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Impacts of Modifications of Standards on the Power Quality Measurement Results

S. Bhattacharyya, J.F.G. Cobben and W. L. Kling

Abstract— Power quality (PQ) standards are needed to achieve coordination between the characteristics of the quality of a network’s power supply and the requirements of the end use equipments. The European standard EN50160 is a reference for the voltage supplied in medium and low voltage European grids. In the recent years, many discussions are done among regulators, network operators and industrial partners to improve this standard. In 2009, the last revision of this standard was approved and a number of modifications are given regarding the supply voltage related parameters. In this paper, a brief analysis is done to find out the implications of those changes to the existing network’s voltage supply characteristics. Five years PQ measurement results of the Dutch networks are used as a reference case and are evaluated based on the new values given in the final draft of the EN50160 standard and the existing Dutch Grid Code.

Index Terms—EN50160 standard, Dutch Grid Code, voltage variation, harmonics, flicker, PQ measurement

I. INTRODUCTION

VOLTAGE quality is a complex and relatively new issue for the regulators. The European standard EN50160 defines, describes and specifies the characteristics of the low and medium voltage supply concerning frequency, magnitude, waveform and symmetry of the supply voltage. This standard is not applicable for any abnormal condition in the network such as when a fault occurs, or an emergency situation arises. The voltage characteristics given in this standard are not intended to be used to specify requirements in equipment product standards. It should be noted that the performance of equipment might be impaired if it is subjected to supply conditions which are not taken into account in the equipment product standard. In the EN50160:1999 [1] standard, the limits of compliance are set only for few voltage quality parameters. The Council of European Energy Regulators (CEER) was not satisfied with the EN50160 requirements to apply for regulation purposes. They wanted improvements on this standard so that it can be applied by the national regulators for fulfilling the voltage quality needs and to compare the performance in different countries. In 2007, the CEER along with the European regulators’ group for Electricity and Gas (ERGEG) published a conclusion paper after the public consultation that suggests a “roadmap” for the revision of EN50160. They considered that the revised EN50160 should be adaptable to various European countries’ needs and also should be harmonized with the IEC standards. In 2009, the final draft of the EN50160 standard was approved by the European Committee for Electrotechnical Standardization (CENELEC) members. In this latest version, the scope is also extended to the high voltage networks. In the Netherlands, PQ measurements have been started several years ago. Therefore, it is certain that the modifications of limiting values in the new version of EN50160 (final draft is called “FprEN50160”) will have impacts on the previously measured PQ data. In this paper, PQ trends in the medium and low voltage Dutch networks are presented. Further, the limiting values of different PQ parameters are compared with the values given in the new FprEN50160 (2009) report [2] and the Dutch Grid Code [3].

II. VOLTAGE QUALITY STANDARD EN50160

The European standard EN50160 is used as a guideline mainly for the network operators. Different voltage-parameters described in the EN50160 (1999) can be sub-grouped as shown in TABLE I.

<table>
<thead>
<tr>
<th>Group -1 Parameters with limiting values</th>
<th>Group -2 Parameters with indicative values</th>
<th>Group -3 Parameters without given values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Voltage dips</td>
<td>Temporary and transient overvoltages</td>
</tr>
<tr>
<td>Slow voltage variations</td>
<td>Short and long interruptions of supply voltage</td>
<td>Interharmonics</td>
</tr>
<tr>
<td>Fast voltage variation</td>
<td>Long-term flicker</td>
<td></td>
</tr>
<tr>
<td>Unbalance</td>
<td>Harmonics</td>
<td></td>
</tr>
<tr>
<td>Harmonics</td>
<td>Signalling voltages</td>
<td></td>
</tr>
</tbody>
</table>

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A. European regulators’ views on the standard EN50160

The standard EN50160 describes electricity as a product which should comply with the quality standards. A frequent criticism of the EN50160 standard was that it gives limits for 95% of the time. The ERGEG considered that more stricter standards are necessary to maintain the voltage supply quality of the present infrastructure. Each party connected to the power system influences the PQ of the network. Therefore, each of them should meet some minimum requirements at the customer’s point of connection (POC) so that the network’s PQ disturbance level can be kept to a lower value than what is specified in the standard. In 2006, the ERGEG published a public consultation paper “E07-EQS-09-03” [4], and seven recommendations were made to CENELEC for revising the EN50160 standard:

- Improve definitions and measurement rules to avoid ambiguity.
- Limits for voltage variations are given for 95% of the time to protect the customers. Hence, 100% of normal operating conditions clause is to be introduced for various voltage parameter limits. Also, avoid long time intervals for averaging measured values (mainly for fast phenomena).
- Enlarge the scope of EN50160 to higher voltage systems.
- Avoid indicative values for voltage events (e.g. short interruptions and voltage dips): EN50160 gives definite boundary values for variations / continuous disturbances but only indicative value or no value at all for discrete disturbances / voltage events.
- Consider duties and rights for all parties involved
- Introduce limits for voltage events differentiated according to the network characteristics
- Introduce power quality contracts to satisfy the need of different customers

The CEER/ERGEG published a conclusion paper “E07-EQS-15-03” [5] that suggests a “roadmap” for the revision of EN50160. They suggested that the future version of EN50160 standard should be harmonized with the IEC standards for definition, monitoring and measurement purposes. Also, it should give “responsibility sharing curves” between the network operators and the customers for various PQ parameters. Every customer should be considered with equal importance to involve them strongly in the process.

B. Final draft of EN50160 standard

Based on the consultations of the CEER/ERGEG, in 2009 the final draft of FprEN50160 was approved by the CENELEC members and was published. This work is a result of an intensive cooperation between the technical committee experts of CENELEC and CEER within the group called “TC 8X WG1”.

TABLE II shows the new additions in the final draft of FprEN50160 (March 2009).

C. EN50160:2009 draft report versus the Dutch Grid Code

The national regulations in some of the European countries differ with the EN50160 standard on the limiting values of some of the PQ parameters. The Dutch national Grid Code gives the limits for different PQ parameters which are mostly in line with the European standard EN50160. Additionally, the Dutch Grid Code gives some limits on various PQ parameters. TABLE III summarizes the additional requirements of the Dutch Grid Code.

Note: $U_p$ is the declared voltage at the customer’s terminal for the MV network. For the LV network $U_p$ is replaced by the nominal voltage ($U_n$).

TABLE II

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage variations - test method</td>
<td>For normal operating condition, one week 95% of the 10 minutes mean rms values shall be within the range of $U_p \pm 10%$. All of them shall be within the limits of +10% and -15% of $U_p$.</td>
<td>For normal operating condition, one week 99% of the 10 minutes mean rms values shall be within the range of $U_p \pm 10%$. None of the above shall be outside the limits of $\pm 15%$ of $U_p$.</td>
</tr>
<tr>
<td>PQ measurement method</td>
<td>Not mentioned</td>
<td>As per standard IEC 61000-4-30</td>
</tr>
<tr>
<td>Voltage dip and swell evaluations and classifications</td>
<td>Not included</td>
<td>Added</td>
</tr>
<tr>
<td>Temporary power frequency overvoltage and transient overvoltage</td>
<td>-</td>
<td>Some indicative values are included</td>
</tr>
</tbody>
</table>

TABLE III

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flicker severity</td>
<td>Maximum limit for Pfi is $\leq 1$ during 95% of the time.</td>
<td>Maximum limit for Pfi is $\leq 5$ during 100% of the time.</td>
</tr>
<tr>
<td>Voltage unbalance</td>
<td>Negative sequence voltage is smaller than 2% of the positive sequence during 95% of time.</td>
<td>Negative sequence voltage is smaller than 3% of the positive sequence during 100% of time.</td>
</tr>
<tr>
<td>Total harmonic voltage distortion</td>
<td>THD(V)$\leq 8%$ for harmonics up to $40^h$ during 95% of the time.</td>
<td>THD(V)$\leq 12%$ for harmonics up to $40^h$ during 99.9% of the time.</td>
</tr>
<tr>
<td>5th harmonic voltage</td>
<td>6% for 95% of the measurement period</td>
<td>9% for the 99.9% of the measurement period</td>
</tr>
<tr>
<td>Fast voltage variations</td>
<td>As per IEC 61000-3-3 limits, relative steady state voltage change should be limited to $\leq 3.3% U_p$.</td>
<td>$\leq 10% U_p$; it is $\leq 3% U_n$ in situations without loss of production.</td>
</tr>
</tbody>
</table>
III. PQ MEASUREMENTS IN THE DUTCH GRIDS

From 1989, the network operators of the Netherlands started to monitor harmonics in their network. In 1996, the PQ monitoring (PQM) program had been extended to 150 locations throughout the country to measure voltage quality for a duration of one week in a year. The measurement was mainly done to ensure that the Dutch networks meet the requirements of EN50160 and the national ‘Grid Code’. In those measurements slow voltage variations, fast voltage variations leading to flicker, asymmetry and harmonic data were recorded. In 2003, another PQ monitoring program (PQM II) was introduced to register the PQ parameters for longer duration: a period of one year. In the PQM-II program, the extra high voltage network (EHV) was also included. The PQ measurement points were selected critically so that the monitoring results could be used as reference data for the whole network. Under PQM-II, continuous PQ monitoring is done at 20 permanent locations in the HV network and all the connection points of EHV network. In the following sections of this paper, PQ trends related to voltage variations, harmonics and flicker in the LV and MV networks of the Netherlands are discussed.

A. Trend of voltage variations in the LV and MV networks

The EN50160 standard gives the limits for the voltage variations in the LV and MV networks as ±10% of the nominal voltage (or declared voltage for the MV networks) for 95% of the measurement time. In the same standard, the lower voltage limit for 100% of the time is given as -15% of the nominal voltage. From the analysis of the PQ data for the years 2005-2008, it was noticed that all voltage variations recorded for the MV and LV networks remained within the boundary limits given in the standard. Fig. 1 shows the general voltage variation trend of the LV networks. From the detailed analysis of the measured data (around 40,000 recorded ‘10 min rms’ data per year), it was found that in 2006 only four measurements and in 2007 twelve measurements exceeded the standard limit of ±10% (not visible in Fig. 1), but stayed within -15%. It is less than 0.01% of the measured data. According to the final draft of the EN50160 report, 99% of the measurements on voltage variations at a particular location should be within the limit of ±10%. Therefore, it can be concluded that the voltage variation in the Dutch LV network fulfills the requirements of the new proposed limits of the FprEN50160.

Fig.2 indicates the voltage variation trend of the MV networks in the Netherlands during the year 2005-2008. Most of the recorded data remained within the standard limits, with an exception in 2005. In the period of November 2005, extreme weather conditions occurred and many voltage events were recorded. Therefore, those measured voltage variation data might not considered in the analysis.

B. Trend of harmonics in the LV and MV networks

Harmonic trend is analyzed for the 5th harmonic voltage and the total harmonic voltage distortion (THD(v)) in the LV and MV networks of the Netherlands. Fig.3 and Fig.5 show the 5th harmonic voltage trends for the LV and MV networks respectively; whereas Fig.4 and Fig.6 indicate the THD(v) for the LV and MV networks during the period of 2005-2008. The standard EN50160 gives as limit 6% for 5th harmonic voltage and 8% for THD(v) on 95% of the measured data. The Dutch Grid Code gives the restriction for 5th harmonic voltage as 9% and THD(v) of 12% for the 99.9% of the measurement period. From the trend analysis of the Dutch MV and LV networks during the period of 2005-2008, it was found that the THD(v) values do not exceed the above conditions of the standards. Only a few 5th harmonic voltage values in the MV networks (around 0.5% of 40,000 recorded data) have crossed the limit of 6% (refer to Fig.10). Also, none of the 5th harmonic voltage values in the present analysis was found to violate the Dutch Grid Code limit of 9%. As mentioned before, during November 2005 there were some extreme...
weather conditions in the Netherlands and many voltage events were recorded in the Dutch grids. Therefore, 0.5% of the recorded data that were exceeding the limits of the EN50160 standard can be considered as an ‘exceptional case’.

It is noticed from the analysis that the average THD(v) value in the MV network is 1.5-2.0% and that of the LV network is 2.0-2.5%. All the measurements of THD(v) remained within the limit of 8% as specified in the EN50160 standard [6].

C. Trend of flicker in the LV and MV Dutch networks

The Dutch network operators register many complaints every year about flicker from their customers. Therefore, it is important to analyze the Plt trend of the Dutch networks that is an indicator for flicker severity. The EN50160 standard gives a limiting value for Plt as 1 for 95% of the measurement period and the Dutch Grid Code gives an additional limit of Plt ≤ 5 for 100% of the measured data. Fig.7 shows the flicker trend of the LV networks during the period of 2005-2008. It shows that approximately 60% of the measured Plt remained 0.25 or below; and around 30% of them have the value in the range of 0.25-0.50.

In this analysis, every year approximately 40,000 data are recorded. In 2005, 613 times the Plt values in the LV network are found to exceed the limiting value of 1. In 2006 and 2007, the same situation occurred in 279 and 300 cases respectively; whereas in year 2008 in 36 similar cases with
Plt>1 were registered. However, in no situation the Plt value in the LV network was recorded higher than 5, as restricted by the Dutch Grid Code.

Fig. 8 shows the Plt trend of the MV networks during the period of 2005-2008. They remained mostly within 0.25 and only occasionally became around 0.5. Instead of that, in few cases the Plt values were registered too high, even exceeding the limit of the Dutch Grid Code. It was found that Plt>5 occurred in 13 cases during the year 2005 and 12 cases in 2008 (shown in Fig.11). These are less than 0.05% of the measured data. The voltage variations and harmonic voltages remained normal during those periods when high Plt values were registered in the network. Hence, it can be remarked that those high flickers are originated locally and did not have much influence to the networks.

IV. IMPLICATIONS OF CHANGES IN THE NEW EN50160 ON PQ MEASUREMENT RESULTS

As discussed in this paper, the new changes in the FprEN50160:2009 will be more challenging for the network operators as they have to fulfill stricter regulations. The voltage variation needs to be restricted to ±10% for 99% of the measurement period in comparison to 95% before. Therefore, only 1% of the measured data are allowed to cross the above standard limits as compared to 5% before. In this analysis, for every year approximately 40,000 data were available. As per the limits of EN50160:2007 standard, 5% data which is around 2000 data are allowed to exceed the limits of ±10% of the declared voltage (U_d) for the MV networks / nominal voltage (U_n) for the LV networks. As per the new limits of FprEN50160 (2009), only 400 data can exceed the limit of ±10% of U_d / U_n. In this analysis, only few voltage variation values in the LV networks (less than 0.03% of all measurements) exceeded the limits of ±10% of U_n, and there is no value in the MV network exceeded that limit. However, in the future when more distributed generations would be integrated in to the power system, voltage variations in the networks are expected to increase. Hence, fulfilling the 99% limit on voltage variation would be a new challenge for the network operators.

Fig.9 shows the THD(ν) trends of the LV and MV networks in the Netherlands. The red and green blocks of Fig.9 represent the 95% of the measured data for LV and MV networks respectively. It is found that all THD(ν) values in the measurements remained within the standard limits of EN50160 and the Dutch Grid Code.

In Fig.10, the 5th harmonic voltage trend of the LV and MV networks of the Netherlands are compared.

The red and green blocks of Fig.10 indicate the 95% of the measured data for the LV and MV networks respectively. It is found that most of the 5th harmonic voltage values in the LV and MV networks of the Netherlands remained within the standard limits of EN50160 and the Dutch Grid Code. In the year 2005, approximately 0.5% of the measured data for the 5th harmonic voltages exceeded the standard limit of 6%. It was considered an 'exceptional case' as extreme weather was recorded during that period.

In Fig.11, the Plt trends of the LV and MV networks in the Netherlands are compared. The blocks shown in Fig.11
(red for LV network and green for MV network) represent the 95% of the measured data. It is found that some of the Plt values in the MV and LV networks of the Netherlands exceeded the limit of Plt=1 as given in the EN50160 standard. In few cases during year 2005 and 2008, few Plt values in the MV networks exceeded the limit of Plt=5 as given in the Dutch Grid Code. After detailed analysis, it is concluded that those high flickers are generated locally because of temporary heavy loads, sudden voltage dips or some other reasons in the neighborhoods. Further, they did not have any visible impact on the voltage quality at other parts of the network.

![Comparison of average Plt trends in the MV and LV networks](image)

**Fig.11 Comparison of average Plt trends in the MV and LV networks**

### V. CONCLUSION

From the analysis of PQ measurement data for the medium and low voltage networks in the Netherlands, it can be concluded that PQ performance of the Dutch networks mostly fulfills the requirement of the EN50160 standard and the Dutch Grid Code. However, some cases it exceeded the standard limits too. Voltage variations in the networks during the measurement period of 2005-2008 remained within the limits given in the EN50160 standard. The new report of FprEN50160:2009 suggested that 99% of the measured data on voltage variation should stay within ±10% of the nominal voltage. With the integration of many distributed generations, it is expected that in future the voltage variations in the network will increase. Thus, the network operators may have stronger challenges to fulfill the requirements of the above limits.

The trends of the total harmonic voltage distortion THD(v) for the LV and MV networks in the Netherlands are always below the EN50160 standard limit of 8% for the 95% measured data and the Dutch Grid Code limit of 12% for the 100% measured data. On average the THD(v) value is around 2-2.5% in the LV networks and 1.5-2% in the MV networks. Similarly, 5th harmonic voltages in the Dutch networks mostly remained within the standard limit. In 2005, around 0.5% of the measured data for the 5th harmonic voltages in the MV networks exceeded the EN50160 standard limit of 6%, but stayed within the Dutch Grid Code limit of 9% for 99.9% of the recorded data. It is to be noted that an extreme weather condition was registered during that period in 2005 when the 5th harmonic voltages in the MV network exceeded the standard limit.

The trend analysis of flicker (Plt) showed that in the Dutch MV networks Plt<5 had occurred only few times (<0.05% of all recorded data) in year 2005 and 2008. Those were probably because of some temporary local events. However, the Plt values for 95% of the measurements in the MV and LV networks remained below the limit of 1, as restricted by the EN50160 standard.

Presently, the standard EN50160 has been modified mainly for voltage variation. The previous limit of 95% is changed by a stricter limit of 99% of the measured data. In future, the EN50160 standard can also be revised for other PQ parameters and the limit may be changed from 95% to 99% or 100% of the measured data. In that case, the limiting values for different PQ parameters have to be selected with care to avoid conflicts among the network users.

### VI. ACKNOWLEDGEMENT

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### VII. REFERENCES


