Quality of Supply Standards: Is EN 50160 the answer?

Abstract

From a regulatory perspective, the European Union has been a leader in developing and implementing quality of supply standards through its implementation of European Norm 50160. Some countries have used EN 50160 as the basis for their national quality of supply regulations. But the standard's statistical models allow eight hours per week of unregulated power quality, and utilities compliance (or non-compliance) is assessed regardless of the severity of any events.

This paper will outline the state of EN 50160 today: its benefits and possible areas of improvement, including those suggested by the European utility regulators themselves. The standard will be compared to national quality of supply standards from countries around the world to identify best practices and contrast the differences. In conclusion, a framework for quality of supply regulation will be proposed that will ensure that compliant utilities are providing a level of service that meets their customers' expectations.

I. Review of EN 50160

History:

The history of EN 50160 dates back to 1989 and the European Union directive 89/336 for Electromagnetic Compatibility. Intended to ensure the reliability of distribution networks (and proper operation of equipment connected to them), the so-called EMC Directive led to a 1989 definition of the physical characteristics of the low and medium voltage distribution systems by the organization UNIPEDE, and finally in 1994 a standard on "Voltage characteristics of electricity supplied by public distribution systems". This standard was developed by a working group under CENELEC (European Committee for Electrotechnical Standardization) and was given the designation European Norm 50160, or EN 50160 [1].

Scope:

The original mandate for EN 50160 was limited to low and medium voltage distribution systems and specifically the following characteristics of the supply voltage: frequency, magnitude, waveform and symmetry of the three-phase voltages. Low voltage is defined with an upper limit of 1 kV RMS and medium voltage with an RMS value between 1kV and 35 kV. In the original scope, higher voltages were not considered.

Supporting the requirement to define voltage characteristics in terms of frequency, magnitude, waveform and symmetry, EN 50160 provided definitions and in some cases measurement methods and compliance levels for 10 characteristics of the supply voltage:

- Power frequency
- Supply voltage variations
- Rapid voltage changes (and Flicker)
- Supply voltage dips
- Short interruptions
- Long interruptions
- Temporary overvoltages
- Supply voltage unbalance
- Harmonic voltage
- Mains signaling voltage

Supply voltage characteristic	Statistical Evaluation	Compliance limit
Power frequency	95% of the time in 1 week 100% of the time in 1 week	50 Hz ± 1% 50 Hz + 4% to -6%
Supply voltage variations	95% of the time in 1 week	Uc ± 10%
Rapid voltage changes (and Flicker)	95% of the time in 1 week	Plt ≤ 1
Supply voltage dips	1 year	None given[1]
Short interruptions	1 year	None given[2]
Long interruptions	1 year	None given[3]
Temporary overvoltages	1 year	None given
Supply voltage unbalance	95% of the time in 1 week	<2%
Harmonic voltage	95% of the time in 1 week 95% of the time in 1 week	See Figure 1 THD <8%
Mains signaling voltage	99% of the time in 1 day	9% @ 100 Hz 1% @ 100 kHz

Table 1: EN 50160 Compliance Limits

1. Indicative value of 1000 dips/year provided
2. Indicative value of "several hundreds" of short interruptions/year provided
3. Indicative value of 50 long interruptions/year provided

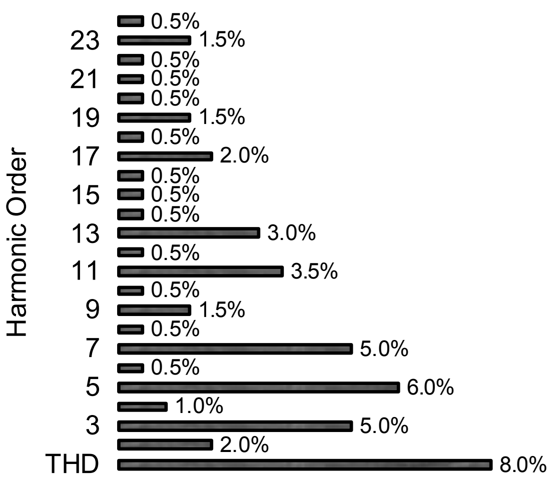

Figure 1: Harmonic limits in EN 50160

Issues with EN 50160

The primary issues preventing EN 50160 from being a comprehensive power quality standard can be broken down into five main points:

1. As a consensus-driven standard, with equal representation from all countries, it reflects the lowest common agreed-upon value for PQ limits.

2. Many of the most costly and most common PQ phenomena (dips, swells and interruptions) do not have compliance limits but only indicative values. In his paper "End use perceptions of Power Quality – A European Perspective" [2] Roman Targosz estimated the cost of dips and short interruptions within the EU at 86.5 Billion euro out of a 150 Billion euro estimated total cost of power quality.

3. The scope is limited to medium voltage (35kV) networks and below.

4. Measurement methods for each characteristic are not defined. By allowing utilities to evaluate compliance with undefined measurement methods, it will be impossible to compare results or apply fair noncompliance penalties.

5. Many characteristics are evaluated for less than 100% of the measurement interval. This allows:

- No limit on supply voltage variations, flicker, voltage unbalance, individual harmonics or THD for 8.4 hours/week
- No limit on mains signaling for 1.7 hours/week

II. Alternative National Quality of Supply Standards

To provide the most accurate comparison, medium voltage compliance limits for all national standards are used when compared to EN 50160.

A. Norway

History:

Regulation of quality of supply began in 1991 with the passing of the Energy Act. In 1995 mandatory reporting of interruptions greater than three minutes was added and 179 network companies were required to report key figures on voltage quality. On January 1, 2005 the Norwegian Water Resources and Energy Directorate (NVE) put into force "Regulations relating to the quality of supply in the Norwegian power system" [3].

Scope:

The NVE regulations apply to all network voltage levels. The regulations provide definitions and in some cases measurement methods and compliance levels for the following supply voltage characteristics:

- Frequency
- Short interruptions
- Long interruptions
- Flicker Pst
- Flicker Plt
- Interharmonic voltage
- Temporary overvoltages
- Voltage dips
- Voltage variations
- Harmonic voltages
- Mains signaling voltage
- Rapid voltage change
- Voltage unbalance

Supply voltage characteristic	**Statistical Evaluation**	**Compliance limit**	**vs.EN50160**
Power frequency	100% of the time	50 Hz ± 2%	Different
Supply voltage variations	100% of the time	Uc ± 10%	Same
Rapid voltage changes	1 change/day Up to 24 changes/day >24 changes/day	6% 4% 3%	Harder
Flicker	95% of the time in 1 week 100% of the time in 1 week	Pst <= 1 Plt <= 0.8	Harder
Supply voltage dips	None given	None given	Same
Short interruptions	1 year	None given	Same
Long interruptions	1 year	None given	Same
Temporary overvoltages	1 year	None given	Same
Supply voltage unbalance	100% of the time	<2%	Harder
Harmonic voltage	Mean value for 10 minutes Mean value for 10 minutes	See Fig. 2 THD <3%	Harder Harder
Mains signaling voltage	None given	None given	Easier

Table 2: NVE Directorate Compliance Limits

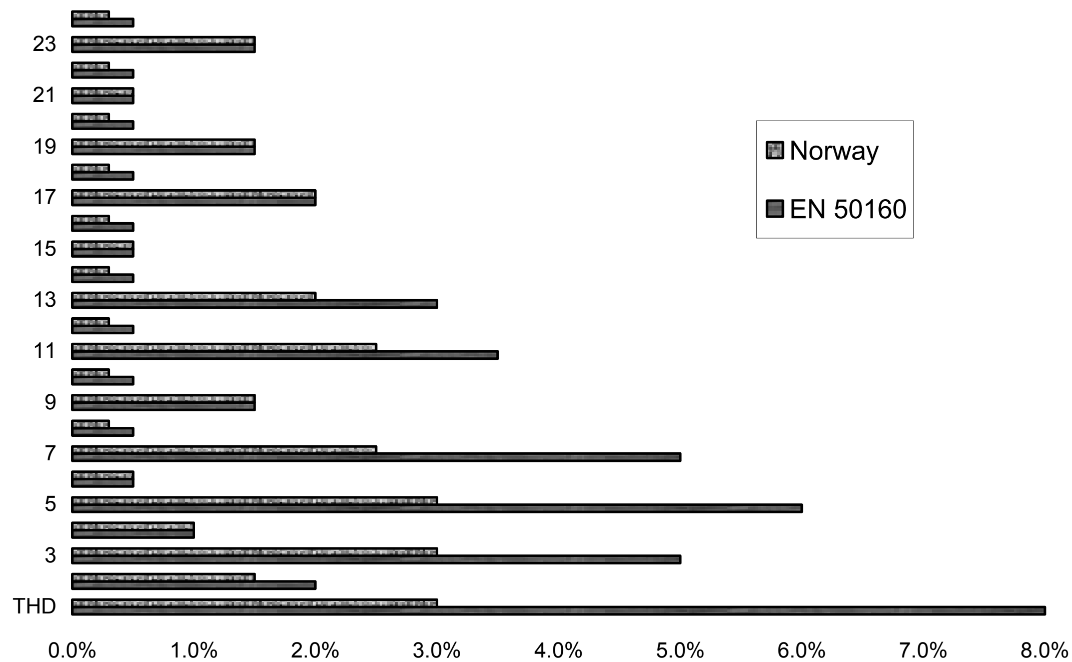

Figure 2: Comparison of EN 50160 and NVE Harmonic Voltage Limits

<u>How NVE regulations address identified limitations in EN50160</u>:

1. By focusing on just one country, Norway has been able to raise the compliance limits on rapid voltage changes, flicker, voltage unbalance and harmonic voltage. Higher order (above the 25^{th}) harmonic limits have been established, and the RMS variation averaging period for supply voltage magnitude is reduced from 10 minutes to 1 minute.

2. Like EN 50160, dips, swells and interruptions still do not have compliance limits. NVE does require mandatory reporting of long interruptions (greater than 3 minutes) and further classifies interruptions as notified (where the customer was informed in advance of an impending interruption) and non-notified. This is a necessary first step to establishing compliance limits but does not set targets.

3. The scope is expanded up to and including 245 kV.

4. Measurement methods for each characteristic are not clearly defined. This clause "Measurements of the quality of supply shall be carried out in accordance with the relevant standards prepared by the International Electrotechnical Commission – IEC or the European Committee for Electrotechnical Standardization – CENELEC." should be expanded to list the specific standards required for each characteristic.

5. Steady-state characteristics have compliance limits for 100% of the measurement period, with the exception of mains signaling voltage.

<u>Limitations of NVE regulations with respect to EN 50160:</u>

1. Mains signaling voltage compliance limits not defined.

2. While frequency limits are defined for 100% of the measurement period, the compliance limit has been reduced from 1% to 2%.

B. China

History:

In 1998 the State Grid Corporation of China produced “Management requirements for the technical supervision of grid power quality” and in 2004 “Management requirements for the voltage quality of the power system and reactive power for the State Grid Corporation of China”. Most of the compliance standards have been developed between 2000 and 2004.

Scope:

Compliance limits apply at all voltage levels. The national standards are based on IEC standards including measurement methodologies, compliance limits and PQ monitoring product requirements. Standards specific to compliance limits are GB/T 12325-2003 “Admissible deviation of supply voltage”, GB 12326-2000 “Voltage fluctuation and Flicker”, GB/T 14549-1993 “Harmonics”, GB/T 15543-1995 “Admissible voltage unbalance factor”, GB/T 15945-1995 “Admissible deviation of frequency for power system”, and GB/T 18481-2001 “Temporary and transient overvoltages”

How Chinese standards address identified limitations in EN50160:

1. The GB/T standards have higher compliance limits on frequency, rapid voltage changes, flicker, temporary overvoltages and low-order harmonic voltages.

2. Dips, swells and interruptions still do not have compliance limits.

3. The scope is expanded up to and including 500 kV.

4. Measurement methods for each characteristic are clearly defined for voltage harmonics (IEC 61000-4-7) and flicker (IEC 61000-4-15). Other characteristics need clearly defined measurement methods.

5. Steady-state parameters have compliance limits for 100% of the measurement period, with the exception of mains signaling voltage.

Supply voltage characteristic	**Statistical Evaluation**	**Compliance limit**	**vs.EN50160**
Power frequency	100% of the time	50 Hz ± 1%	Harder
Supply voltage variations	100% of the time	Uc ± 10%	Same
Rapid voltage changes	<= 1000/hour Other	4% 2%	Harder Harder
Flicker	95% of the time 100% of the time	Pst <= 1 Plt <= 0.8	Harder Harder
Supply voltage dips	None given	None given	Same
Short interruptions	1 year	None given	Same
Long interruptions	1 year	None given	Same
Temporary overvoltages	1 year	√3 per unit	Harder
Supply voltage unbalance	95% of the time	<4%	Easier
Harmonic voltage	Mean value for 10 minutes Mean value for 10 minutes	Odd <2.4% Even <1.2% THD <3%	Harder Harder Harder
Mains signaling voltage	None given	None given	Easier

Table 3: GB/T Compliance Limits

<u>Limitations of Chinese standards with respect to EN 50160:</u>

1. Mains signaling voltage compliance limits not defined.

2. Higher voltage unbalance compliance limits (4%).

3. Higher-order harmonics have higher compliance limits than EN 50160. However, due to the natural high-frequency attenuation of the power system and the more stringent limits on low-order harmonics (which typically dominate networks due to power converters), the overall harmonic voltage compliance limits should be considered more stringent than EN 50160.

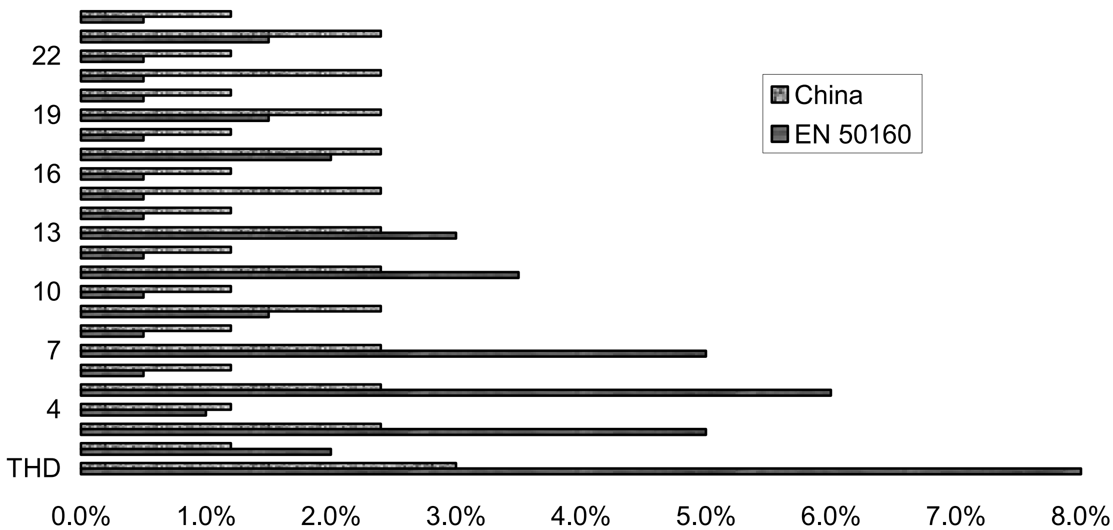

Figure 3: Comparison of EN 50160 and GB/T Harmonic Voltage Limits

C. South Africa

History:

The establishment of an Electricity Regulator in South Africa in 1995 led to the creation of five national Quality of Supply standards (NRS-048) between 1996 and 1998. In 2004 the National Energy Regulator Act was passed and in 2005 the National Energy Regulator of South Africa (NERSA) was established. NERSA enforces Quality of Supply standards within South Africa.

Scope:

Quality of Supply regulation applies to all voltage levels, and provides NERSA with a means of evaluating distribution companies. NRS-048-2 “Electricity Supply – Quality of Supply Part 2: Voltage characteristics, compatibility levels, limits and assessment methods” [4], defines measurement methods, compliance levels and limit levels.

Table 6 shows the characteristic values for the number of voltage dips at medium voltage not exceeded by 95% and 50% of all sites

<table>
<tr><td>Depth</td><td>20-150 ms</td><td>150-600 ms</td><td>0.6-3s</td></tr>
<tr><td>10-15%</td><td colspan="3">Y</td></tr>
<tr><td>15-20%</td><td></td><td></td><td rowspan="2">Z1</td></tr>
<tr><td>20-30%</td><td></td><td rowspan="3">S</td></tr>
<tr><td>30-40%</td><td>X1</td><td rowspan="3">Z2</td></tr>
<tr><td>40-60%</td><td>X2</td></tr>
<tr><td>60-100%</td><td colspan="2">T</td></tr>
</table>

Table 5: Classification of voltage dips

	X1	**X2**	**T**	**S**	**Z1**	**Z2**
95%	20	30	110	30	20	45
50%	7	7	7	6	3	4

Table 6: Number of voltage dips by classification, not exceeded at 50% and 95% of all sites

Supply voltage characteristic	**Statistical Evaluation**	**Compliance limit**	**vs.EN50160**
Power frequency	99.5% of 1 year 100% of 1 year	50 Hz ± 2% 50 Hz ± 2.5%	Harder
Supply voltage variations	95% of the time in 1 week 100% of the time in 1 week	Uc ± 5% Uc +10%	Harder
Rapid voltage changes	None given	None given	Same
Flicker	95% of the time in 1 week	Plt <= 1	Same
Supply voltage dips	Less than 0.85 p.u.	None given	Same
Short interruptions	1 year	None given	Same
Long interruptions	1 year	None given	Same
Temporary overvoltages	None given	None given	Same
Supply voltage unbalance	95% of the time	<2%	Same
Harmonic voltage	95% of the time in 1 week 95% of the time in 1 week	See Fig. 4 THD <8%	Harder Same
Mains signaling voltage	99% of the time in 1 day	Same as harmonics	Easier

Table 4: NRS-048 Compliance Limits

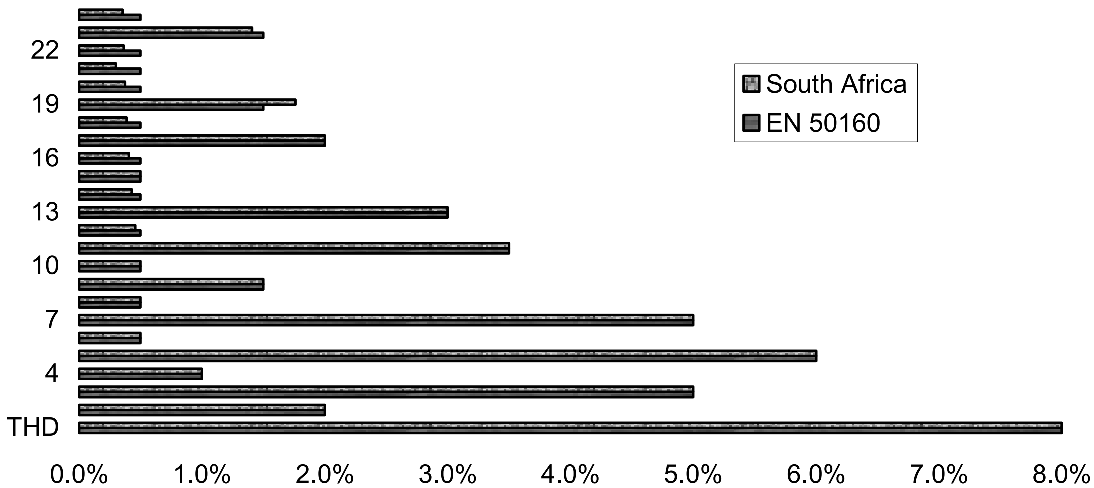

Figure 4: Comparison of EN 50160 and NRS Harmonic Voltage Limits

<u>How South African standards address identified limitations in EN50160</u>:

1. NRS-048 imposes stricter compliance limits on voltage variations, frequency, and individual harmonic levels. In the standard, 100% compliance to tighter voltage unbalance limits is noted as being considered.

2. Like EN 50160, dips, swells and interruptions still do not have compliance limits. NRS-048 classifies dips according to magnitude and duration (see table 5) and sets characteristic values. Interruptions are classified as notified (where the customer was informed in advance of an impending interruption) and non-notified. Voluntary and involuntary customer load reductions are also identified. This is a necessary first step to establishing compliance limits but does not set targets.

3. The scope is expanded to extra-high voltage.

4. Measurement methods for some characteristics are clearly identified. Flicker is to be measured according to IEC 61000-4-15 and Frequency to IEC 61000-4-30 Class A. For other characteristics, the measurement method is not clearly defined.

5. Voltage variations and frequency characteristics have compliance limits for 100% of the measurement period. NRS-048 introduces limit levels in addition to compliance levels.

D. Colombia

While not directly comparable to EN50160 due to lack of compliance limits, the national utility regulator in Colombia (Comisión de Regulación de Energía y Gas, or CREG) is clearly working towards power quality compliance limits. The recently enacted resolutions CREG 024 – 2005 and CREG 016 – 2007 require continuous monitoring of several power quality characteristics. Once statistics have been collected the regulator will move to implement compliance targets.

The CREG resolutions require reporting of 10-minute values for voltage interruptions (number and duration), voltage deviations greater than 10% from nominal and greater than 60 seconds in duration flicker Pst, voltage unbalance, and voltage dips or swells lasting longer than one-half cycle.

Based on the data being collected, it is unlikely that the CREG regulations will address many of the key shortcomings in EN 50160. The focus on dips, swells and interruptions is appropriate based on the economic impact of these characteristics, but flicker is used as a generic indicator of voltage waveform quality. Individual harmonic and THD compliance limits should be set as well.

III. Improvement suggested by European Regulators for EN 50160

The European Regulators Group for Electricity and Gas released a series of recommendations to improve EN 50160 in their July 2007 report "Towards Voltage Quality Regulation in Europe – An ERGEG Conclusions Paper" [5]. In this paper, ERGEG supports the following:

"− some definitions, especially for voltage events like dips/swells and interruptions,
should be improved in order to get comparable measurements all around Europe;

− indicative values for voltage events should be avoided in the text of the EN 50160
norm, they can form the content of informative annexes or technical reports instead;

− binding limits for voltage variations should be also targeted to customer protection and therefore the 95%-of-time clause should be reconsidered;

− the scope of a VQ standard should be larger than the actual EN 50160 scope; the HV-EHV networks should be included and also the concept of "normal operating conditions" should be clarified;

− product standards should also be reconsidered where appropriate in order to give correct signals to customers when they make their choices on the electrical products.

In the current draft of EN 50160, the following improvements have been made:

− Definitions for voltage variations measurement methods are specified. IEC 61000-4-30 methods have been applied.
− The 95%-of-time clause has been removed for voltage variations, which now have a 99% compliance target and 100% limit.
− The scope of the standard has been extended to high voltage.

The draft standard still does not specifically identify measurement methods and retains a 95%-of-time clause on many voltage quality characteristics.

IV. Recommendations for a National Quality of Supply Standard

By reviewing the development of Quality of Supply standards worldwide, best practices can be identified and used as a framework for new standards development.

In China and South Africa, measurement methods are more clearly defined than in other national standards. Clearly this is critical when applying compliance limits (and associated penalties) and when attempting to compare one utility to another or one country to an international benchmark. The ability to draw economic investment to a country or region will require standardized measurement methodology. Quality of Supply compliance measurements should be based on international power quality measurement methods as defined by an IEC 61000-4-30 Class A device.

As is the case in most national standards, all voltage levels in the network should have appropriate compliance and limit levels.

Compliance limits set at 95% of a measurement interval should be strictly set, and limit levels for 100% of the interval must be defined. South Africa's NRS-048 addresses this and allows utilities and customers to source appropriate equipment for the quality of power they will be exposed to.

For non-steady state characteristics (dips, swells and interruptions), compliance limits should be defined. But these limits should be based on the impact to the customer, and so dips and interruptions should be classified on magnitude, duration, and customer notification.

Harmonic voltage limits should be set based on the likelihood of occurrence and the damage they can cause. Norway and China addressed this issue by imposing harsher limits on the more common low-order harmonics.

V. Conclusions

It is clear when reviewing the Quality of Supply standardization efforts that utilities and regulators have focused on the most pressing local problems. But with increased globalization of industry, including the free transport of electrical distribution and production equipment, it will be increasingly necessary for power quality to be consistently monitored and regulated. Applying the recommendations in this paper, derived from the best practices of national regulators, would provide a common framework for quality of supply regulation and a necessary first step towards globally acceptable limits.

VI. Biography

Brian Kingham received his Bachelor of Electrical Engineering from the University of Victoria in 1995. In 1995 he joined Power Measurement (now Schneider Electric) and is currently the Utility Market Manager for the company's Power Monitoring and Control division.

VII. References

[1] European standard EN 50160 Voltage characteristics of electricity supplied by public distribution systems, CENELEC TC 8X, 2006

[2] End use perceptions of Power Quality – A European Perspective, Roman Targosz, EPRI PQA 2007

[3] The Norwegian directive on quality of supply, The Norwegian Water Resources and Energy Directorate, Karstein Brekke, Frode Trengereid and Espen Lier, ISSN: 1501-2840.

[4] NRS-048-2, Electricity Supply – Quality of Supply Part 2: Voltage characteristics, compatibility levels, limits and assessment methods

[5] Towards Voltage Quality Regulation in Europe – An ERGEG Conclusions Paper Ref: E07-EQS-15-04