Recommending power quality indices and objectives in the context of an open electricity market

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Recommending Power Quality Indices and Objectives in the Context of an Open Electricity Market

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on behalf of Joint Working Group CIGRE C4.07 /CIRED members*

Abstract-- **This paper presents proposed power quality indices and objectives in view of the measurement results gathered internationally by the working group for supporting future recommendations. Planning levels and voltage characteristics are proposed. Voltage levels under consideration by the WG are MV, HV and EHV. Future directions for measuring and reporting power quality are also discussed.**

Index Terms-- **Power quality, harmonics, voltage dips, flicker, unbalance, electromagnetic compatibility, deregulation.**

I. Introduction

Power Quality has increased in importance over the years due to an increased dependence of modern industrial, commercial and service activities on the widespread use of electronics for optimizing processes.

Following the recent transition of the electricity industry toward a liberalized market, it is not surprising that customers and regulators are focusing on power quality (service continuity and voltage quality). In this new context, system operators will have to report more and more to external parties, namely to users and to regulators, about power system performance. In some countries, regulators may even impose penalties in case of non-observance of the power quality objectives.

Relevant power quality indices and objectives are prerequisites for assessing site and system performance with respect to power quality. Some site indices have already been defined in standards, but others are still missing - in particular for HV and EHV systems.

Joint working group CIGRE C4.07/ CIRED (formerly WG 36.07) was formed in 2000 with the scope of recommending power quality indices and objectives to guide the network operators in their new responsibility. The starting point of the working group activities is the evaluation of the indices and objectives proposed in the technical reports IEC 61000-3-6 [1] and 7 [2] concerning harmonics and flicker, with a possible extension of these concepts to voltage unbalance. Other documents in use in different countries were also considered for the review of existing indices and objectives. Additionally, the working group discussed indices for two other significant types of disturbances, that is to say voltage dips and interruptions. An important part of the working group activities consisted in gathering power quality measurement data available internationally in order to provide a reference basis for the future WG recommendations.

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II. Power Quality Indices

A. General considerations

To enable efficient and consistent evaluation of system performance with respect to power quality, it is necessary to have common indices and measurement methods for assessing and reporting power quality. Few would argue about the need for common power quality indices, preferably standardized ones. Such indices will eventually facilitate the task of system operators with their obligation to routinely report power quality performance. System operators may also in future be penalized in case of non-compliance to some quality objectives. This adds to the incentive for having well defined and recognized power quality indices.

A number of indices have been proposed in different standards and technical documents such as IEC 610000-3-6 and 3-7 [1][2], IEC 61000-4-7 and 4-30 [3][4], and EN 50160 [5]. The aim of JWG C4.07 was not primarily to develop new indices, but to review and to recommend the most appropriate among existing indices. For an overview of existing indices and objectives, the reader may refer to [7] and [8].

Two categories of indices can be distinguished given their use:

- Indices for planning purposes. These are used primarily to assess internal quality objectives (planning levels) set by the system operator for evaluating the impact of all disturbing loads on the supply system. These should be simple indices and be the same as those used for contractual emission purposes (more than one index may be needed here for controlling the impact of higher emissions allowed for short periods of time) ;
- Indices for characterizing and reporting system performance. These are used to assess external quality objectives or limits within which any customer can expect the voltage characteristics to remain under normal operating conditions. These should also be simple indices and be the same as those used for reporting performance to

management, contracting to power quality performance in general and for reporting performance at a regulatory level.

It is important to realize that planning levels should not exceed voltage characteristics. Voltage characteristics represent the total disturbance level that should not be exceeded at any supply points; it is the result not only of emissions from loads connected a given voltage level and downstream, but it also includes transferred disturbances from upstream voltage levels. A margin is thus required between those two sets of objectives. This margin may be obtained by specifying different levels, or by using different indices for planning levels and voltage characteristics as this is often the case especially at HV-EHV.

Two levels of indices can be distinguished given their use in reporting «voltage characteristics» performance:

- Site indices : the performance at a specific site;
- System indices : the performance of a system.

It is also recognized that more complex indices may be needed by the system operator for investigations, diagnostics or specific contractual application purposes. These specific types of indices were not considered as part of the scope of this working group.

B. Harmonics

Planning levels: Based on the indices proposed in [1], the working group recommends that planning levels be assessed by using one or more of the following indices (more than one index or more than one probability value ─ ex.: 99% and 95% may be needed for planning levels in order to assess the impact of higher emission levels allowed for short periods of time such as during bursts or start-up conditions) :

- The 95% probability daily value of $U_{h\ vs}$ (r.m.s. value of individual harmonic components over 'very short' 3 s periods);
- The maximum or the 99% probability weekly value of $U_{h\ sh}$ (r.m.s. value of individual harmonics over 'short' 10 min periods);
- The maximum or the 99% probability weekly value of $U_{h\ vs}$.

The basic standard to be used is the IEC 61000-4-30 [4]. The minimum measurement period should be one week.

The 95% probability value should not exceed the planning level. Maximum or 99% probability indices, planning levels may be exceeded by a factor (eg.: 1,5 – 2 times or more) to be specified by the system operator, depending on the system and load characteristics. It is also noted that maximum values can be inflated by transients having rich harmonic contents that need to be removed from measured values (the flagging concept introduced in the 4-30 [4] can only flag transients if the rms voltage gets outside the normal range; therefore using maximum values for harmonic indices may not be relevant).

Voltage characteristics: For practical reasons such as allowing easy comparison of voltage characteristics between LV-MV and HV-EHV, and also for having common monitoring methods, the working group recommends the same site indices for HV-EHV systems voltage characteristics as defined in EN 50160 for LV-MV systems, that is :

- The 95% percentile of weekly value of $U_{h\ sh}$ (10–min) (individual harmonic voltages up to 40 and THD).

A system index under consideration is the percentage of site indices that exceed the voltage characteristics in a given reporting period.

C. Flicker

Standard IEC 61000-4-15 [6] defines two basic indices so-called short term flicker severity index P_{st} (10-m) and long term index P_{lt} (2-hr). Experience also indicates that P_{lt} and P_{st} quantities are often correlated by a quasi-constant factor that depends on the characteristics of the disturbing process. Therefore specifying both may be seen as redundant.

Planning levels: Recommendations of JWG C4.07 are that P_{st} values should be sufficient for assessing planning levels as follows :

- The 95% probability weekly value of P_{st} ;
- The 99% probability weekly value of P_{st} .

The basic standard to be used is the IEC 61000-4-30. The minimum measurement period should be one week.

The 95% probability value should not exceed the planning level. The 99% probability value may exceed the flicker planning levels by a factor (ex.: 1-1,5) to be specified by the system operator, depending on the system and load characteristics.

Another index $P_{lt\ 99}$ weekly was proposed in [2], but is not recommended here. Indeed, $P_{lt\ 99}$ is actually equal to the maximum weekly value (1% of the time in a week is less than 2-hour). Maximum or 99% P_{lt} values may not be relevant because they can be inflated by dips or short interruptions unless such events are flagged according to recent IEC Std 61000-4-30 and removed from statistical results.

Voltage characteristics: As for harmonics, JWG C4.07 recommends the same site indices for HV-EHV systems voltage characteristics as defined in EN 50160 for LV-MV systems :

- The 95% percentile of weekly value of P_{lt}.

For a system index for flicker, it should be recognized that in many systems, only few worst sites are monitored for flicker, so it may be difficult to get an unbiased sample from the total population.

D. Voltage Unbalance

Voltage unbalance is defined as the ratio of the negative-sequence component to the positive-sequence component at fundamental frequency.

Because of the similarity of effects caused by harmonics and voltage unbalance (thermal effects) the working group recommends using similar site and system indices for both (refer to section *B. Harmonics*). The evaluation procedure should also follow IEC 61000-4-30 [4].

E. Voltage dips

Voltage dips are a different type of phenomenon to those discussed before. Where it is possible to determine a harmonic index any moment in time, one has to wait for a voltage dip to occur. This requires a somewhat different approach that was defined only recently in standards such as [4], technical report [10], or underway [11].

From the rms voltage as a function of time, two basic characteristics should be determined for dips :

- retained voltage (the lowest rms voltage on any phase during the event) ;
- and duration (the time the rms voltage stays below the threshold –duration can be started on one phase and terminated on a different phase).

IEC 61000-4-30 [4] defines the calculation of the retained voltage and duration (Note that the retained voltage is obtained from measurement of $U_{rms(1/2)}$ - the value of the rms voltage measured over one cycle and refreshed each half cycle). The voltage should be indicated in percent or per unit, the duration in milliseconds. It is also good practice to record the rms voltage profile versus time during dips for future reference.

The value of the dip-starting threshold used to start the recording of the dip may affect the number of shallow dips captured. The choice of the dip-ending threshold affects the duration value. No specific threshold value is mandatory although 90% is often used: it is up to the user to decide when a temporary reduction of the voltage is counted as a voltage dip, but the values used should be indicated. When time aggregation is used for the calculation of site indices, the method and aggregation time used should also be indicated.

Site indices are calculated from single–event indices, i.e. the retained voltage and the duration obtained for all voltage-dip events at one site during a certain period of time. To give a value to the performance of a power system, as far as voltage sags are concerned, a five-step procedure is proposed in [11]. The basic algorithm is shown in Figure 1, where both measurements are calculations are indicated as possible sources of information. This procedure can also be used for assessing other types of voltage quality system indices.

System indices are calculated from the site indices of all monitored sites over a certain region. System indices can be presented in the same way as site indices. The required level of detail is typically lower for system indices than for site indices. System indices can be calculated from the value not exceeded by 95% of the sites being monitored for instance (under consideration). Weighting factors can be introduced to take into account the sites not monitored and the difference in importance between different sites.

Different system indices may be set for different type of networks (underground, overhead…) or voltage levels, etc.

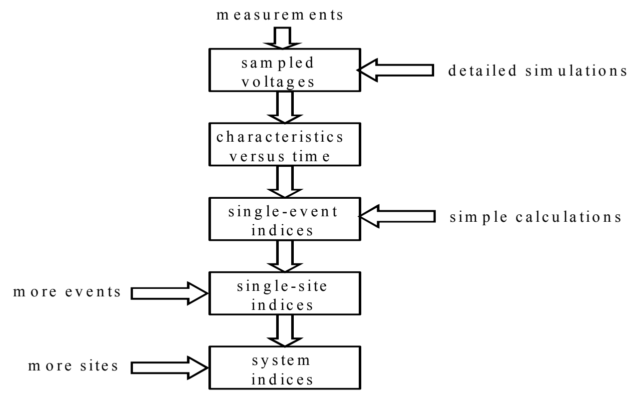

Figure 1 : The procedure for obtaining voltage sag system indices according to [11]

F. Long interruptions

The proposed philosophy of transmission system interruption performance reporting is to define the performance of the transmission system at the points it is required to supply; a transmission system interruption is thus defined as an interruption of supply by the circuits of the transmission system to a delivery point. The actual impact on customers is not considered, as this can be impacted by factors over which the transmission company has no control.

For the purpose of defining system indices, the differentiation of momentary and sustained interruptions is considered as a fixed duration of 1 minute.

Interruptions can be categorised by three parameters: their frequency (number of events), duration (or restoration time), and severity (size of load affected: for a transmission system, the size of lost load is a better measure than the number of customers affected).

The following indices are being discussed for defining Transmission system delivery point interruption performance:

- SAIFI-MI: the system average interruption frequency - momentary interruptions.
- SAIFI-SI: the system average interruption frequency - sustained interruptions.
- SAIDI: the average duration of (sustained) interruptions for all delivery points.
- SAIRI: the system average (sustained) interruption restoration time for delivery points experiencing interruptions (Note that SAIRI can be derived by dividing SAIDI by SAIFI-SI).

Severity indices based on System Minutes indices are also considered for transmissions system (sustained) interruptions. Consideration is being given to categorising System Minutes (SM) by two types of common indices :

- SM < 1: The *cumulative system minute value* as a result of single events with an individual system minute contribution of less than 1 minute. This provides an indication of the annual trend in "normal" interruption severity, and may be better than the alternative method of counting the *number of events* of degree "0".

- SM ≥ 1 (degree *n*): The *number of interruption events* with an individual severity of 1 or more system minutes. The degree of severity may be 1,2 or 3, depending on the severity of the event. This provides a description of the nature of severe events.

For distribution systems at MV, some work is being done by IEEE 1366 working group [12], so JWG C4.07 will consider and possibly propose common indices.

III. POWER QUALITY OBJECTIVES

A. General considerations

Concerning the objectives or the levels of power quality needed, the situation differs from that of indices because the level of quality is not absolute but it depends on the price clients are willing to pay for. Taking into account customers expectations and the actual supply system characteristics, regulators will have to define basic quality objectives in such a way as to reach an optimal balance between quality and price of electricity [7] [8] [9].

For system objectives for the waveform parameters, a requirement may be that a high percentage of sites (value to be agreed between the regulator and the system operator) meet the voltage characteristics in a given reporting year.

As mentioned before, the working group collected measurement data on the actual power quality for systems worldwide (in order to provide a reference basis for recommendations). Data were collected for MV, HV and EHV systems and some results are summarized below.

B. Harmonics

Relevant measurement data for harmonics consist of 2 measurement surveys for MV systems totalling 178 sites, 7 surveys for HV systems totalling 284 sites and 2 other surveys at EHV totalling 217 sites. Surveys covering less than 10 sites or lasting for less than one week were discarded. The so-called very-short 3-sec indices as proposed in [1] are generally not available, and most common index available here for comparison is $U_{hsh\ 95}$ for all-site and for 95%-site in each survey.

For MV systems, available measurement results for $U_{hsh\ 95}$ are lower than the planning levels except maybe for a few worst sites. For HV systems however, results indicate that 5th harmonic planning level is often exceeded (as shown Figure 2, for 6 out of 7 HV surveys, the 5th harmonic voltage $U_{5sh\ 95}$ range between 2,4% and 3,2%, while the planning level is 2%). Similar results were observed at EHV from the two survey results are available. For other harmonic orders, measurement results are in general lower than planning levels.

In view of these results, it is clear that to design a system against the planning level for 5th harmonic proposed in [1] will be difficult for HV systems and might involve mitigation measures. On the other hand, planning levels are indicative values that can be reviewed to match actual system characteristics.

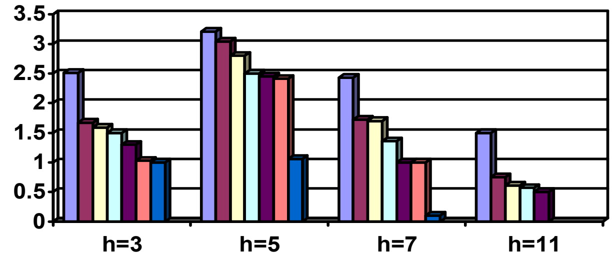

Figure 2 : Low order harmonic voltages (ordinate in %) from different surveys at HV for $U_{hSh\ 95}$ considering all sites

For voltage characteristics, it is recommended that 5th harmonic voltage for HV-EHV systems be set at least at 3% (and THD at 4%) since survey results showed this level can also be reached and sometimes exceeded in a few cases.

At MV, no change to planning levels and voltage characteristics can be recommended as the measurement data available does not show evidence of such a generalized trend that could support any recommendation for changes.

C. Flicker

Measurement data for flicker gathered so far by the working group consist of measurement surveys on MV systems from 3 different countries, from 8 countries for HV systems and surveys from 5 countries for EHV. These data often give high values of flicker severity (often higher than the severity limits defined by standards). The Figure next shows measurement results for one of the most commonly available index $P_{st\ 95\%}$ (%of sites vs. P_{st}).

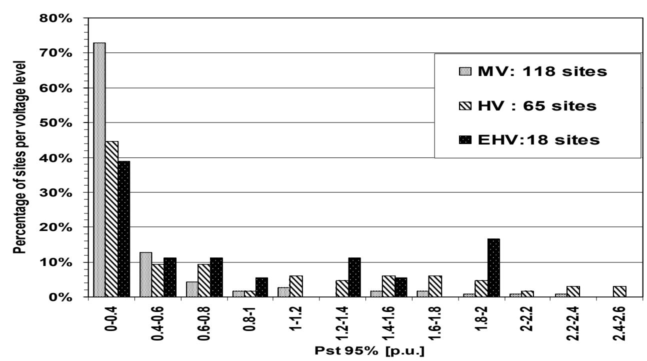

Figure 3 : Flicker measurement results for Pst 95% for MV, HV and EHV systems

The measurement results show evidence of actual difficulties in respecting the commonly-used planning levels at many of the recorded worst locations (i.e. planning levels for P_{st} are between 0,8 and 0,9, and for P_{lt}, between 0,6 to 0,7 [2]). In many countries, the actual flicker level is sometimes more than double the planning levels without known problems.

In view of high flicker levels measured at HV, the working group recommends increasing planning levels and voltage characteristics at HV-EHV by taking into account the flicker attenuation factor between EHV, HV, MV and LV. Thus, planning levels and voltage characteristics can be increased while still complying with the compatibility levels at LV where sensitive lighting equipment is connected. To enable this, the system operator has to evaluate the flicker transfer factor for the various system operating conditions for the site considered.

Furthermore, considering the technical and cost implications of meeting flicker requirements for utilities and system users, JWG C4.07 recommends that further study be undertaken. Aspects to be analyzed include :

- Time of the day or night when high flicker levels occur (eg.: weight daylight hours less severely);
- Influence of sensitivity to flicker of the new type of lighting in use [13];
- Transfer factor between different voltage levels.

D. Voltage Unbalance

The available statistical data covers 99 sites at MV, 76 sites at HV and 25 sites at EHV. Figure 4 shows the most commonly available index short-term (10 min) voltage unbalance factor (%of sites vs. 95% Unbalance Factor in %).

Results show that:

- none of the reported MV sites is over the limit of 2%;
- for HV sites, more than 11,8% of sites (9 out of 76) reach or exceed 1% voltage unbalance, while less than 4 % of sites (3 out of 76) exceed 1,5% voltage unbalance.
- at EHV, very few sites (only 2 out of 25) have voltage unbalance exceeding 1%.

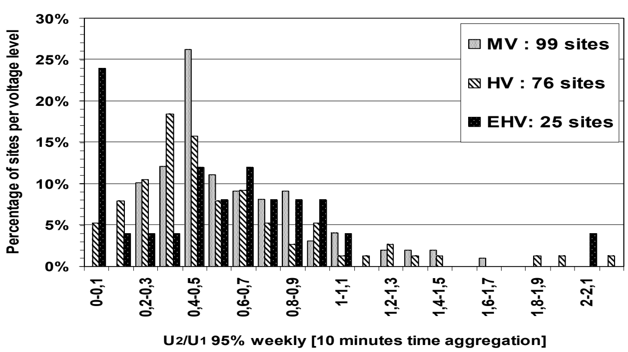

Figure 4 : Short term (10 min) voltage unbalance factor (95%) results for MV, HV and EHV systems

The above results still provide useful indications for voltage unbalance planning levels. The working group is considering different possibilities among which the following levels based on the available measurement results:

- 2% at MV;
- 1,5% at HV;
- and 1% at EHV.

At the time of preparation of this paper, different values are also being considered for voltage characteristics.

E. Dips and interruptions

Objectives for site indices cannot be given due to the very large difference between the number of voltage dips to be expected at different sites and the difficulty for the system designer or operator to control the number and severity of dips. Year-to-year comparison of the values of site indices for one site may be used to see trends in the voltage quality of this site. Comparison for different sites is not recommended with the exception as an aid in the choice of a suitable location for an installation containing sensitive equipment. Indices can only be used to identify typical levels of disturbances for different types of sites and as such a feedback for improvements towards the network operator.

Finally for interruptions, the benchmarking of transmission performance is complicated by the combination of unique influencing factors in each country (geography, environmental conditions, load density, the location of generation sources, the degree of excess capacity, network topology, system voltage levels). The dominant benchmarking approach for Transmission companies is therefore based on historical performance of the company itself. Use of the proposed indices will facilitate future benchmarking of utilities that have similar networks and operating environments.

IV. Conclusions

Activities of joint working group CIGRE C4.07/ CIRED should be completed by the end of 2003. The final report to be issued later should also send a signal to the equipment manufacturers as for the need for having power quality monitors able to measure the relevant power quality indices.

The issues being discussed within the working group are of course much wider than that can be summarized in this paper. The CIGRE report of the WG will give more details.

V. References

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French summary mandatory per CIGRE rules

Recommandation d'indices et d'objectifs de qualité dans le contexte d'ouverture des marchés de l'électricité

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au nom du groupe de travail conjoint CIGRE C4-07 /CIRED*

À la suite de l'ouverture des marchés de l'électricité dans plusieurs pays, les exploitants de réseaux électriques devront de plus en plus faire rapport de la qualité de fourniture de leurs réseaux aux usagers et aux organismes de réglementation. Dans certains pays, les organismes de réglementation peuvent même imposer des sanctions en cas de non respect des objectifs de qualité prévus.

Le groupe de travail conjoint Cigré C4.07 / Cired (auparavant Cigré GT 36.07) portant sur les indices et objectifs de qualité de l'électricité a été constitué en 2000 avec comme mandat d'élaborer des recommandations pour guider les exploitants de réseaux dans leurs discussions avec les clients et les organismes de réglementation. Quelque 27 experts en matière de qualité de l'électricité de tous les continents ont été assignés à ce groupe de travail et ont contribué activement aux discussions au cours des deux dernières années; leurs travaux doivent être complétés pour la fin de 2003. Les aspects considérés dans le GT concernent les harmoniques, les déséquilibres, le papillotement ainsi que les indices des creux de tension et des interruptions longues. Les niveaux de tension à l'étude sont la moyenne tension, la haute tension et la très haute tension.

Le but de cet article est d'informer et de susciter la discussion auprès des forums techniques regroupant des experts internationaux en la matière afin que les futures recommandations du GT puissent faire un consensus le plus large possible.

L'article passe d'abord en revue le mandat groupe de travail et les étapes accomplies jusqu'à présent. On expose ensuite les orientations quant aux recommandations éventuelles du GT concernant les indices et objectifs de qualité de l'électricité (terme englobant la qualité de tension et la continuité de service).

Plus spécifiquement, le besoin d'indices communs de qualité de l'électricité sera passé en revue afin de proposer les indices les plus appropriés parmi ceux existants. Des méthodes pour évaluer la performance des réseaux seront également abordées. De même, en ce qui concerne les objectifs de qualité existants, ils sont passés en revue à la lumière des résultats des mesures de qualité de tension recueillis par le groupe de travail au niveau international pour supporter les futures recommandations d'objectifs adéquats pour les niveaux de planification et les caractéristiques de la tension.

Concernant les harmoniques, il serait possible de hausser les valeurs indicatives du niveau de planification du $5^{ième}$ harmonique en HT-THT jusqu'à 3% selon les caractéristiques du réseau considéré. Pour le papillotement, plusieurs résultats de mesures confirment les difficultés à respecter les limites actuelles d'environ 1 p.u. (Pst ou Plt). Aussi, l'expérience en réseau HT-THT de cas de papillotement atteignant le double de ces limites ne révèle pas de problèmes connus ou généralisés. Eu égard aux répercussions financières et techniques des limites actuelles de papillotement, le GT recommande également d'entreprendre des études plus approfondies pour mieux quantifier les facteurs d'influence pour les cas de dépassements non problématiques jusqu'à deux fois les limites. Pour le déséquilibre de tension en HT-THT, les résultats des mesures disponibles fournissent des indications utiles pour de futurs niveaux de planification pour les réseaux HT et THT.

Enfin, ajoutons que le rapport final du groupe de travail devra envoyer un signal aux fabricants d'équipement quant au besoin d'avoir des moniteurs de qualité de l'électricité capables mesurer les indices appropriés, et de faciliter la gestion des données et le processus de rendre compte de la qualité d'électricité fournie par les réseaux.

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