilities.

THE DANISH POWER QUALITY SURVEY

The publication of the European standard EN 50160 in 1994 lead to a revision of the existing Danish recommendations on power quality in low and medium voltage systems [2].

Since power quality had never been measured systematically in Denmark, the following question was asked during the work with the recommendations.

Is the power quality in Denmark in accordance with international standards and national recommendations?

It was decided to start a survey, where the power quality was monitored in as many points as possible in the low voltage system [3]. The objective was to gather more information about the present state of the power quality. In addition, knowledge about the expectable level of power quality might be valuable in the international standardisation work.

Customers connected to their own 10/0.4 kV (or 10/0.69 kV) transformer were excluded. Because of this decision, the power quality of the delivery points (PCC[1]s) of medium and large industry customers is not included in the results presented in this paper.

Power quality problems near larger industry customers are very often well known by the customer and by the local utility. This means that actions are taken to improve the power quality when there are significant disturbances for the customer himself or for the nearest neighbours.

The growing concern about the state of the power quality was more focused on the hundreds of thousands of ordinary customers, i. e. homes, farms, administration, service industry and smaller production industry.

The measurings took place in the period from November 1996 to May 1998. They included approximately 200 individual delivery points in the grid. The measurings had a one-week duration, and they were repeated four times in each point, with a three-month interval, in order to investigate seasonal variations for selected parameters.

About 60 % of the measuring points were selected in areas which can be characterised as mainly urban. The rest were located in rural areas. Seventy-five percent of the selected measuring points are in the categories of domestic and farms.

The measured parameters are:

- The voltage level
- Flicker[2], P_{st} and P_{lt}
- Total Harmonic Distortion (THD) and individual harmonics
- Voltage dips and swells

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[1] PCC: Point of Common Coupling
[2] st: short term - 10 min. value; lt: long term - 2 hours value

- Voltage unbalance
- DC voltage
- Voltage transients.

The frequency is considered so stable that it is of no interest. Interharmonics could not be measured with the measuring equipment. Only the voltage (three phased) has been measured.

All interruptions longer than 3 min. are removed from the data.

THE VOLTAGE LEVEL, FLICKER AND HARMONICS

The voltage level

One single data set contains roughly 1000 ten-minute mean values, which correspond to one week of measuring. The mean value, standard deviation, 5 % and 95 % percentile are calculated for each phase in each data set.

Representing all data sets, the total average, minimum and maximum values have been found for each of the above mentioned statistical figures. The result for the voltage level is shown in table 1.

Table 1. Statistical figures for the voltage level in one of the phases.

	Statistical figures representing all data sets		
	Average	Minimum	Maximum
Mean value	227.8 V	212.9 V	239.3 V
std.dev.	2.7 V	1.1 V	8.9 V
5 % per.	223.1 V	203.8 V	235.6 V
95 % per.	231.6 V	219.1 V	242.9 V

Table 1 shows that the overall average of the voltage level (227.8 V) is close to the nominal voltage of 230 V. The mean value will however, differ widely from delivery point to delivery point. From the standard deviation it is seen that the voltage variations during one week are very dependent of the delivery point.

The smallest registered 5 % percentile is about 204 V and under the limit of 207 V. Voltages under 207 V were recorded in 6 % of the data sets. Only 0.5 % of the measurings showed “under-voltages” lasting more than 5 % of the measuring time. Voltages over the limit of 244 V (+6 %) are very rare (seen in less than 1 % of the measurings), and cannot be characterised as a general problem.

There is no pronounced difference between the average voltage level in urban and in rural areas. However, there seems to be a little lower mean voltage in some urban areas compared to other areas. This could be explained by the fact, that the voltage level on the busbar in an urban substation (50/10 kV) is often lower compared to the busbar-voltage in a rural substation. The lower voltage on the busbar can be chosen because of the relatively low voltage drop in the 10 kV feeders of the urban grid.

Flicker

The P_{st} values have been measured in all the measuring points. The flicker level is analysed on the basis of both the long term and the short term values.

The result of the flicker measurings is quite clear. There are distinct problems in observing the limit of P_{lt} = 1. Even though the EN 50160 only acquires compliance with the limits for 95 % of the time, every tenth delivery point, and in some cases every third, cannot meet this demand.

There are P_{lt} values exceeding the limit 1 in approximately 50 % of all data sets. Generally, the flicker level is higher in rural areas than in urban areas.

Figure 1 illustrates the results from the flicker measurings. The mean value, 5 % percentile and 95 % percentile are calculated in each of the data sets. The mean, minimum and maximum are then found, which represent all data. Figure 1 distinguishes between measurings in urban and in rural areas. Even though some of the largest flicker values recorded are found in city areas, the average is in general highest in the rural areas.

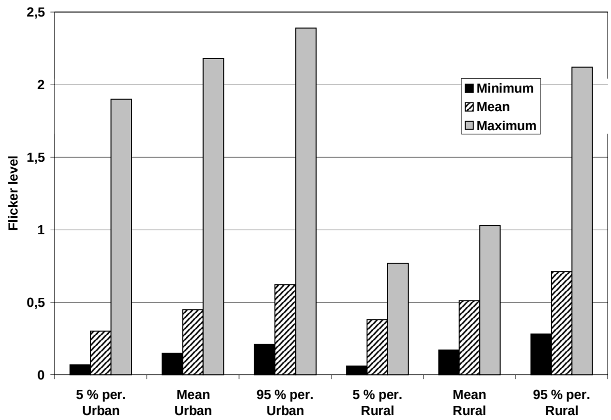

Figure 1. Flicker (P_{lt})

On the assumption that flicker has a normally distributed density function, the expectable flicker level in a Danish low voltage delivery point is shown in table 2.

Table 2. Statistical figures for expectable flicker values.

	95.5 % of the PCCs have flicker mean values equal to or less than:	95.5 % of the PCCs have flicker 95 % percentiles equal to or less than:
Urban areas	0.85	1.18
Rural areas	0.87	1.33

The majority of the values, which exceed the limit, are found in the interval from 1.0 to 1.5. However, values above 1.5 appear relatively frequently.

Harmonics

The total harmonic distortion (THD) and the individual harmonics of the order 3, 5, 7, 9, 11, 13, and 15 have been measured in all measuring points. Harmonics are normally one of the most important parameters in power quality matters. The emission of harmonic currents from non-linear equipment can cause significant disturbances. Since the numbers of non-linear loads in households and industry are increasing these years, a high level of harmonic pollution in the voltage was expected.

The measurings of the total harmonic distortion (THD) are shown in figure 2. It is clear that the measurings are far from the limit of 8 % of Un. Further, it is noticed that the level of THD seems to be higher in urban areas than in rural areas. The short circuit level is generally higher in town areas which should reduce the harmonic content of the voltage, but the density of harmonic current emitting equipment is high as well. This could be an explanation to the fact that the level of THD is highest in urban areas.

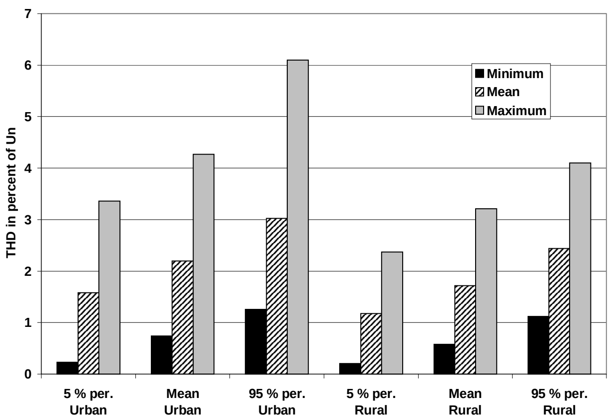

Figure 2. THD

Concerning the 3rd order harmonics, some very low mean values have been observed. Values nearby or above 3-4 % of Un are found in a very limited number of the measurings. This must be compared with the limit of 5 % of Un.

From a general point of view, these measurings do not give rise to any worries about 3rd harmonics. It must be noticed that this conclusion does not clear off all problems with 3rd harmonics, especially not on a local level, where 3rd harmonic currents can cause serious problems in the neutral conductor, e.g. in office buildings.

In proportion to the limit (6 % of Un) the content of 5th harmonics is higher, compared to the result of the 3rd harmonic. The level of 5th harmonics is not close to 6 % of Un in general, but places with a high level, where the limit is exceeded some periods during the week, can be found. Like the results of the THD, a significant difference in the level of 5th harmonics between urban and rural areas is observed.

The odd harmonics from order 7 to 13 are far below the limits given in the standards.

The 15th harmonic has a limit of 0,5 % of Un. This is exceeded in 8 % of the data sets, and in approximately 3 % of the data sets, in more than 5 % of the measuring time.

One must be aware that these results do not include measurings at medium size or large industries. This might affect the results, so that the measured overall level of harmonics is lower than it would be, if measurings at these customers were included.

OTHER POWER QUALITY PARAMETERS

Voltage dips

The European Standard EN 50160 states that voltage dips under 85 % of Un must be avoided. Voltage dips under this limit were found in 30 % of the measurings.

There is a large difference from point to point in the number of recorded dips. In some places there are very few, in others many, but most of these are found in the interval 90-85 % of Un. Nevertheless, 30 % of the measurings have dips under 85 % of Un, the number of dips in each separate data set which goes below the limit is very limited.

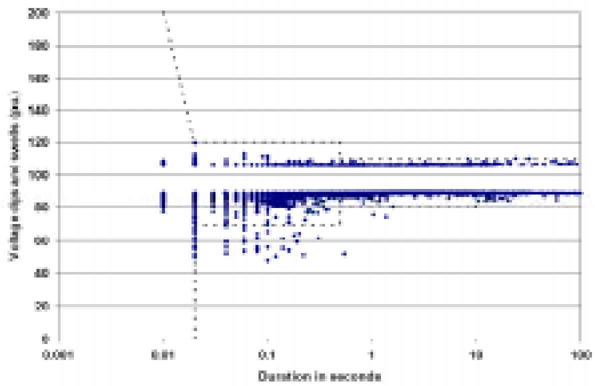

Figure 3. CBEMA[3] curve representing approx. 300 delivery points in rural areas. There are 64,000 registrations on the curve. Forty-eight of these are in the area from 40 to 70 % of Un.

An approximated CBEMA curve is shown in Figure 3, representing 300 delivery points in the category of rural areas. There are 64,000 registrations on the curve. Only 48 of these are found in the area from 40 to 70 % of Un.

DC voltage

The content of DC in the AC voltage is investigated. The results indicate that a level of +0.4/-0.3 V_{DC} will not be exceeded in nine out of ten of cases. The level of DC was within the limits of +0.2/-0.3 V_{DC} in 80 % of the measurings.

Unbalance

The assertion that the unbalance of the voltage in the low voltage system is increasing is seen now and then. The

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[3] The Computer Business Equipment Manufactures Association.

measurings in the survey cannot tell whether or not this is true, but the results show that the limit of a 2 % ratio between the negative and the positive sequence voltage is exceeded in approximately 10 % of the data sets. However, the violations were in most cases present less than 5 % of the measuring time.

Voltage transients

The occurrence of transients in the voltage was recorded in a few delivery points (26). The limited number was due to the equipment used in the measurings.

The total number of voltage transients recorded in the 26 points is shown in figure 4. Because of some repeated measurings, the figure represents the transients in 50 data sets (50 weeks). It appears that the majority of the transients are smaller than 1000 V and has a duration not exceeding 500 μs.

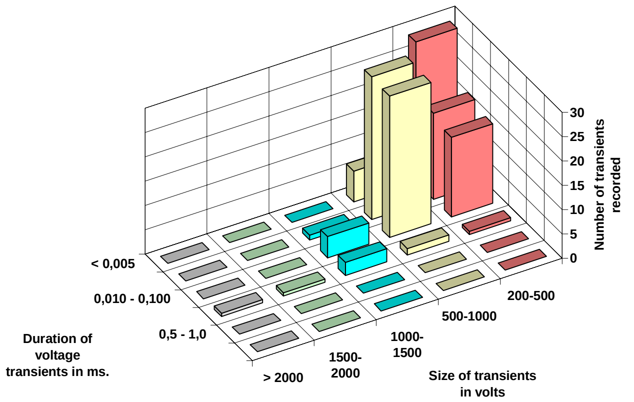

Figure 4. Total number of voltage transients recorded.

Only transients bigger than 200 V plus the immediate voltage were recorded.

VARIATIONS IN THE LEVEL OF POWER QUALITY

The repeated measurings (four times) in each individual point were used to investigate the daily variations and the seasonal variations of the parameters voltage level, flicker (P_{st}) and total harmonic distortion (THD).

Seasonal variations

For all three of the mentioned parameters a statistical test was carried out. The hypothesis that there is no significant change in the level of respectively voltage, flicker and THD from one season (three-month period) to another was tested.

This hypothesis was rejected in all three cases, which indicates that the time of year has some influence on the level of the voltage, the flicker and the THD.

Even though it is not the case in all the measuring points, there seems to be a tendency towards a lower level of voltage in the wintertime. This is not surprising, since the load is higher in the winter.

Concerning the flicker level, there are some variations during the year, but it is not possible to generalise. The variations from one three-month period to another in one specific measuring point do not match the variations measured in another point.

There seems to be some variations in the level of THD during the year, in some of the measuring points. The highest level is apparently in the summer-time. It is however, difficult to explain this observation.

Daily variations

The variations over a 24 hours period are compared for Wednesdays and Sundays for each of the three parameters. The comparisons distinguish between urban and rural measurings, and between summer and winter periods.

The variations in the voltage level follow the load profile[4] inversely. This means that the voltage is low when the load is high. This is obviously a pattern, which could be expected. There is no pronounced difference between the weekdays, summer and winter or urban and rural areas.

The level of flicker is highest in the daytime hours. The peak values are much higher in rural areas, as described earlier in this paper. These results are valid for both Wednesdays and Sundays.

Finally we have the THD, were the level is lowest in the morning hours and significantly higher in the evening. Having in mind that 75 % of the measurings are done in domestic areas or near farms, this THD peak in the evenings most likely results from television sets or perhaps fluorescent lamps. Figure 5 shows an example of the variations in the THD level in urban areas, on a Wednesday in the summertime. The figure shows at each time (10-minute value) the mean, the 5 % and the 95 % percentile of the measured THD in a number of measuring points.

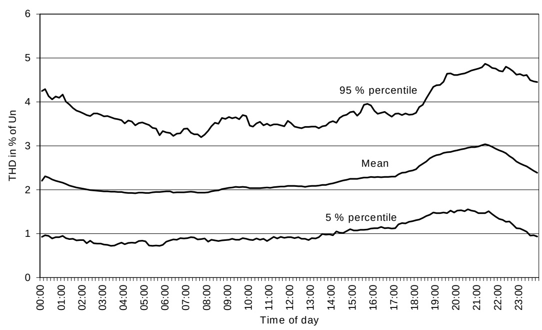

Figure 5. Mean, 5 % and 95 % percentile for THD 10-minute values in 162 data sets. The THD is measured on Wednesdays in the period from April to September.

[4] Houses without electric heating.

POWER QUALITY AND THE SHORT CIRCUIT IMPEDANCE

The short circuit impedance is registered in every measuring point included in the survey. This is done in order to investigate relations between the measured parameters and the short circuit level.

Table 3 shows characteristic values for the impedance of some typical components in the Danish low voltage system. The values are expressed in ohms and they are calculated at 400 V.

Table 3. Impedance for typical components in the Danish low voltage system.

Component	**Resistance**	**Reactance**
200 kVA Transformer	0.011 Ω	0.059 Ω
400 kVA transformer	0.005 Ω	0.019 Ω
630 kVA transformer	0.003 Ω	0.013 Ω
95 mm^2 cu apb cable	0.195 Ω/km	0.078 Ω/km
95 mm^2 al apb cable	0.320 Ω/km	0.078 Ω/km
95 mm^2 al pex cable	0.320 Ω/km	0.070 Ω/km
50 mm^2 al pex cable	0.641 Ω/km	0.072 Ω/km
35 mm^2 cu overhead line	0.505 Ω/km	0.319 Ω/km

Table 4. 50 %, 90 % and 95 % percentiles of the short circuit impedance at the measuring points.

	Rural area Ω	Urban area Ω
50 % percentile	0.35 + j0.12	0.18 + j0.07
90 % percentile	0.72 + j0.32	0.30 + j0.13
95 % percentile	0.80 + j0.34	0.33 + j0.16

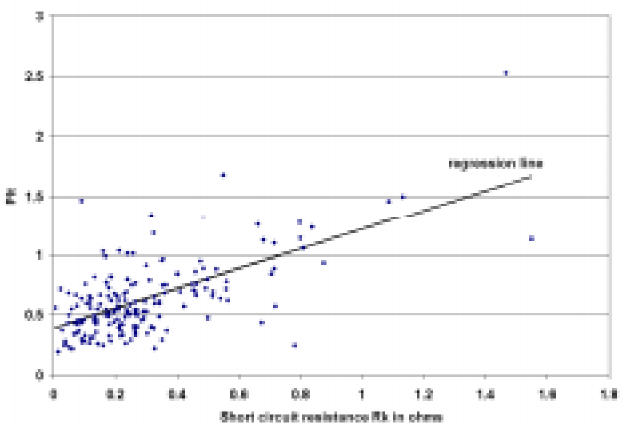

Figure 6. Correlation between the average flicker level in a delivery point and the corresponding short circuit resistance.

It appears from table 4 that some of the measurings are done in the weaker parts of the low voltage system.

It is demonstrated in the analysis, that there is no relation between the voltage level and the short circuit impedance in the point, where the voltage is measured.

As expected there seems to be some correlation between the flicker level and the short circuit level. Nevertheless , it is not possible to argue that a low short circuit impedance necessarily will lead to a low flicker level.

CONCLUSIONS

The Danish power quality survey included 200 delivery points in the low voltage system. All measurings were done at customers, who did not have their own 10/0.4 kV transformer.

In total, the power quality was measured four times one week in each individual point with a three-month interval.

All voltage parameters have been measured, except for the frequency and interharmonics.

The measurings showed that there seems to be no problems with the voltage level. Surprisingly the level of harmonics was far from alarming. The highest THD level appears to be in the evening hours, probably because a majority of the measurings was done in domestic areas.

Flicker is the only measured power quality parameter, which can be characterised as a problem. More than 10 % of all the data sets have P_{lt} values which exceed the limit of one for more than 5 % of the measuring time. From a general point of view, the highest values and the longest duration are found in rural areas.

Further investigations of these high flicker levels could be very interesting, e.g. what is the generator in households, farms and service industry and how does the flicker propagate in the system?

This kind of investigations will probably be the next step in the mapping of the power quality situation in Denmark.

REFERENCES

[1] European Standard EN 50160, "*Voltage characteristics of electricity supplied by public distribution systems*", CENELEC 1994.

[2] Recommendation 16, "*Power quality in the low voltage system*", DEFU 1995 (In Danish).

[3] Draft of technical report "*Measurings of the power quality in the Danish low voltage system*", DEFU 1999 (In Danish).

[4] IEC 1000-3-2, *Electromagnetic compatibility (EMC) part 3: Limits-Section 2: Limits for harmonic current emission (equipment input current ≤ 16 A per phase), first edition 1995-03.*