HARMONIC LEVEL MEASUREMENTS ON FRENCH LOW-VOLTAGE NETWORKS

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ABSTRACT

EDF has been conducting a harmonic survey on public LV networks since 2000. Its objectives are to obtain a state of play of the harmonic levels on these networks and to evaluate their evolution over several years. The main purpose of this paper at CIRED 2007 is to present the harmonic levels measured on French public LV networks in 2006 and their development since 2000. The influence of the assessment method on the results obtained is also considered: periods of measurements, criterion used to assess the measured levels.

INTRODUCTION

Harmonic voltage levels in low-voltage networks represent an important aspect of power quality. From the point of view of electromagnetic compatibility, they must be kept within the compatibility levels to enable all the equipment supplied by the public networks to function satisfactorily. In other respects, since electricity is also defined as a product, the utility could be held responsible for excessively high harmonic levels and any damage they cause to customers' property. Therefore, in Europe the harmonic voltage limits given in EN 50160 should also be met.

The number of non-linear loads is increasing, particularly with the development of electronics in equipment for the general public and variable speed in industry. This induces an increase in harmonic disturbance levels on the public networks. Moreover, we have already observed high levels in certain places such as winter sports resorts. Consequently, utilities are faced with the risk that the permissible levels defined in standard EN 50160 will be exceeded on a significant number of networks in the future.

In order to assess this risk, EDF started a harmonic survey on the public LV networks in 2000. The objectives were to obtain a state of play of the existing harmonic levels on these networks, then to evaluate their evolution over several years.

A paper at CIRED 2003 [1] described the results obtained during the first whole year of measurements. The main purpose of this paper at CIRED 2007 is to present the harmonic levels reached in 2006 and their development since 2000. The influence of the assessment method on the results obtained is also considered: periods of measurements, criterion used to assess the measured levels.

DESCRIPTION OF THE HARMONIC SURVEY

The characteristics of the survey were described in detail in [1]. Here we will only mention the main points.

Choice of the measurement locations

The results described in this paper were obtained from 16 measuring instruments installed inside the MV/LV substations supplying 16 typical public LV networks in 2000, and from 4 additional measuring instruments installed at the end of typical LV feeders in 2002.

The purpose of the 16 typical LV networks is to provide an assessment of the harmonic levels on the French LV networks. The choice of these LV networks was made virtually randomly. They are divided up as follows:
- 5 LV networks supplying residential customers,
- 4 LV networks supplying light industry,
- 7 LV networks supplying offices or commercial zones.

The purpose of the 4 measuring instruments installed at the end of LV feeders is to observe harmonic voltage drops on LV networks.

The system of measurement

In addition to these measuring instruments, the system of measurement also includes one measurement processing station, which reads the measurement data from the measuring instruments, stores them in a database and processes them to extract overall results.

The quantities measured

The measuring instruments measure the r.m.s. harmonic quantities by means of an FFT over a 200-ms window, then calculate the average values of these quantities over consecutive intervals of 10 minutes. To limit the amount of data, the measuring instruments only record the 10-minute values of the fundamental component, the 3rd, 5th, 7th, 9th, 11th and 13th harmonics, and the total harmonic distortion.

RESULTS IN MV/LV SUBSTATIONS IN 2006

In this section, we present the results obtained from the measuring instruments that were installed on the 16 typical LV networks in 2000. The measurement period considered extended from July 1st 2005 to June 30th 2006.

Harmonic levels obtained over the whole year

From the data transmitted by the measuring instruments, the

measurement processing station calculates the statistical distribution of the measured quantities over the whole year's measurements. For each measured quantity and for each typical LV network, it deduces a 50 % value, a 95 % value and a maximum value over the whole year. Thus we can obtain the distribution of harmonic levels for these networks as a whole. Figure 1 gives the distribution of the 50 %, 95 % and maximum values for harmonic order 5, which is the most critical one at MV/LV substations.

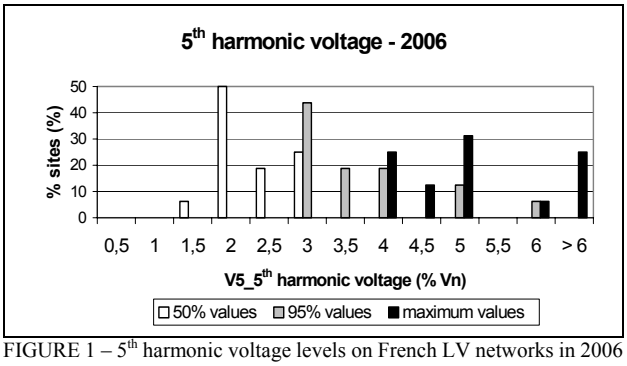

FIGURE 1 – 5th harmonic voltage levels on French LV networks in 2006

For the 5th harmonic voltage, the 95 % level measured over one year is between:
- 2 and 3 % for 7 typical LV networks,
- 3 and 4 % for 6 typical LV networks,
- 4 and 6 % for 3 typical LV networks.

If we compare it to the compatibility level equal to 6 %, the overall 5th harmonic level is therefore high for about 20 % of the LV network sample considered.

For the other harmonic orders, the 95 % levels over one year are always lower than half the compatibility levels.

Seasonal variations

These results only give overall levels over one year. However, harmonic levels vary a lot during the year.

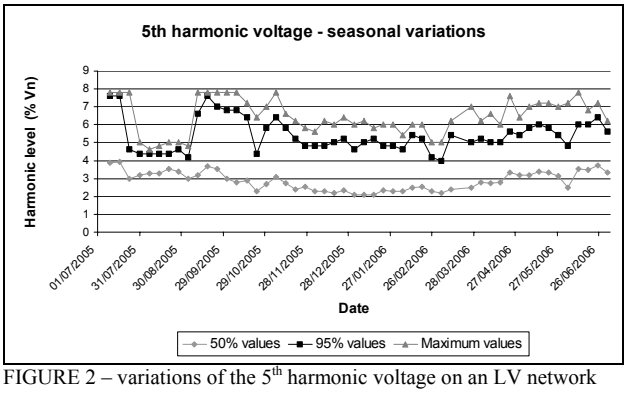

FIGURE 2 – variations of the 5th harmonic voltage on an LV network

The measurement processing station also calculates the statistical distribution of the measured quantities over each week's measurements. For each typical LV network and for each measured quantity, it deduces a 50 % value, a 95 % value and a maximum value over each week. Figure 2 gives the variations of these weekly values over one year on one of the LV networks considered. In that case, the 95 % value of the 5th harmonic voltage varies between 4 and 7,6 %.

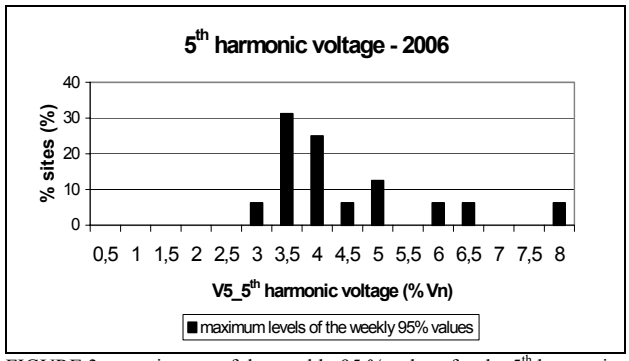

FIGURE 3 – maximums of the weekly 95 % values for the 5th harmonic

If we refer to standard EN 50160, every weekly 95 % value should be lower than or equal to 6 % for the 5th harmonic voltage. Thus, an LV network does not comply with EN 50160 if the maximum of the weekly 95 % values exceeds 6 %. For each typical LV network, the measurement processing station calculates this maximum weekly 95 % value over the whole year.

Figure 3 gives the distribution of these levels for the 16 LV networks considered in the case of the 5th harmonic. Thus, 2 out of these 16 networks did not comply with standard EN 50160 in 2006, because of the 5th harmonic.

RESULTS AT ENDS OF LV FEEDERS IN 2006

Harmonic voltage drops on LV networks

The harmonic voltage levels observed on customers' premises are generally higher than those measured inside the MV/LV substations. This is due to harmonic voltage drops that are created by the flow of harmonic currents through the various impedances of the LV network. As explained in [1], these voltage drops are particularly high for triplen harmonics, which are the harmonics whose order is a multiple of 3, such as the 3rd and 9th harmonics. In that case, the harmonic voltage transmitted by MV networks is low, but the harmonic current in the LV neutral conductor is in general roughly three times higher than the ones in the line conductors. Therefore, the triplen harmonic voltages seen on customers' premises may be much higher than the ones measured in MV/LV substations.

Harmonic levels over one whole year

Figures 4 and 5 present the results obtained from the 4 measuring instruments installed at the end of French LV feeders. They give the 95 % value for the 3rd and 9th harmonic voltage at each site, as well as the corresponding value measured at the MV/LV substation supplying the site.

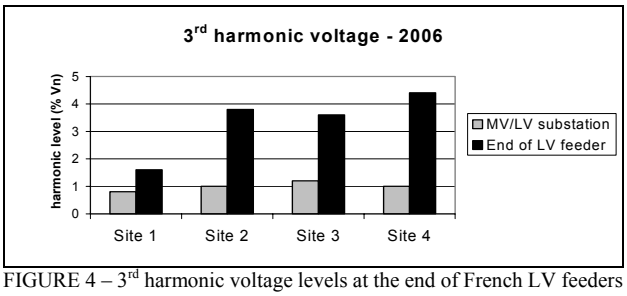

FIGURE 4 – 3rd harmonic voltage levels at the end of French LV feeders

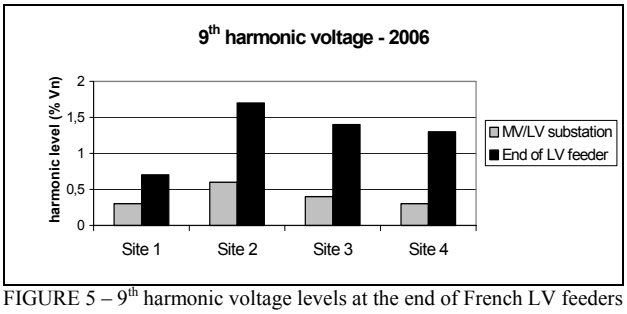

FIGURE 5 – 9th harmonic voltage levels at the end of French LV feeders

For these 4 sites, the 3rd harmonic voltage level over one year was close to the compatibility level (equal to 5 %) on three sites. For the 9th harmonic, the measured voltage level exceeded the compatibility level (equal to 1,5 %) on one site, and was very close to it on two other sites.

Seasonal variations

If now we consider the weekly harmonic voltage levels on the same year's measurements, 3 of the 4 sites at the end of LV feeders did not comply with EN 50160. For the 3rd harmonic, the limit was exceeded on one site for 4 weeks. For the 9th harmonic, the limit was exceeded on two other sites, for 28 weeks on one site and for 3 weeks on the other.

EVOLUTION OF HARMONIC LEVELS

Relevance of measurements over one year

From the example given in Figure 2, we can see that the harmonic levels change a lot from one week to another. Therefore, it is very difficult to assess the long-term evolution of harmonic levels only from measurements carried out each year over a period of one week. It is necessary to have quantities measured over whole years in order to obtain results independent of seasonal variations.

Harmonic levels in the MV/LV substations

From the measured quantities over one whole year's measurements on each site, the measurement processing station calculates the global statistical distribution of these quantities over the whole set of 16 typical LV networks. For each measured quantity, it deduces a 95 % value over each year. Thus Figure 6 gives the evolution of the 5th harmonic voltage level on the 16 typical LV networks considered between 2001 and 2006.

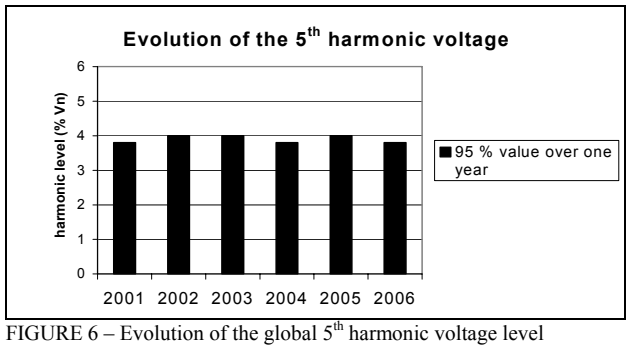

FIGURE 6 – Evolution of the global 5th harmonic voltage level

We can see that the 5th harmonic voltage level has remained stable for 5 years. We also obtained similar conclusions for the other harmonic orders.

If now we consider the compliance with EN 50160, for each of the years between 2001 and 2006, from 1 to 4 networks, out of the 16 typical ones considered, did not comply with this standard for a total period of 1 to 20 weeks. But again, we have noticed no significant evolution in harmonic levels.

Evolution of the regulation context

The preceding results seem to contradict the observations made in the 90's. Due to the increase in the number of non-linear loads, at that time the harmonic levels were rising, roughly 0,1 % per year for order 5. On the contrary, although the amount of non-linear equipment continues to increase, the harmonic levels seem to stabilize.

This new situation is probably a positive consequence of the EN 61000-3-2 coming into force in 2001. The requirements then became more severe for some types of equipment, such as television sets and personal computers, which required some manufacturers to use harmonic filters when necessary. Thus, at present the increase in harmonic levels due to the development of non-linear equipment would be compensated by the decrease in harmonic current emissions thanks to harmonic filtering in some products.

If this is true, harmonic levels should start to increase again when the products impacted by new EN 61000-3-2 have been completely renewed. Therefore, it remains essential to continue the harmonic survey in order to observe the evolution of harmonic levels and to resist any temptation to relax emission limits for equipment.

CONSIDERATIONS ON THE METHOD OF ASSESSMENT

Impact of the measurement duration

Most harmonic measurements are carried out for the period of one week. The purpose of this section is to compare the results obtained in that case with the ones obtained when the measurement duration is equal to one year.

Let us consider the particular case of the 5th harmonic on the LV network as illustrated in Figure 2. In this case:
- The 95 % value over the whole year is equal to 6,0 %.
- The 95 % value over one week is lower than the 95 % value over the whole year for 38 weeks, equal to this value for 3 weeks and higher for 10 weeks. So, the value over one week is generally lower than the value over the whole year.
- The average of the weekly 95 % values is equal to 5,4 %.

If now we consider the 16 MV/LV substations supplying the typical LV networks, then for the 5th harmonic voltage level:
- The 95 % value over one week is lower than the 95 % value over the whole year in 58 % of the cases, equal to this value in 14 % of the cases and higher in 28 % of the cases.
- The average difference between the 95 % value over the whole year and the weekly 95 % values is equal to 0,34 %.

Therefore, the fact of carrying out harmonic surveys over one week instead of one whole year tends to underestimate harmonic levels. For the 5th harmonic, this underestimation is about 0,3 to 0,4 % on average.

Impact of the criterion used to assess the levels

Standard IEC 61000-2-2 defines compatibility levels as reference values for coordination in the setting of emission and immunity limits. They are generally based on 95 % probability levels on entire systems, using distributions which represent both time and space variations of disturbance levels. According to this definition, the value that should be compared to a harmonic compatibility level is the corresponding global 95 % harmonic voltage level over a whole year and related to all the networks in a large area. In the case of French LV networks, this value is equal to 3,8 – 4 % for the 5th harmonic. Even if it does not entirely correspond to its definition, it may also be interesting to compare the compatibility level to the level reached on each LV network. In that case, although the 5th harmonic level is not very far from the compatibility level for about 20 % of the LV networks, it is never exceeded on the considered sample.

European standard EN 50160 defines the characteristics of the voltage at the customer's supply terminals. So the limits apply at any point of public networks. Moreover, for each harmonic order and during each period of one week, 95 % of the 10 minute mean r.m.s. values shall be less than or equal to the limit given. According to this definition, all weekly 95 % values at any point of public networks should meet the limits given. In the case of French networks, about 15 % of the LV networks do not comply with EN 50160 because the 5th harmonic limit is exceeded for at least one week. In the same way, other LV networks do not comply with this standard because the 3rd or 9th harmonic levels do not meet the limits at the end of LV feeders.

So, even if the levels given in IEC 61000-2-2 and EN 50160 are the same, the criterion defined in EN 50160 is far more severe than the criterion corresponding to the definition of compatibility levels. Therefore, the fact that it is becoming more and more difficult to meet harmonic voltage limits at all points on public LV networks does not imply that the compatibility levels given in IEC 61000-2-2 should be increased, but should lead to consider EN 50160 evolution in order to be more consistent with EMC principles.

CONCLUSION

EDF has been conducting a harmonic survey on French LV networks since 2000.

At MV/LV substations, the most critical harmonic order is the 5th one. The measurements on a sample of 16 typical LV networks revealed that, for the 5th harmonic voltage, the 95% level over one whole year was between 4 and 6% for about 20 % of the LV networks. Moreover, about 15 % of these networks did not comply with standard EN 50160.

Additional measurements made on LV feeders showed high harmonic voltage drops for orders 3 and 9. Thus, although they are generally low in MV/LV substations, the levels of 3rd and 9th harmonic voltages at the end of typical LV feeders are generally far higher and may exceed the compatibility levels given in IEC 61000-2-2 or the limits defined in EN 50160.

Since the beginning of the harmonic survey in 2000, we have noticed no significant evolution in harmonic voltage levels. This stabilization, compared with the rate of increase noted in the previous years, is probably a positive consequence of the EN 61000-3-2 coming into force in 2001, requiring the use of harmonic filters for some types of equipment. But when these products have been completely renewed, the levels should start to increase again. Therefore, it is essential to continue observing the evolution of harmonic levels and to resist any temptation to relax emission limits for equipment.

Lastly, this paper has shown the impact that the assessment method may have on the results. Thus, the use of a period of one week instead of one whole year tends to underestimate harmonic levels. The criterion defined in EN 50160 leads to more severe limits than the criterion corresponding to the definition of compatibility levels. That explains why EN 50160 limits are sometimes so difficult to fulfil.

REFERENCES

[1] L. Berthet, D. Boudou, X. Mamo, P. Eyrolles, J. Martinon, 2003, "State of play of the harmonic levels on the French low-voltage networks", CIRED 2003, session 2, paper 31