A European Benchmarking of Voltage Quality Regulation

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***Abstract*—The Council of European Energy Regulators has been publishing Benchmarking Reports on the Quality of Electricity Supply since 2001. For the 2011 edition of the Benchmarking Report the 29 member countries of CEER were joined by the 9 NRA's from the Energy Community and the NRA from Switzerland. This paper contains the main results, findings and recommendations on voltage quality from the 2011 edition.**

***Index Terms*—Power quality, Electricity supply industry deregulation, Europe, Voltage dips, Power system harmonics**

I. Abbreviations

BR, Benchmarking Report (on Quality of Electricity Supply)
CEER, Council of European Energy Regulators
CENELEC, European Committee for Electrotechnical Standardization
CP, Contracting Parties (of the Energy Community)
ECRB, Energy Community Regulatory Board
EHV, Extra High Voltage, over 150 kV
HV, High Voltage, above 36 kV –to 150 kV included
LV, Low Voltage, up to 1 kV
MV, Medium Voltage, above 1 kV to 36 kV included
NRA, National Regulatory Authority
VQM, voltage quality monitoring

II. Introduction

THE Council of European Energy Regulators (CEER) [1] periodically surveys and analyses the quality of electricity supply in its member countries (27 member states of the European Union, Iceland and Norway), addressing three major aspects: the availability of electricity (continuity of supply), its technical properties (voltage quality) and the speed and accuracy with which customer requests are handled (commercial quality).

These surveys and analyses take the form of CEER Benchmarking Reports on Quality of Electricity Supply. The first report was issued in 2001 [2], followed by the second, third and fourth editions in 2003, 2005 and 2008 respectively [3] [4] [5]. Similarly, information on the national regulations and its effects in the Energy Community Contracting Parties (CPs) were gathered by the Energy Community Regulatory Board (ECRB) in the 2009 ECRB Report on the Quality of Electricity Service Standards and Incentives in Quality Regulation [6].

In addition to National Regulatory Authorities (NRAs) from CEER member countries, the 9 NRAs from the Energy Community [7] and the National Regulatory Authority of Switzerland joined the benchmarking practice for the 2011 edition [8].

A detailed survey was sent out in March 2011 to the CEER member countries and the Energy Community CPs to obtain information on all three aspects of quality of supply. The survey contained detailed questions about existing and planned regulations on quality of supply, monitoring practices as well as questions on existing quality levels.

In this paper we present the main results from the 2011 edition as well as the recommendations from CEER and ECRB on voltage quality.

III. Legislation, Regulation and Standardization

A. *EN 50160 as a basis for regulation*

The European voltage-characteristics standard, EN 50160, remains the basic instrument for voltage quality regulation in Europe. This document sets limits for a number of voltage disturbances: power frequency; supply voltage variations; flicker; unbalance; harmonic voltage; and mains signalling voltages.

To improve the standard and to increase its usefulness as a harmonized regulatory framework, a cooperation between CEER and CENELEC was started in 2006. This led to the publication of a new version of the standard EN 50160:2010 with the following improvements compared to the earlier edition:

- ✓ an improved structure dividing continuous phenomena and voltage events;
- ✓ improved definitions for voltage dips and swells;
- ✓ standardized classification tables for voltage dips and swells;
- ✓ the applicability of the standard up to and including 150 kV;

The text of this paper is based on the text in the 5th Benchmarking Report on Quality of Electricity Supply (BR). Where the text of this paper deviates from the text of the BR, it is the personal opinion of the authors and not necessarily the opinion of CEER, of ECRB, neither of the national regulatory authorities the authors work for.

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- ✓ the removal of a note allowing supply voltage variations outside any limits when customers are connected "in remote areas with long lines or not connected to a large interconnected network";
- ✓ improved limits for supply voltage variations in the medium voltage network;
- ✓ the removal of ambiguous indicative levels for voltage events (e.g. "thousands of voltage dips") from the normative part of the standard.

The survey in the Energy Community has shown that CPs are undertaking activities towards implementation of EN 50160 as the main instrument for voltage quality regulation. EN 50160 has been introduced in the majority of CPs, mainly as a voluntary standard or through national legislation and regulation, either through a reference to EN 50160 or by adopting the limits given in EN 50160. However, voltage quality regulation is still primarily applied only on LV and MV level and only for supply voltage variations. FYR Macedonia is the only CP where the new version of the standard EN 50160:2010 has been adopted.

B. Regulation beyond EN 50160

The CEER survey reveals that EN 50160 is for regulation used in many countries. However, a growing number of countries are introducing national requirements on voltage quality that deviate from EN 50160.

In the Energy Community, all the CPs have reported national voltage quality requirements that differ from EN 50160. Different requirements are implemented for different reasons, for example historical, different network characteristics, or introducing new stricter limits. In Moldova and Ukraine, voltage quality limits for different voltage characteristics are defined by an interstate standard on voltage quality approved by the Interstate Council of Standardization, Metrology and Certification. National requirements in the Energy Community CPs as well as in the CEER member countries are stricter than those set by EN 50160.

An overview of the status in CEER countries is given in Table I through Table V for different voltage disturbances. For a complete and more detailed overview, the reader is referred to the 2011 Benchmarking Report.

Table I show that for supply voltage variations, most countries use a 10-minute integration period to calculate the r.m.s. voltage. The exceptions are Hungary and Norway, where a 1-minute period is used. Some countries use 95% limits, as in EN 50160, but a smaller permissible range of voltage variations, for example Hungary and Spain. Other countries allow a 10% deviation from the nominal voltage, as in EN 50160, but during 99.9 or 100% of the time, for example, The Netherlands (99.9% for HV) and Sweden. Some countries apply two-stage limits, either a larger range for 1 minute than for 10 minute r.m.s. values (Hungary) or a large range for 100% than for 95% of time (The Netherlands).

Besides the limits shown in Table I, different time and limits are applied in Italy for HV networks in normal, alarm, emergency and restoration conditions as well as temporary islanding operation of normally interconnected MV networks.

TABLE I
VOLTAGE QUALITY REGULATION DIFFERENT FROM EN 50160 – SUPPLY VOLTAGE VARIATIONS

Period	Time	Limit	Country (voltage level)
10 min	95%	±7.50% of U_n	HU(LV)
10 min	100%	±10% of U_n	HU(LV),SE(HV,MV,LV)
1 min	100%	+15% / -20% of U_n	HU(LV)
10 min	95%	±5% of U_n	PT(HV)
10 min	95%	±7% of U_n	ES(MV,LV)
1 min	100%	±10% of U_n	NO(LV)
10 min	95%	±10% of U_n	NL(MV)
10 min	100%	+10% / -15% of U_n	NL(MV)
10 min	99.9%	±10% of U_n	NL(HV)
10 min	95%	+6% / -10% of 230 V	IT(LV)

Table II shows that for flicker both P_{st} and P_{lt} are used, whereas EN 50160 only sets limits for P_{lt}. Either 95% or 100% limits are in use. Most interesting is the wide range in limits, from 0.35 to 5. This range in limits is much larger than for other voltage disturbances.

TABLE II
VOLTAGE QUALITY REGULATION DIFFERENT FROM EN 50160 – FLICKER

Indicator	Time	Limit	Country (voltage level)
P_{st}	95%	≤ 0.35	CY(HV, MV, LV)
P_{lt}	95%	≤ 0.35	CY(HV, MV, LV)
P_{st}	95%	≤ 0.8	CZ(HV, MV, LV)
P_{lt}	95%	≤ 0.6	CZ(HV, MV, LV)
P_{st}	100%	≤0.85 (planning level)	IT(HV)
P_{lt}	100%	≤ 0.62 (planning level)	IT (HV)
P_{st}	95%	≤ 1.2	NO(MV, LV)
P_{st}	95%	≤ 1	NO(HV)
P_{lt}	100%	≤ 1	NO(MV, LV),PT(HV)
P_{lt}	100%	≤ 0.8	NO(HV)
P_{st}	100%	≤ 1	PT(HV)
P_{lt}	100%	≤ 5	NL(HV,MV,LV)

As shown in Table III all countries use a 10-minute integration period for unbalance. Norway, Sweden and The Netherlands use 100% limits; 95% limits but with a smaller permissible level are used by Italy. At HV, The Netherlands has again introduced a 99.9% limit.

Table IV gives the limits for harmonics: for THD and/or for individual harmonics. In most cases a 10-minute integration period is used; Norway has an additional limit for a 1-week integration period.

TABLE III
VOLTAGE QUALITY REGULATION DIFFERENT FROM EN 50160 – UNBALANCE

Indicator	Period	Time	Limit	Country (voltage level)
V_{un}	10 min	95%	≤ 1%	IT(HV)
V_{un}	10 min	100%	≤ 2%	NO(HV,MV,LV), SE(HV,MV,LV)
V_{un}	10 min	100%	≤ 3%	NL(MV,LV)
V_{un}	10 min	99.9%	≤ 1%	NL(HV)

TABLE IV
VOLTAGE QUALITY REGULATION DIFFERENT FROM EN 50160 – HARMONICS

Indicator	Period	Time	Limit	Country (voltage level)
THD	10 min	100%	≤ 3%	IT(HV)
THD	10 min	100%	≤ 8% 0,23 ≤ U ≤ 35 kV ≤ 3% 35 < U ≤ 245 kV	NO (HV,MV,LV)
THD	1 week	100%	≤ 5%	NO(MV,LV)
Individual	10 min	95%	Table	PT(HV)
Individual	10 min	100%	Table	NO (HV,MV,LV)
Individual	10 min	100%	Table (as in EN 50160)	SE (HV,MV,LV)
THD	10 min	95%	≤ 8% U < 35 kV ≤ 6% 35 ≤ U < 150kV	NL (HV,MV,LV)
Individual	10 min	99.9%	Table U < 35 kV	
THD	10 min	99.9%	≤ 12% U < 35 kV ≤ 7% 35 ≤ U < 150kV	

For voltage events, no limits are given in EN 50160, and also at national level, almost no such limits are in place. The only exceptions are shown in Table V: limits for voltage dips and voltage swells in Sweden; limits for single rapid voltage changes in Norway, Sweden and The Czech Republic.

TABLE V
VOLTAGE QUALITY REGULATION DIFFERENT FROM EN 50160 – EVENTS

Voltage disturbances	Indicator	Limit	Country (voltage level)
Voltage dips	The dip-table is divided in the three areas A, B and C (see Fig. 1 and Fig. 2)		SE(HV,MV,LV)
Voltage swells	The swell-table is divided in the three areas A, B and C		SE(HV,MV,LV)
Single rapid voltage change	Number of voltage changes per 24 hours	$\Delta U_{steady\ state} \geq 3$ %: ≤ 24 0,23 ≤ U ≤ 35 kV ≤ 12 35 kV < U $\Delta U_{max} \geq$ 5%: ≤ 24 0,23 ≤ U ≤ 35 kV ≤ 12 35 kV < U	NO(HV,MV,LV) SE(HV,MV,LV)
	Number of voltage changes per hour	< 1 $\Delta U_{max} = 3$ [1–10] $\Delta U_{max} = 2.5$ [10–100] $\Delta U_{max} = 1.5$ [100–1000] $\Delta U_{max} = 1$	CZ(HV)

The regulation for voltage dips (and swells) in Sweden [10] is based on the "responsibility-sharing curve" (Fig. 1 and Fig. 2). The regulation states that there shall not be any voltage dips in Area C and that the network operator has the responsibility to mitigate voltage dips in Area B to the extent that the mitigation measures are reasonable in relation to the inconvenience for electricity users that are related to the voltage dips. Dips in Area A are counted as single rapid voltage changes: the total number of events (dips in area A plus rapid voltage changes) should be below the limits for rapid voltage changes. Note that, beyond Area C, there are no specific numerical limits on the number of voltage dips. It has to be determined, for every individual case, whether the number of dips is acceptable or not. However, the regulation gives the following general recommendation: "When assessing what mitigation measures are reasonable in relation to the inconveniences, for example historical data, other similar networks under similar circumstances, technical possibilities, and costs for mitigation might be considered".

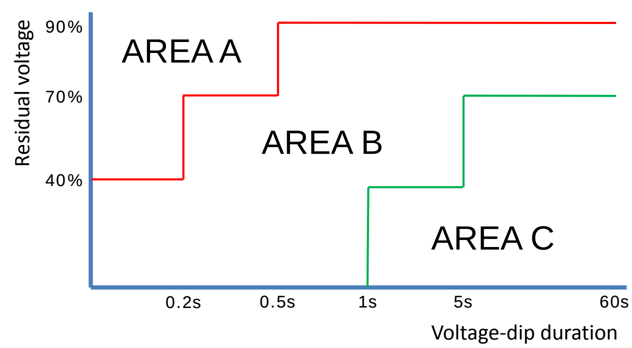

Fig. 1. Voltage dip regulation in Sweden, up to and including 45 kV.

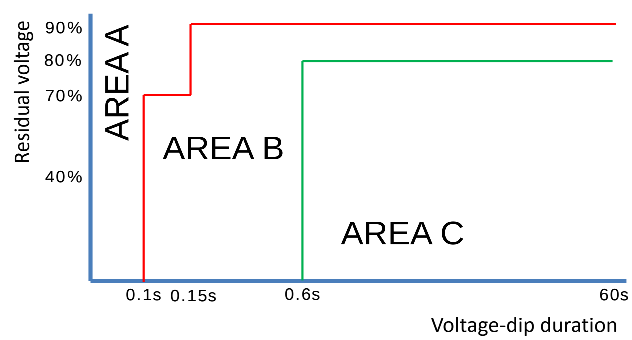

Fig. 2. Voltage dip regulation in Sweden, above 45 kV.

C. Further improvements needed in EN 50160

CEER retain the view that the standard EN 50160 can be satisfactory from a regulatory point of view, only if certain further improvements are made. CEER considers the following improvements necessary:

- ✓ an effective extension to the high voltage networks (with effective limits and requirements) and the consideration of extra high voltage networks;
- ✓ the adoption of new limits for supply voltage variations in distribution networks (especially in low voltage networks);

- ✓ the introduction of limits for voltage events, taking into account the different characteristics of the European networks; for voltage dips and voltage swells one or more responsibility-sharing curves should be defined;
- ✓ a general framework for sharing the voltage quality responsibilities between network companies, equipment manufacturers and users.

Further, the need for a proper regulation of voltage quality will increase in the future, especially against the background of the expected large implementation of distributed generation.

CEER believes that harmonized voltage quality requirements are necessary. Unless the above-mentioned improvements are implemented as soon as possible, the standard EN 50160 will miss its objective to harmonize the voltage quality standards and performances across the European electricity networks, due to the fact that national deviations will increase further. Further strengthening of the voltage quality regulation in the individual member countries, followed by attempts to harmonize the differing regulations, would be the only alternative.

Taking into account that in some of the Energy Community CPs EN 50160 still has not been implemented, while in the other CPs EN 50160 is implemented mainly on the limited scope of MV and LV voltage levels and voltage variations, further efforts should be put into extension of EN 50160 to higher voltage levels as well as to other voltage disturbances. Considering that the EN 50160 introduction process is in an early stage in the Energy Community, joint activities on the implementation and harmonization in line with the CEER views are recommended in the Energy Community.

D. Voltage quality verification issues

The network users in the majority of the European countries, including Energy Community CPs, are entitled to get a verification of actual voltage quality levels at their point of connection. Even in several countries where this is not compulsory, the network operators offer such verification. Still, this good practice is not adopted in all countries. Only one country (Slovenia) reported a predefined charge for voltage quality verification measurements. In some countries, the customer pays only if the measurements are found to be within the limits.

Further, the CEER survey reveals that increasing attention is given to providing individual users with information on voltage quality at their point of connection (or close to it). This includes information for users to be connected. The obligation for system operators to provide individual information on and verification of voltage quality upon a user's request should be adopted by all countries. This obligation should be accompanied by a detailed description of the procedure by the network operator so that all relevant information is available to the customer, including the cost of the service (if any).

Special emphasis should be given in the Energy Community to the introduction of legal obligations for system operators to provide individual information on voltage quality to users. Such legal obligations have been defined only in Bosnia and Herzegovina.

With respect to individual voltage quality issues, customer compensation, penalties or other sanctions are applied in the majority of the reporting CEER member countries. Three categories are identified here:

a) Customer compensation by the network operator according to the conditions of a contract between the customer and the network operator,
b) Customer compensation by the network operator in case of a violation of the overall voltage quality limits or in case of a late response to a measurement request by a customer, and
c) Monetary penalties applied to the network operator in case of voltage quality problem mishandling (late response, problem not resolved, mitigation measures ordered by the NRA are not taken, etc).

In the majority of the Energy Community CPs, monetary penalties, customer compensation or other types of sanctions are not envisaged in the legislation or regulation and consequently not applied in case of violation of voltage quality limits. Only in Ukraine, the customer has the right to compensation in the case that the system operator does not provide voltage quality in line with standards. However, in some of the CPs, monetary penalties are defined for the network operator in the case that a voltage quality problem is not resolved in line with the mitigation measures and deadlines requested by the authorized body, which is usually the State Inspectorate.

CEER recommends that the NRA or the network operator keeps statistics on complaints and verification results and correlates these with the results from continuous voltage quality monitoring (if in place). NRAs should use such statistics for regulatory decisions regarding voltage quality, while system operators should use it for identifying areas that need improvements or further investigation.

E. Emission requirements

A number of CEER member countries and Energy Community CPs have regulated the emission requirements from individual network users. All, except two, use voltage limits or planning levels that should not be exceeded after connection. This could make it difficult or impossible to connect when the existing voltage distortion level before connection is already high. In most cases reference is made to the indicative planning levels in IEC 61000-3-6, 3-7 and 3-12. In France and Serbia current limits are set, but these are also dependent on the short-circuit level. Connection could become expensive for customers at locations with a low short-circuit level.

In a number of CEER member countries penalties are foreseen for customers in case of violation of the maximum-permissible level of disturbance. In the Energy Community CPs, penalties for customers in the case of violation of emission limits, other than disconnection, are not envisaged.

Different methods exist for maintaining a sufficient level of voltage quality, including strengthening the grid by the network operator or installing preventative measures by the connected customers. Limits on emission from individual customers are necessary to maintain the voltage disturbance levels below the voltage quality requirements without excessive costs for other customers. The limits on emission should be reasonable for both the network operator and the customers causing the emission. Unreasonable requirements should not result from for example low short-circuit levels. Whereas a margin between the planning levels and the voltage quality requirements is deemed good engineering practice, this margin should not be excessive.

In the Energy Community CPs where voltage quality requirements for network operators still have not been implemented, introduction of emission limits for individual network users into legislation or regulation should go hand in hand with the legal establishment of voltage quality standards that network operators have to comply with.

The roles of the different stakeholders are described in detail in the 2011 Benchmarking Report. It is important to emphasize that all the relevant aspects of emission limits should be subject to regulatory scrutiny. An adequate level of transparency must be ensured throughout.

F. Impact on network users – Cost estimation studies

The impact of voltage quality disturbances on the network users were investigated by CEER in 2010. CEER set out guidelines in the domain of nationwide studies on estimation of costs due to voltage quality disturbances [12].

The results from cost-estimation studies on customer costs due to various voltage quality disturbances are important input when deciding where to focus regulation. Therefore, CEER recommends that NRAs should perform national cost-estimation studies regarding voltage disturbances.

IV. Voltage Quality Monitoring

A. VQM systems in operation

Voltage quality monitoring systems in operation were reported by 14 CEER member countries; Table VI gives an overview of these. The total number of instruments in Norway is not declared in detail, but given the large number of network operators in Norway (157 DSOs + 1 TSO), the measurement scheme results in several hundreds of instruments.

In the Energy Community, a voltage quality monitoring system has been implemented only in Bosnia and Herzegovina, on a voluntarily basis for the purpose of statistics and research. Additionally, detailed procedures and obligations for the establishment of a voltage quality monitoring system have not been defined in legal and regulatory frameworks in the majority of the CPs. Only in FYR Macedonia legislation defines detailed procedures and obligations for implementation of a voltage quality monitoring system.

The number of monitoring locations varies significantly between countries: Cyprus reports only 16 locations versus almost 300 000 reported by France.

Table VI
Voltage quality monitoring systems in operation – Number of measurement units at different voltage levels

Country	Monitoring since	Number of measuring units installed			
		EHV / HV	MV	LV	Total
Austria	April 2011		299		299
Bulgaria	June 2010	495	1 372		1 867
Cyprus	Distribution: 2000 Transmission: 2010		+	+	16
Czech Republic	2006	160	694	14 525	15 379
France	EHV and HV: 1998 MV: not available LV: March 2010	208	45 000	250 000	295 208
Greece	March 2008			500	500
Hungary	2004		157	585	742
Italy	2006	165	600	(by meters)	765
Latvia	1999		Yes	20	20
the Netherlands	EHV and HV: 2004 For all DSOs: 1996	28	60*	60*	28
Norway	2006	°	°	°	°
Portugal		53	101	166	320
Romania	2008	22	130#		152
Slovenia	2004	183	183		366

Continuous monitoring is ongoing in more than half of the responding countries. This can be either under direct control of the regulator (where the regulator owns the monitors, the data collection system and the data) or compulsory but performed by the network operator. In some countries the data is published, in other countries not.

In most countries the network operator pays for the monitoring scheme and recovers these costs via the network tariffs for all customers. In some countries individual customers may request the continuous monitoring of the voltage quality at their connection point at extra cost.

Another positive development is the increasing number of monitoring instruments in LV and MV networks, at the supply terminals or close to it. Half of the respondent countries with ongoing monitoring (14) are monitoring all voltage levels.

CEER recommends countries to encourage network operators to continuously monitor voltage quality in their transmission and distribution networks. Monitoring should take place at such locations that a good estimation can be made of the voltage quality as experienced by the customers. It is further acknowledged that the data from continuous voltage quality monitoring can provide useful information for the network operator resulting in significant cost savings and information to support investment decisions.

The principle aims of compulsory or regulator-controlled monitoring should be: to verify compliance with voltage quality requirements (both overall and for individual customers); to provide information to customers on their actual or expected voltage quality; and to obtain information for the setting of appropriate future requirements. This should be considered when deciding about the need for voltage quality monitoring.

B. Smart Meters

There is growing attention to the evaluation of voltage quality and its deviations through smart meters. 10 countries reported developments in this field: smart meters have the technical possibility to measure some voltage quality parameters (supply voltage variations in many cases, voltage dips and swells and harmonics in some cases). The introduction of smart meters with voltage quality monitoring capabilities could make it easier for customers to get access to the desired information on voltage quality.

With regard to the use of smart meters for voltage quality monitoring, it is important to know whether the measurements are performed in accordance with international standards and/or good engineering practice or can only provide initial information about voltage deviations prior to further measurements.

It is important to exploit the capabilities of available and installed smart meters to the extent and benefits possible but also to ensure that voltage quality monitoring through smart meters does not result in an excessive increase in price of the meters or tariffs for the network users. CEER do not deem necessary the monitoring of all voltage quality parameters through smart meters for all LV users.

C. Measured parameters

Although voltage quality monitoring is taking place in several countries, the measured voltage quality parameters vary strongly from country to country. Voltage dips are continuously monitored in almost all countries; this confirms that voltage dips are seen as an important issue. Supply voltage variations, flicker, voltage swells, voltage unbalance and harmonic voltage are continuously monitored in most countries. Transient overvoltages, single rapid voltage changes and mains signalling voltage are monitored in a small number of countries. There remains a lack of standardized measurement methods for rapid voltage changes, transient overvoltages, and mains signalling voltages.

For voltage dips some early trends towards harmonization were triggered by the latest edition of the standard EN 50160, with a new table for the classification of voltage dips and swells [9]. However, the remaining differences in measurement methods make a direct comparison of the results still not possible. Even though EN 50160 as well as international expert groups recommend to measure phase-to-phase voltages at MV, HV and EHV, this is not common practice. A systematic overview of measurement methods and voltage-dip indices is presented in the 2011 Benchmarking Report.

For many countries in which voltage quality is being monitored, at least some of the obtained data is publicly available. In addition, most regulators have access to at least aggregated data, if not to data for individual measuring points in the networks. In several countries, individual voltage quality data is also made available to customers. In most cases, the network operators are responsible for the publication of voltage quality data.

When reporting the results from voltage-dip monitoring, it is important to accurately define how characteristics (like residual voltage) and indices (like the number of severe dips per year) are calculated. The voltage-dip tables recommended in EN 50160 should be used to present the results from voltage dip monitoring.

When presenting and interpreting voltage dip indices, care should be taken to not mix short shallow dips with long deep dips, as both their impact on equipment and mitigation measures required are significantly different. A distinction between major and minor dips, see section V, in combination with the voltage dip tables recommended in EN 50160, is a possible approach.

System indices should not only include the average number of dips per site per year, but also values not exceeded at a certain percentage of sites. These so-called percentiles give a better impression of the actual voltage quality as experienced by individual customers than the average number of dips only.

D. Publication of monitoring results

CEER recommends countries that monitor voltage quality in their transmission and distribution networks to publish results regularly. It is also strongly suggested to store as much (raw) data as feasible for several years where feasible in an easily-accessible format to allow future queries that cannot be foreseen yet.

With increasing numbers of monitors, the amount of available voltage quality data also increases quickly. However, resources available to network operators and/or regulators to analyze all of this data are limited. It is suggested that the data from voltage quality monitoring are made available, as far as appropriate, for research and educational purposes, including - among others - a better understanding of the changes in voltage quality parameters related to the introduction of new types of generation and consumption. A mechanism should be in place to prevent the data from being used against the network operators, for example by not identifying the exact measurement location. Results of such research must be made publicly available without undue delay.

V. VOLTAGE QUALITY DATA

A. Number of major dips

Actual levels of voltage dips are reported in the 2011 Benchmarking Report for 6 countries: France, Hungary, Italy, The Netherlands, Portugal and Slovenia. To enable a direct comparison between the data from different countries, an "indicative responsibility-sharing curve" has been introduced to distinguish between major dips (dips below the curve) and minor dips (dips above the curve).

The indicative responsibility curve shown in Fig. 3 is close to equipment immunity Class C as proposed by CIGRE/CIRED/UIE joint working group C4.110 [11], a recent proposal by the Italian regulator for the classification of voltage dips, and one of the curves used in the new Swedish regulation on voltage dips (Fig. 1). The difference is that, according to the curve in Fig. 3, the 80% border is extended all the way up to 1 minute. Table VII shows the average number of major dips per location per year for those countries that provided data on voltage dips.

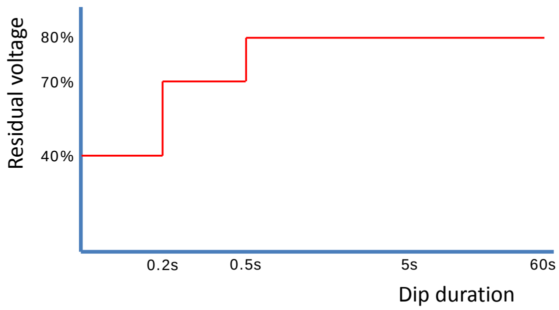

Fig. 3. Indicative responsibility-sharing curve for voltage dips.

TABLE VII
NUMBER OF MAJOR DIPS IN DIFFERENT COUNTRIES (PER MONITOR-YEAR)

Country	2008	2009	2010
France (transmission)	2.1	2.5	1.7
Hungary (LV)		25.2	
Hungary (MV)		13.3	
Italy (MV)	26.6	18.8	15.9
Italy (HV)			3.3
The Netherlands (HV)	1.0	2.0	2.3
Portugal (HV)	18.7	15.3	

The number of major dips presented in the table has been obtained by summing the dips below the responsibility sharing curve and applying a normalization factor consisting of the number of locations at which voltage dip measurements are being performed and the monitor duration at each measurement location. Table VII therefore shows the average number of major dips per measurement location per year. The comparability of the numbers is thus only limited by the voltage level in which the measurements were performed and by the differences in network structure. Both of these factors have an impact on the expected number of voltage dips. It should also be noted that the table shows the average number of dips over all measurement locations. The spread between individual locations is much larger [11].

The table shows large differences in the number of major dips in the networks in the different reporting countries. However, the number of countries and the number of years are too small to draw any further conclusions.

B. Variation between sites

Both France and Italy provided information on the average number of voltage dips as well as on the 95-percentile over all measurement locations. The results from France are shown in Table VIII and Table IX according to the table recommended in EN 50160. On average a location in the French transmission network experienced 1.68 major dips during 2010; the number of dips at the 95% site was 7.6 during 2010. Thus, 5% of the locations experienced more than 7.6 dips during 2010 (or, 4.5 times more than the average).

TABLE VIII
THE AVERAGE NUMBER OF VOLTAGE DIPS PER YEAR IN THE TRANSMISSION NETWORKS IN FRANCE IN 2010 (PER MONITOR-YEAR)

Residual voltage u [%]	Duration t [ms]				
	$t \leq 0.2$	$0.2 < t \leq 0.5$	$0.5 < t \leq 1$	$1 < t \leq 5$	$5 < t \leq 60$
$90 > u \geq 80$	24.00	1.60	0.73	0.11	
$80 > u \geq 70$	5.40	0.38	0.23	0.05	
$70 > u \geq 40$	3.30	0.33	0.27	0.15	
$40 > u \geq 5$	0.42	0.15	0.07	0.01	
$5 > u$					

TABLE IX
THE 95TH PERCENTILE OF VOLTAGE DIPS PER YEAR IN THE TRANSMISSION NETWORKS IN FRANCE IN 2010 (PER MONITOR-YEAR)

Residual voltage u [%]	Duration t [ms]				
	$t \leq 0.2$	$0.2 < t \leq 0.5$	$0.5 < t \leq 1$	$1 < t \leq 5$	$5 < t \leq 60$
$90 > u \geq 80$	65	9.3	3	1	
$80 > u \geq 70$	17	1.3	1	0	
$70 > u \geq 40$	15	1	1.3	1	
$40 > u \geq 5$	2	1	0.3	0	
$5 > u$					

The results for MV locations in Italy are shown in Fig. 4 and Fig. 5, using the contour chart recommended by IEEE std. 493, IEEE std. 1346 and JWG C4.110 [11]. The figures can be compared by, for example, comparing the location of the 5-dips-per-year contour.

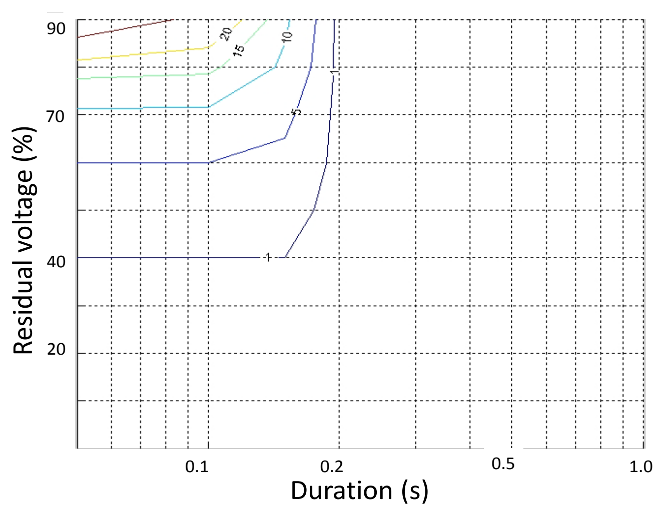

Fig. 4. Distribution of voltage dips at MV in Italy 50%-sites year 2010

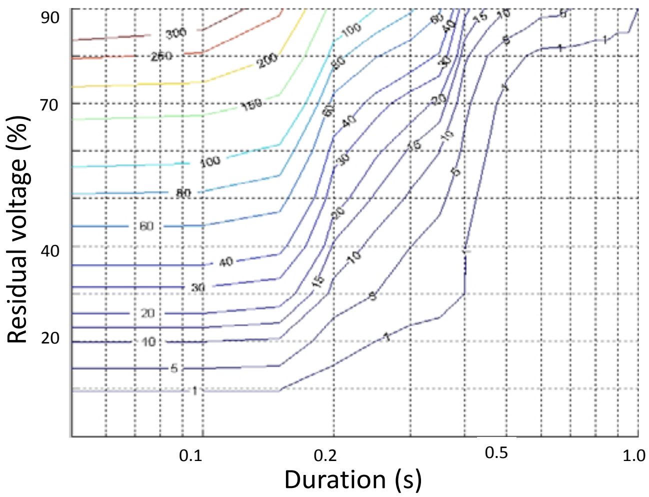

Fig. 5. Distribution of voltage dips at MV in Italy 95%-sites year 2010

VI. Conclusions

A number of findings and recommendation were obtained from the survey results, the analysis of the survey results, and the subsequent discussions within CEER and the Energy Community. Strongly summarized formulations of those findings and recommendations are listed below. For specific details and exact formulations, the reader is referred to the original document [8].

- ✓ Finding #1: Voltage characteristics are regulated through EN 50160 in combination with stricter national requirements in most of the countries.
- ✓ Recommendation #1: Implement voltage quality requirements for all voltage levels and all phenomena, particularly for voltage events. Further improve EN 50160 as a harmonized instrument for voltage quality regulation. Use the results from cost-estimation studies of voltage disturbances when deciding where to focus regulation.
- ✓ Finding #2: Verification of and information on the actual voltage quality levels at individual connection points is guaranteed in most of the responding countries.
- ✓ Recommendation #2: Ensure individual voltage quality verification and information.
- ✓ Finding #3: Regulation of emission levels of network users varies across countries.
- ✓ Recommendation #3: Set reasonable emission limits for network users.
- ✓ Finding #4: Many countries have continuous voltage quality monitoring systems.
- ✓ Recommendation #4: Introduce a voltage quality monitoring obligation into national legislation and regulation. Broaden the scope of continuous voltage quality monitoring programs. Exploit the possibilities offered by smart meters without excessive price increase for customers.
- ✓ Finding #5: Differences exist between countries in the choices of monitored voltage quality parameters and in the reported voltage dip data.
- ✓ Recommendation #5: Define harmonized characteristics and indices for voltage dips.
- ✓ Finding #6: Voltage quality data is publicly available in some European countries.
- ✓ Recommendation #6: Ensure availability and regular publication of voltage quality data.

The Benchmarking Reports have demonstrated the importance of a continued exchange of information on quality indicators, actual quality levels, standards, regulatory mechanisms and strategies. Their publication has facilitated obtaining information about the regulation of voltage quality and about the effects of this regulation in European countries. Good practices for monitoring and regulating voltage quality in electrical networks are described in the 2011 Benchmarking Report and summarized in this paper. The findings and recommendations from the 2011 Benchmarking Report will form a basis for further development of voltage quality regulation and monitoring. It is important that NRAs continue exchanging best practices for regulating electrical network industries, as done in the benchmarking reports.

VII. Acknowledgement

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